

VISUAL EVOKED RESPONSE CORRELATES  
OF INTER-HEMISPHERIC DIFFERENCES  
IN VERBAL AND NON-VERBAL PROCESSING

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## SUMMARY

Ten experiments are reported which are concerned with visual evoked response (VER) correlates of the processing of visual stimuli. In Experiments 1 and 2 VERs were elicited by letters requiring verbal and non-verbal processing respectively. The results suggest that hemispheric differences in VERs to lateralised stimuli reflecting the anatomical arrangements of the visual system are modified by the way the stimuli are processed. These conclusions were supported by a third experiment in which non-verbal processing of non-verbal stimuli was required.

A further three experiments investigated VERs elicited by midline presentation of the letter and pattern stimuli. It was concluded that the right hemisphere is pre-eminent for the initial processing of visually presented stimuli and that when subjects had foreknowledge of the stimuli the  $P_2-N_2$  component reflected whether or not the stimuli were subjected to verbal processing, and whether such processing was asymmetrically distributed across the hemispheres.

Experiment 7 attempted to find a VER index of the limits of trans-callosal connections between the striate cortices, with inconclusive results.

Two further experiments, utilising the stimuli employed in Experiments 1-6, were designed to investigate whether the  $P_{300}$  component of the VER reflected hemispheric asymmetries of processing. No such effects were found in Experiment 8 which provided new evidence pertaining to the relationship between

P<sub>300</sub> and behavioural measures of information-processing.

The results of Experiment 9 suggested that P<sub>300</sub> could reflect asymmetrical processing, a conclusion supported by the results of the final experiment in which P<sub>300</sub>s were elicited by simple lateralised stimuli.

The general conclusion drawn from these experiments is that the VERs reflected both structural and dynamic aspects of information-processing and indicated that important determinants of the flow of stimulus information in the brain are the nature of the stimulus, the task-set of the subject and the interaction of these two factors.

The following publication is based on two of the experiments reported in this thesis:

Rugg, M.D., & Beaumont, J.G. Interhemispheric asymmetries in the visual evoked response: Effects of stimulus localisation and task. *Biological Psychology*, 1978, 6, 283-292.

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## CHAPTER 1

### Introduction and Overview

#### 1a Introduction

The study of the relationship between cerebral activity and cognitive processes can occur on many different levels, the most fundamental of which is perhaps the study of the activities of single neurones. Whilst great progress has been made in single-unit studies of processes such as the early stages of perception (see, for example, Blakemore, 1975), what Donchin (1976) has called 'convergent' processes, they are of little utility in the study of 'divergent' processes, those in which the output of single neurones affect large populations of neurones functionally dependent upon each other. Following Freeman (1973), Donchin argues that the study of divergent processes requires the 'analysis of the population statistics of masses of neurons' (p.200). One way in which the analysis of neuronal populations manifests itself is in the scalp-recorded macropotentials of the EEG (Elul, 1972), the transient modification of which forms the basis of evoked response techniques.

Within the realm of neuropsychology the elucidation of the relationship between cognitive and neural activity, particularly in terms of the localisation of functionally discrete neuronal populations, has long been a primary goal. For many years the principle technique available for such

investigations was the investigation of brain-damaged individuals, the hope being that the correlation of different patterns of cognitive deficit with different lesions would elucidate the localisation of cognitive activity within the brain. Although of great importance, such studies must be supplemented by data from neurologically normal populations before their results are known to be generalisable (see section 1b), and it is only in the last two decades that the study of the normal population from a neuropsychological perspective has flourished. The range of studies of intact individuals has been limited by the range of techniques that it is possible to apply and has centred on the investigation of lateral asymmetries of processing in the cortex, the investigation of which is greatly facilitated by the decussated nature of the human sensory pathways. Within this paradigm animal models are of little value because of the high level of complexity of the cognitive activities investigated (e.g., language) and the fact that no suitable animal model of functional laterality appears to exist. Thus, until relatively recently investigators have been confined to the use of behavioural indices from which to infer the nature of the cortical processes underlying cognitive activity.

The majority of the processes investigated with respect to lateral asymmetries would fall into Donchin's (1976) 'divergent' category; activities involving the function of neuronal populations rather than individual neurones. The investigation of such activities via the study of brain macropotentials is an obvious means of furthering the understanding of cortical/cognitive relationships. Although fraught with problems (for an historical review see Lindsley, 1969) such techniques, in theory at least, allow the

investigator to use a far shorter chain of inference between the observed phenomenon (e.g., an evoked response) and its cause, i.e., a particular pattern of neuronal activity, than do behavioural indices such as, for example, reaction-time.

This thesis is concerned with the use of the visual evoked response as a tool to investigate the patterns of cortical activity underlying the processing of simple verbal and non-verbal stimuli under different task conditions, and the processing of unilaterally presented unstructured stimuli. The emphasis of the experiments described is on possible hemisphere asymmetries in the mediation of this processing and, in particular, the way in which the cerebral hemispheres interact in the course of such processing. The experiments also attempt to shed some light on the means by which visual evoked responses are modulated by different modes of information-processing.

#### 1b Lateral asymmetries of cognitive activity - clinical studies

As noted above, the elucidation of the functional and anatomical organisation of cognitive activity in the human brain has long been a goal of neuropsychology. From early in the history of the discipline a principal focus of such endeavours has been the investigation of lateral asymmetries in the mediation of important psychological processes such as language and perception. The well-known observations of Broca (1861) and Wernicke (1874) gave rise to the widely-accepted view that the cortical areas responsible for the mediation of language were located, in the vast majority of individuals, in the left cerebral hemisphere; expressive language was mediated predominantly by an area of left frontal

cortex (Broca's area) whilst receptive capacities were located more posteriorly, in the region of the auditory association cortex (Wernicke's area). The observations of Dejerine (cited in Geschwind, 1961) completed the picture by suggesting that the region around the left angular gyrus mediated the visual-verbal transformations fundamental to the processes of reading and writing. A modern version of this 'classical' conception of the organisation of language in the brain has been presented by Geschwind (1970), who demonstrated how such a model can account for a wide variety of aphasic syndromes. It has, however, received much criticism (Bogen & Bogen, 1976; Brown, 1976), particularly from Bogen and Bogen (1976), who argued that its simplicity was obtained at the expense of ignoring the richness and variety of the available clinical data. The most general premise of the model, that language abilities are predominantly the preserve of the left hemisphere in the vast majority of individuals, has not been seriously questioned for many years.<sup>1</sup> In contrast to the early precise descriptions of the specialisation of the left hemisphere the activities of the right hemisphere were described in vague terms, and were often considered to consist of low-level, 'vegetative' functions, although it is noteworthy that as early as 1876 Hughlings Jackson (see Taylor, 1932) ascribed to the right hemisphere the activities of perceptual, particularly visuospatial, integration; this

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<sup>1</sup> It should be noted that this and all subsequent discussions refer, unless explicitly stated otherwise, to the brain organisation of right-handed individuals. Mixed and left-handers form a highly heterogeneous population with respect to lateral asymmetries in cognitive activity (see, for example, Hardyck & Petronovitch, 1977) and the generalisation of findings obtained from right-handers to such populations is unsound.

suggestion was practically ignored for many years. Recent work, however, has produced a dramatic confirmation of this hypothesis.

The introduction of controlled experimental testing of brain-damaged populations has led to the support and extension of the notions, described above, regarding differential hemispheric involvement in differing cognitive activities. Whilst there are methodological problems in comparing populations differing with respect to the laterality of lesion, e.g., ensuring that the lesions are of the same size and aetiology, accurately localising the lesions, explaining experimental tasks to aphasic subjects, etc., a number of general conclusions are possible on the basis of the large number of studies now published (see Joynt & Goldstein, 1975; Hecaen & Albert, 1978, for reviews). It is clear that left hemisphere damage results not only in aphasic disorders but, even in the absence of observable aphasia, in deficits in cognitive abilities associated with verbal operations (Newcombe, 1974). Deficits in motor skill acquisition are also associated with left hemisphere damage (Kimura, 1977). On a general level, right hemisphere damage gives rise to a set of cognitive deficits many of which have in common the fact that the deranged abilities require the integration of simultaneous elements into a meaningful whole (i.e., 'gestalt' or 'synthetic' processes). Deficits are thus found, for example, in facial recognition (De Renzi, Faglioni & Spinnler, 1968), spatial memory (De Renzi, Faglioni & Previdi, 1977), tonal pattern recognition (Milner, 1967) and tactile perception (Boll, 1974). Of interest also is the finding that right hemisphere damage can give rise to deficits in relatively simple perceptual operations such as the judgement

of line position and orientation (Warrington & Rabin, 1970), stereoscopic fusion (Carmon and Bechdoldt, 1969) and the perception of simple forms (Kimura, 1963).

The importance of the locus of damage within a hemisphere has been shown most clearly by Corsi (cited in Milner, 1971), who demonstrated a dissociation between verbal and visuo-spatial stimuli, recognition and recency judgements and side of lesion. Deficits were observed with respect to the visuospatial material only in the patient group with right hemisphere lesions; these were confined to recency judgements concerning the stimuli in the case of frontally lesioned patients and recognition memory in the case of patients with temporal lobe damage. An analogous finding was obtained for left-sided lesioned patients with the verbal material. Such clear demonstrations of lateral asymmetry of higher function are not reported in comparisons of patients with unilateral posterior lesions; both parietal lobes are, for instance, implicated to some extent in spatial orientation processes (Critchley, 1953). Laterally dependent deficits do occur, however. Perceptual deficits in operations such as the judgement of line orientation are most acute in the case of right posterior damage (De Renzi, Faglioni & Scotti, 1971). Whilst damage to either angular gyrus gives rise to cross-modal matching deficits (De Renzi & Scotti, 1969), that to the left side also results in dyslexia and dysgraphia (Geschwind, 1961). The nature of the constructional apraxia following large parietal lesions is also found to vary with side of lesion; only apraxia caused by right-sided damage is characterised by gross spatial distortions (Arrigoni & De Renzi, 1964).

The conclusion that can be drawn from a consideration of

studies of the effects of unilateral brain damage is that they provide overwhelming support in favour of regarding the brain as a highly lateralised system, with verbal and sequential operations mediated predominantly by the left hemisphere and perceptual, particularly visuospatial, operations requiring holistic or synthetic modes of processing being mediated mainly by the right hemisphere. The extent to which such evidence can be generalised in detail to intact individuals is, however, questionable. Recovery of function following brain damage is a well known phenomenon as are the differential effects of traumatic (e.g., bullet wounds) and gradual (e.g., tumour) lesions (Joynt & Goldstein, 1975). It is always possible that the residual cognitive activities observed in populations of brain-damaged individuals are mediated by structures and strategies which are not implicated in the same operations in intact individuals. The possibility also exists that damaged tissue may give rise to neural 'noise' disruptive to surviving tissue (Moscovitch, 1973) and hence cause depressed performance on tests the mediation of which does not involve the damaged tissue. It is also pertinent to note the obvious fact that simply because a given lesion results in a particular deficit does not mean that the damaged tissue exclusively mediated the affected cognitive activity, nor even that it had an important rôle. For instance, destruction of the ~~left~~ occipital cortex and the splenium will result in severe dyslexia (Geshwind, 1961). It would, however, be completely erroneous to suggest on the basis of this that these structures were responsible for the ability to read; their destruction results in fact in a disconnection syndrome in which the cortical area mediating visual-verbal transformation (the angular gyrus) is separated

from visual input. Over-reliance on observations of cognitive deficit following unilateral lesions can lead to an over-emphasis of the importance of the lateralisation of the presumptive loci of cognitive activities and an underemphasis of the possibility of interactions between a particular locus and more diffusely distributed areas also crucial for the mediation of the cognitive ability in question. This is not to deny the importance of studies of clinical populations, however, and further reference will be made to such studies when pertinent.

An important source of knowledge regarding asymmetry of function in man has come from the work of Sperry and his associates with Bogen and Vogel's series of callosum-sectioned patients (Bogen & Vogel, 1962). Reviews of this work will be found in Gazzaniga (1970), Levy (1974a,b) and Sperry (1975). With the use of precise experimental techniques evidence rapidly accrued demonstrating that in these patients the disconnected cerebral hemispheres were capable of independent functioning and, moreover, were specialised for different cognitive activities. Thus, whilst the left hemisphere was superior to the right with respect to language and cognitive operations requiring logical and sequential processing, the right demonstrated a superiority for holistic and gestalt operations, particularly those involving visuo-spatial elements. It is of interest to note that with the possible exception of expressive language no cognitive operation has been found exclusively to be the province of one hemisphere; some residual ability is found in the relatively unspecialised hemisphere. This is particularly the case with receptive language capacities, which appear to be quite extensively bilaterally organised (Zaidel, 1976, 1977). Also of interest



is the observation that notwithstanding the disconnection of the cortico-cortico connections between the cerebral hemispheres the subjective unity of consciousness is not substantially altered (Trevarthen, 1974), nor is the unity of the midbrain-mediated 'ambient' visual field (Trevarthen & Sperry, 1973). The findings demonstrate the importance of sub-cortical mechanisms in the regulation of cortical function.

Whilst the findings pertaining to callosum-sectioned patients are of great interest, and are broadly in line with data from other clinical populations their generality to normal populations must seriously be called into question in the light of the comments of Beaumont (1978a) and Whitaker and Ojemann (1977). These authors have noted a number of reasons why generalisation from the callosum-sectioned population may be unjustified, the most important of which being that none of the small series of patients studied was free from pathology prior to operation, the majority having suffered from serious epilepsy from an early age. Hence, the possibility of abnormal organisation of cognitive activities in the brains of these patients, in compensatory response to the eliptogenic lesions, is high and cannot be ruled out.

#### 1c Lateral asymmetries of cognitive activity - normal studies

The study of lateral asymmetry of cognitive activity in intact individuals is facilitated by the fact that the sensory channels in man are all to some extent decussated. Decussation is complete in the case of the visual system (Noback & Demarest, 1977) and is arranged such that input via

each lateral visual field is transmitted along the geniculocalcarine pathways to the contralateral cerebral cortex. Thus appropriate stimulation techniques allow direct access to either cerebral hemisphere. In the case of the auditory and somatosensory systems decussation is incomplete; both ipsilateral and contralateral projections exist. The contralateral projections in these two sensory systems are, however, considerably more extensive (Witelson, 1977, p.219) and there is evidence in the case of the auditory system that the contralateral system is functionally predominant, particularly under conditions of dichotic stimulation (Darwin, 1975). Since the early 1960s studies utilising techniques designed to exploit arrangements of the human sensory systems have demonstrated that the relative efficiency with which stimulus input is processed substantially depends upon three interacting factors: the nature of the stimulus or stimuli, the nature of the stimulus processing used by the subject, and the route of stimulus input. Thus, Kimura (1961, 1967) has demonstrated in a dichotic listening paradigm that a right ear advantage obtains for the recall of verbal material and a left ear advantage for the recall of musical material. This has been interpreted as reflecting the relative specialisations of the two hemispheres for verbal and musical processing in that the verbal input from right ear benefits from its more direct route to the left hemisphere and vice-versa with respect to musical input. Similar effects have been reported with tactile stimuli presented dichaptically (Witelson, 1974).

With respect to the experiments to be reported in this thesis the effects of stimulus and task on the processing of material presented tachistoscopically to the lateral visual fields is of some relevance. A right visual field (RVF)

(left hemisphere) advantage is typically found for the processing of verbal material, this being the case when stimuli are presented either unilaterally, or bilaterally when adequate fixation control is employed (Hines, 1972; White, 1972). The effect is found with different measures of performance such as recall (Hines, Satz, & Clementino, 1973) and reaction-time (RT) (Gross, 1972). A left visual field (LVF) superiority has been reported with a variety of non-verbal stimuli and tasks, including facial recognition (Rizzolatti, Umiltà, & Berlucchi, 1971), dot detection (Davidoff, 1977), colour memory and discrimination (Malone & Hannay, 1978; Pennal, 1977) and the recognition of complex geometrical forms (Umiltà, Bagnara, & Simion, 1978). It is clear that a crucial factor mediating results of studies such as those cited above is the nature of the cognitive processing which subjects employ to accomplish the task they are set. Thus, a RVF advantage is found for the recognition of lines which are oriented in the easily verbalisable positions of  $45^{\circ}$ ,  $90^{\circ}$  and  $180^{\circ}$  but this is reversed when intermediate line positions are involved, these presumably being less amenable to verbal labelling and thus engaging the visuospatially mediated mnemonic capacities of the right hemisphere (Umiltà, Rizzolatti, Marzi, Zamboni, Franzini, Camarda, & Berlucchi, 1974). In a similar vein the LVF advantage for faces is reversed if famous faces, easily verbalisable, are used as stimuli (Marzi & Berlucchi, 1977). A LVF superiority has been reported for a task involving the matching of words along purely physical dimensions (Gibson, Dimond, & Gazzaniga, 1972). When the task involves matching unilaterally presented letter pairs a RVF advantage in RT obtains when the letters are matched on the basis of name; this advantage occurs for stimuli

presented in the LVF when matches are based on the physical characteristics of the letters (Cohen, 1972; Geffen, Bradshaw, & Nettleton, 1972). These studies, in which VF differences in the processing of the same stimuli are shown to be manipulable by varying the associated task, provide convincing evidence that the task demand imposed upon the subject is an important variable in studies of lateral asymmetry.

It is also of interest to note that Bryden and Allard (1976) have demonstrated that in a letter recognition task the normally reliable RVF advantage can be reversed by the use of cursive or unfamiliar typefaces. This was accounted for by postulating that early stages of the visual processing of input are more efficiently performed by the right hemisphere. It was hypothesized that when this operation was important, such as with cursive or unfamiliar lettering, then this would be indexed by a shift towards an LVF advantage in stimulus processing, notwithstanding the ostensibly verbal nature of the task.

The studies cited above, particularly those of Cohen (1972) and Geffen et al (1972) illustrate the importance of the need to control the cognitive strategies utilised by subjects in the performance of tasks designed to engage primarily one or other cerebral hemisphere. The mere use of verbal or non-verbal stimuli does not guarantee that subjects will process these stimuli in the required manner. The study of Bryden and Allard (1976) highlights the fact that a task may contain more than one important element and that as different elements place more demand upon the information processing system of the subject they are likely to have proportionately more effect in determining the direction of any asymmetries in performance.

Whilst VF studies have contributed much to the knowledge regarding cerebral asymmetries of processing in intact individuals and have in general corroborated and extended findings from clinical populations they are subject to severe limitations. It is impossible, for instance, to derive information about the nature of the information processing involved in a task without involving the output system; it is not always the case that stimulus processing and response selection are closely coupled (Kutas, McCarthy, & Donchin, 1977). Moreover, in many VF experiments, two different models may be postulated to account for the observed effects. These have been formulated by Cohen (1972). One of them postulates that the relative deficits in processing observed with stimuli presented in the LVF in the case of verbal processing, and the RVF in the case of visuospatial processing result from the transcallosal transmission (and possible degradation) of the stimulus information to the appropriately specialised hemisphere. The other model postulates that stimuli are processed in the hemisphere to which they are originally transmitted and therefore VF differences reflect the relative specialisations for the cognitive operations involved. Cohen (1972) further notes that one of the models might obtain for some types of information processing and the other one for other types. Other investigators have not been afraid to apply one or other model in the design and interpretation of experiments (cf. Hines, 1977, and Levy, 1974a, p.149). Moscovitch (1973) has attempted to test the models as outlined above. This was done by presenting verbal stimuli to each visual field and requiring responses from either the left or right hand. The assumption was that each hand was controlled by the contralateral hemisphere and as such

inferences could be made regarding information flow in the brain on the basis of RTs obtained under different VF/hand combinations. The assumption that the hands are subject only to contralateral control, meaning that the source of response initiation is known, does not appear to be justified, however. The motor pathways are far from perfectly decussated (Levy, 1974a, p.143). Moreover, Filbey and Gazzaniga (1969) have reported that whilst a RVF advantage in dot detection was obtained using a vocal RT measure, explained as being due to information from the right hemisphere having to cross the corpus callosum to initiate a response, this effect disappeared when a right finger manual response was used. This suggests that whilst control of speech output may be lateralised to the left hemisphere, this is not the case for response initiation of the right hand. Moreover, Swanson, Ledlow and Kinsbourne (1978) have presented data which suggests strongly that structural considerations with respect to hand of response are irrelevant when any process other than reaction-time to very simple stimuli is considered as the differences caused by these structural factors (e.g., hand of response) are far overshadowed by 'higher-level' effects such as mode of processing and attentional bias. It is therefore likely that Moscovitch's (1973) methodology and results, which he considered to support the 'callosal transmission' model of VF effects, are based on a false assumption. It is arguable that the elucidation of the mechanism or mechanisms underlying VF effects requires the use of techniques which permit the mapping of information flow in the cortex from the time of stimulus input. The most likely candidate as such a technique is that involving evoked responses, as will be discussed subsequently.

1d Explanations of lateral sensory field effects:

The explanations discussed above as a means of accounting for the observed asymmetries between the hemispheres for differing cognitive activities have been of a structural nature. They have assumed that the reason for the effects noted in the previous section is that transmission of stimulus information along the afferent pathways to the appropriate hemisphere is advantageous compared with the alternative of transmission to the hemisphere unspecialised for the required cognitive activities; the explanation is essentially an anatomical one. A radical alternative account of these effects has been presented by Kinsbourne (1970). Whilst not denying that the hemispheres are differentially specialised he has hypothesized that sensory field effects are the result of attentional bias in the sensory fields and are not due to the advantage of direct compared with indirect input to the appropriately specialised hemisphere. Kinsbourne proposed that attentional bias was the result of differential hemispheric activation causing a focusing of attention to the areas of the sensory fields contralateral to the activated hemisphere. This in turn was the result of processing, or being primed to process, in a mode requiring the specialisation of only one hemisphere. Thus, the RVF advantage for verbal material is considered to result from the stimuli activating the left hemisphere, which in turn biases attention towards the RVF, leading to a processing advantage for stimuli appearing there. Whilst some support exists to suggest that attentional effects of this nature may influence lateral asymmetries of processing (Kinsbourne, 1974, 1976) the hypothesis cannot account for many of the results of studies investigating

VF effects. The clearest prediction made by the attentional model is that if a typical VF experiment is carried out utilising a random and equal mixture of stimuli requiring verbal and visuospatial processing no VF effects should be observed, as both hemispheres will be equally activated and attention will be evenly distributed over the whole VF. In such circumstances, however, VF differences congruent with a structural/anatomical model are still found (Berlucchi, 1975; Cohen, 1972) even when subjects know in advance which VF is going to be stimulated on each trial (Geffen et al., 1972; see also Hellige, 1978). Kimura and Durnford (1974) have argued that Kinsbourne's hypothesis logically reduces to a statement about the processing capacities of the two hemispheres and that in any case the hypothesis is so vague as to be of little use. Although the latter point may be valid it should be noted that the former is not. Kinsbourne's hypothesis has as its basic premise that the two hemispheres have structural or functional differences giving rise to specialisation for different types of information processing. The crux of the hypothesis is that the anatomical arrangements of the sensory systems are irrelevant to explanations of lateral sensory field effects; the biasing of attentional capacity in the lateral fields is the mechanism giving rise to the observed asymmetries in information processing. The results of the experiments reported above demonstrate that Kinsbourne's model fails its clearest test. Whilst it is likely that activation and attentional effects may in some circumstances be of relevance (see, for example, Kershner, Thomae, & Callaway, 1977) the most parsimonious explanation accounting for the behavioural effects of lateralising input to the cerebral hemispheres



would appear to be a structural/anatomical one. The details of the flow and processing of the stimulus information within and between the hemispheres remains to be elucidated.

## CHAPTER 2

### Averaged Evoked Responses

#### 2a Introduction:

Whilst electrical responses to sensory stimulation in animal preparations have been studied since the turn of the century it is only relatively recently that similar studies have been carried out in intact humans. This is because the small size of scalp-recorded evoked responses (ERs) results in their being buried in the on-going EEG and thus requiring signal enhancement techniques such as averaging prior to analysis. These techniques have been greatly facilitated by the advent of small, cheap laboratory computers (Donchin, 1976). Although the means to analyse scalp-recorded ERs evoked by single stimuli (based mainly on correlational iterative filters of the Woody type) do exist (Wastell, 1977; Squires & Donchin, 1976), the overriding majority of ER studies rely on the technique of averaging to enhance the ER relative to the background EEG. This involves the summation of samples of EEG time-locked with respect to the eliciting stimuli. Under ideal conditions, i.e., when the ER is perfectly time-locked to the eliciting stimulus and does not vary from trial to trial, and variation in background EEG is entirely independent of the stimuli, signal-to-noise enhancement is proportional to the square root of the number of samples summed. These conditions are rarely realised entirely (Vaughan, 1974) and in

practice most studies involve the use of between around 30 and 120 eliciting stimuli to form an ER (Butler & Glass, 1976).

Neurophysiological investigations of spontaneous EEG have led to the conclusion that its most probable source is the statistical summation of the slow dendritic potentials of individual neurones (Elul, 1972). It is considered likely that ERs (with the exception of the very earliest components which may contain contributions from afferent thalamic axonal volleys) are caused by the temporary synchronisation of this process in a group or groups of functionally related neurones (Regan, 1972).<sup>1</sup> The difficulties of accurately localising the source of ER components is immense and much effort has gone into developing volume conduction models utilising dipole theory in an effort to explain the topographical distribution of ERs (e.g., Vaughan, 1969, 1974; Jeffreys & Axford, 1972a,b). This approach has been severely criticised by Regan (1972, p.16) as being based on unsupported and arbitrary assumptions. Regan makes the further point that any model so constructed does not solve the problem; it is possible for many different models, all based on different sets of assumptions, to describe adequately a given set of electrophysiological phenomena. In spite of these reservations consideration of the topographical distributions of ERs, combined with knowledge about the physical orientation of cells within the cortex suggests strongly that some inference as to the location of ER generators is possible. The fact that early components of the auditory, somatosensory and visual ERs each

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<sup>1</sup> This discussion assumes that such ERs are not subject to any of a number of artefacts of extra-cortical origin. The nature of these artefacts is discussed in a subsequent section.

show large voltages at electrodes placed to detect activity in the respective projection cortices suggests strongly that the source of these components is in or near these modality-specific areas (Goff, Matsumiya, Allison, & Goff, 1969; Goff, 1974; Vaughan & Ritter, 1973). The more diffuse distribution of later components suggests that these have a more general distribution, probably arising from association cortex (Vaughan & Ritter, 1973).

However they are elicited ERs typically consist, in the time domain, of a number of positive and negative deflections within a period of approximately 500 msec. The interpretation of these is difficult, not least because of the wide inter-subject variability which is often observed (Butler & Glass, 1976) and has been ascribed to individual differences in cortical anatomy (Jeffreys, 1971). It is not clear the extent to which ER components, i.e., the individual positive and negative peaks, reflect 'real' neuronal events such as depolarisation or are artefacts of the conduction medium and recording method (Regan, 1972). Nor is it clear how changes in latency and amplitude of an ER component should be interpreted in neurophysiological terms. For example, an amplitude change could reflect a numerical increase in the contributing neurones or an increase in the synchrony of the same neuronal population. Because no clear formulation exists as to the neurophysiological significance of the components of the scalp-recorded ER there are no obviously appropriate means of measuring or analysing them. The traditional and most frequently applied means of analysing ER waveforms proceeds in the time domain by measuring the latency from stimulus onset and amplitude of each component with the assumption that the individual components are most probably

physiologically meaningful and that, even if they are not, they provide convenient points for measurement. It is not immediately clear whether amplitude measures should be taken as the voltage difference between a pre-stimulus baseline and individual components or as the difference between consecutive components, i.e., peak-to-peak. Although the former measure is favoured by Goff et al (1969) it should be noted that it has the disadvantage that the amplitude with respect to the baseline of later components will be influenced by the relative amplitudes of preceding ones; e.g., a negative peak closely following a positive one may be entirely above the baseline and thus be assigned a positive value. Peak-to-peak measures are not distorted in such a manner. Their main drawback is that it is assumed that the two components, and the area of waveform between them, reflect a unitary process best described by a single measurement. If they are not closely dependent then the measure serves to confound any variations between waveforms which may be present. This problem is perhaps most acute when the peak-to-peak measure is over a relatively large temporal area of the ER in which case there is an increased likelihood that the components may be independent with respect to the experimental conditions (e.g., Hillyard, Hink, Schwent, & Picton (1973) demonstrated that  $N_1$  (around 150 msec) and  $P_3$  (around 350 msec) of the auditory ER were enhanced by different aspects of the experimental treatment). Under the circumstances where ER components are likely to be differentially affected by a set of variables then it is arguable that the baseline-to-peak amplitude is the more appropriate measure. In other circumstances for the reasons stated above, peak-to-peak measures may be preferable.

Regardless of how the amplitude measurements are made, the most commonly applied method of evaluating differences between ER waveforms which have been subject to the type of time-domain analysis described above is to subject the data pertaining to each component in the waveforms to an appropriate statistical test, e.g., a t-test when pairs of ERs are compared or an ANOVA in the case of more than two simultaneous comparisons. A disadvantage of this approach to ER analysis is that if a large amount of inter-subject variability exists in the morphology of a set of ERs it may not be possible to find the same set of components in all subjects' ERs.

A number of other approaches to the measurement of and evaluation of differences between ERs are currently utilised in an effort to circumvent the problem of inter-subject variability and to attempt to derive information which is qualitatively different from that obtained from the time-domain analysis described above. Donchin (1969) has developed a method of evaluating ERs based on principal components analysis. This involves the extraction from subjects' ERs of a number of 'factors', plots of amplitude against time, which are considered to account for the variance over time of the ERs. Differences in the factor loadings and distributions between experimental conditions are evaluated statistically. The technique has received severe criticism from Vaughan (1974) who states that 'This procedure is sufficiently elaborate and obscure in its physiologic justification to ensure rather limited application' (Vaughan, 1974, p.183). Vaughan argues that the procedure is both arbitrary and redundant, in that it provides no information not apparent from observing the original ER waveform averaged across

subjects. To this might be added the comment that whilst the extracted factors are considered to represent the components of the ER (and are validated by reference to the original waveforms), in some circumstances factors are derived which are wholly uninterpretable (see Dunchan-Johnson & Donchin, 1977, for an example of these problems). Thatcher (1977a,b) has utilised factor analysis techniques in a manner similar to that of principal components analysis; the same criticisms apply.

A relatively common means of evaluating differences between ER waveforms is correlational analysis (see, for example, Buchsbaum & Fedio, 1970; Goff, Rossiter, Galbraith, & Saul, 1977). With this technique pairs of waveforms are correlated using the amplitude at each sample point as the dependent variables. It has the advantage of circumventing the problems of inter-subject variability by allowing intra-subject estimates of waveform differences which may then be used in an across subjects comparison. As noted by Donchin (1969) and Vaughan (1974) the technique yields correlation coefficients with an unknown number of degrees of freedom because of the extreme lack of independence between adjacent sampling points of each ER. Moreover, no information is yielded regarding the point or points in time at which any factors contributing to differences in correlations occur; neither is it possible to determine whether such differences are due to morphological changes in one or both ERs or are caused by a shift in the relative latencies of morphologically similar ERs. A related technique involves the use of serial pair-wise statistical comparisons between the sampling points of pairs of waveforms (e.g., Thatcher, 1977a; Posner, Klein, Summers, & Buggie, 1973). This has the advantage of analysing

the whole length of waveforms with respect to possible differences and yet allowing temporal specification of any differences found. It has the serious drawback that the high degree of mutual dependence existing between contiguous points leads to great difficulty in the interpretation of significant results. Another problem is that the use of large numbers of tests means that the accepted level of significance for any single test must be kept very low to guard against the possibility of type 1 error.

Techniques have been developed to analyse ERs in the frequency domain. These normally involve spectral analysis based on Fourier transforms of ER waveforms and are usually applied to steady-state ERs driven by sinusoidal stimulation (Regan, 1972). When applied to ERs elicited by discrete stimuli it is clear that the criticism raised above with reference to correlational analysis, namely that of lack of knowledge about where in the waveform differences are occurring, is particularly relevant. Moreover, it is difficult to see the physiological justification for the analysis in the frequency domain of what is an event in which it is probable that, under many circumstances, components occurring at different times after stimulus presentation represent different processes (see section 2c). The technique has been developed by Davis and Wada (e.g., Davis & Wada, 1977) to include the coherence analysis of pairs of ERs, a means of determining the power shared and phase relationships in discrete frequency bands.

Although all the techniques described above for the measurement of ERs have some advantages, in circumstances in which inter-subject variability is not so great as to prevent individual components being recognised consistently across



subjects there appears to be most advantage in the utilisation of the 'traditional' time-domain measures of ERs. These allow the specification of the timing of components of, and differences between, ERs and, with the use of the appropriate amplitude index, measure the amplitude of discrete segments of possible physiological significance which can be subjected to statistical tests of known reliability.

## 2b ER recording methodology - some general considerations:

The methodological issues concerning ER recording have been extensively discussed in the literature (e.g., Donchin, Callaway, Cooper, Desmedt, Goff, Hillyard, & Sutton, 1977; Cooper, Osselton, & Shaw, 1974; Goff, 1974; Regan, 1972). The purpose of this section is not to duplicate these authors but to highlight some of the more important points. All of the above authors stress the importance of using electrodes, amplification characteristics and computer sampling rates which are appropriate for the experimental situation. There is, for example, no point in using a sampling rate of 1 point per 10 msec if inter-ER latency differences in a component are anticipated to be in the region of, say, 5 msec. A point particularly stressed by Donchin, Callaway et al (1977) is that recording bandwidth and sampling rate should be such that all frequencies of the recorded ERs are adequately passed without distortion. Care is also required to ensure adequate control over sources of extra-cranial artefacts, especially eye movement artefact, which is particularly troublesome when recording the long latency slow waves of the ER (Donchin, Callaway et al, 1977). Other possible artefacts requiring attention include myogenic potentials, caused by muscular

contractions time-locked to the stimulus and electromyographic interference, the result of placing a recording electrode over an active muscle group. The use of high quality electrodes and amplification with good common-mode rejection characteristics minimises the problems associated with non-biological sources of artefact, most notably line noise.

An important and unresolved problem in ER research is the choice of reference electrode. All electrophysiological recordings are the representation of the voltage change between two points over time. In the case of ER recording one point is normally the 'active' or 'exploring' electrode and the other a so-called reference electrode. Many investigators have attempted to find a reference site which is electrically inactive, i.e., at a constant voltage with respect to ERs, as this would allow all observed ER activity to be attributed to the exploring electrode. This is problematic in that the positioning of one of a pair of electrodes at a non-cephalic site leads to a great deal of extra-cortical artefact, particularly ECG (Goff, 1974), yet the only way to ensure that an electrode is inactive is to position it some distance away from the putative cortical generator(s) of the ER being recorded. Goff et al (1969) considered that the most appropriate reference fulfilling the criteria of electrical inactivity and lack of artefact was the earlobe contralateral to the site of the exploring electrode, but Lehtonen and Koivikko (1971) reported that this site was active, particularly for visual stimulation. These latter investigators utilised non-cephalic references from which ECG was partialled out using potentiometers. Although of use for control studies of that type the complexity of the technique and the inconvenience caused to

subjects has meant that it has not been widely used.

Vaughan and his co-workers (e.g., Simson, Vaughan, & Ritter, 1977a,b) utilise the tip of the nose or chin as an inactive reference arguing (Vaughan, 1969) that in co-operative, relaxed subjects these sites are artefact free. As noted by Goff et al (1969), however, in most subjects these sites give rise to large myogenic artefacts. Many investigators favour the use of linked reference sites, particularly the mastoids or earlobes. The assumption behind the use of such sites is that any activity at each site will combine to produce cortically symmetrical signals, minimising the possibility of the distortion of ERs due to asymmetrical reference activity. It is important to note that such an assumption can only be valid if the impedance between each reference site and the exploring electrodes is equal; in other circumstances the reference with the lower impedance will predominate (Mowery & Bennett, 1957).

No entirely satisfactory solution to the problem of choice of reference electrode yet exists. It is arguable that the most appropriate site depends upon the aims of the particular experiment. When knowledge of the detailed morphology of the ER recorded from a particular exploring electrode is important, as in the case of topographical mapping studies, then the use of a site which is as inactive as is practicable is necessary, notwithstanding the attendant disadvantages of such sites. In the case where ER components which have a diffuse distribution over the scalp are being recorded (e.g., late positive components (Simson et al, 1977a)) then a reference which is relatively inactive with respect to these components, such as the mastoid or earlobe, is required. When such recordings are being made from homotopic scalp areas

with a view to evaluating possible ER asymmetries, thus necessitating a symmetrically active reference, an arrangement such as linked mastoids is possibly the best compromise (although it should be noted that this does not guarantee that the two sites will not be differentially active). When the aim of the experiment is to record ERs from homotopic modality-specific cortical sites, as is the case with many studies relating ERs to lateral asymmetries of processing (see section 2d) then an active midline electrode is the most suitable reference. This is because any differences in ERs so recorded can be ascribed with confidence to differential activity in the exploring electrodes. This is not necessarily the case with a bilaterally linked reference, in which either unequal impedances or differential activity will result in a reference which is asymmetrical with respect to cortical activity, and will therefore lead to ambiguities in the interpretation of any asymmetries observed in ER waveforms. The use of individual reference sites for each exploring electrode, such as ipsilateral or contralateral ear lobes, exacerbates the problem. The disadvantage associated with the use of a midline reference is that it is unclear the extent to which the morphology of ERs so recorded is influenced by the activity at the reference, which may be considerable (Lehtonen, 1973; Regan, 1972, p.220, fig. 5.3); all that is known is that this activity contributes to each channel to the same extent.

It is pertinent to note in this section some general methodological problems associated with ER studies designed to investigate psychological variables, a number of which have been discussed by Näätänen (1975). Perhaps the most pervasive problem considered by this author is that relating

to different levels of preparedness on the part of subjects during sequences of eliciting stimuli. He notes that if the aim of an experiment is to evaluate differences in ERs elicited by different stimulus types then failure to ensure that these occur unpredictably will invalidate the experiment. This is because it will be impossible to separate the effects on the ER of the stimuli and associated processing from those caused by differential preparatory set, this latter effect leading to differences in phasic arousal levels and peripheral orientation. Many early attempts to relate differences in ERs to differences in selective attention to the eliciting stimuli have been criticised on these grounds (Näätänen, 1975). Another important consideration when eliciting ERs with stimuli requiring cognitive processing is the possibility of variation in subjects' strategies. As noted in section 1c, subjects are capable of processing even explicitly verbal material in a non-verbal manner and care must be taken to ensure that subjects process eliciting stimuli in a known fashion and not heterogeneously. This may often require the use of a task which can only be performed through one cognitive strategy.

Other methodological points which are particularly relevant to studies of lateral asymmetries in ERs will be discussed in section 2d(ii).

## 2c Relationship of ERs to stimulus and psychological parameters

It is currently assumed by most investigators that ER components to a large extent represent progressive stages of analysis of a stimulus event (see, for example, Donchin, McCarthy, & Kutas, 1977). This assumption is based on a large

amount of evidence which indicates that whilst manipulation of modality and stimulus parameters has a very significant effect on early (<80 msec approximately) and middle (80-200 msec approximately) components of ERs psychological variables are found mostly to affect middle and late (>200 msec approximately) components (Callaway, 1975; Vaughan & Ritter, 1973; Regan, 1972). Components with a latency of more than about 300 msec are reported to be unaffected in topography or form by the modality of the eliciting stimulus (Squires, Donchin, Squires, & Grossberg, 1977; Ford, Roth, Dirks, & Kopell, 1973) and may, in appropriate circumstances, be observed in the absence of such a stimulus (Ruchkin & Sutton, 1973; Sutton, Tueting, Zubin, & John, 1967). Donchin (Donchin, 1976; Donchin, Kutas, & McCarthy, 1977) has labelled the modality-specific components of ERs exogenous components, emphasizing their dependence on environmental events. In contrast, later modality non-specific components are named endogenous components, reflecting their independence of stimulus parameters. This dichotomy corresponds to that drawn by Vaughan and Ritter (1973) between stimulus-evoked and association cortex potentials, their terminology emphasizing the putatively differing origins of the two sets of components.

It is clear that investigation of the effects of psychological parameters on exogenous components of ERs must take into account the sensitivity of these components to variations in stimulus parameters. Stimulus dimensions such as size, intensity, duration and complexity, variations in all of which cause changes in ERs (Regan, 1972), must be held constant over all experimental conditions. Care must also be taken to eliminate the methodological problems noted in the

previous section (2b). The psychological parameter which has most often been investigated in relation to exogenous ER components is that of selective attention. Typically, investigators have attempted to associate differences between ERs to differences in attention to the eliciting stimuli and as noted in the previous section, many experiments purporting to show such effects have been comprehensively criticised by Näätänen (1975) on methodological grounds. However, more recent studies, carried out in the light of such criticisms, have also reported attentional effects, some of which replicate the findings of earlier investigators. The most well-replicated finding in this field is that the biasing of attention to detect input in one or other ear results in a larger  $N_1$  (a negative peak occurring between 80 and 150 msec) in the auditory ERs to stimuli occurring in the attended ear compared to those to stimuli in the unattended ear (see, for example, Hillyard, Hink, Schwent, & Picton, 1973; Hink, Van Voorhis, & Hillyard, 1977; Näätänen & Gaillard, 1977). That this effect is unlikely to be peripheral in its locus is suggested by the experiments of Baribeau-Braum, Campbell and Picton (1977) and Picton and Hillyard (1974) which showed that enhancement of  $N_1$  occurred in the absence of any change in earlier ER components. An analogous effect has been reported with ERs elicited by visual stimuli located in different points in space (Van Voorhis & Hillyard, 1977; Eason, Harter, & White, 1969) in that middle latency components were enhanced to stimuli emanating from the attended spatial loci. The studies noted above strongly suggest that central states, or at least those associated with attention, can have a modifying effect on exogenous components of ERs.

Because of their sensitivity to cognitive factors endogenous components, recorded maximally over the parietal areas (Vaughan, 1969), have been subjected to much investigation in psychologically oriented paradigms. Investigation has to a large extent centred on the late positive component ( $P_{300}$ )<sup>1</sup> of evoked responses. Briefly, the behaviour of this component has been shown to be related to a number of psychological factors. Sutton, Braren, Zubin and John (1965) first reported that the amplitude of this component increased as a function of subjects' uncertainty about the nature of the eliciting stimulus. Using simple stimuli and tasks (such as the detection of a dim flash in a train of brighter ones)  $P_{300}$  amplitude has been shown to be quantitatively related to subjects' perceptions of the probability of the occurrence of the eliciting stimulus; the smaller the subject's subjective probability the greater the amplitude of  $P_{300}$  (Squires, Petuchowski, Wickens, & Donchin, 1977; Dunchan-Johnson & Donchin, 1977; Squires, Wickens, Squires, & Donchin, 1976). Amplitude of  $P_{300}$  is also enhanced by stimuli which are task relevant, rare or novel (Squires, Donchin, Herning, & McCarthy, 1977; Courchesne, Hillyard, & Galambos, 1975). It has further been shown that the amplitude of  $P_{300}$  is the same regardless of whether it is elicited by the repeated presentation of one task-relevant (target) stimulus embedded in a sequence of irrelevant stimuli or by a class of targets with the same overall probability of occurrence as the single target (Courchesne, Hillyard, & Courchesne, 1977), suggesting that the probability of individual stimuli is not necessarily a

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<sup>1</sup> The term  $P_{300}$  is generic, and covers late positive components peaking between around 300 and 600 msec, the precise latency depending on experimental conditions.



determining factor of  $P_{300}$  magnitude. This is also suggested by the study of Donchin, Kubovy, Kutas, Johnson, & Herning (1973) who demonstrated that  $P_{300}$  amplitude increased as a function of the complexity of the cognitive activity required following a stimulus.  $P_{300}$  latency has been associated with time taken to recognise the eliciting stimulus as measured by correlations of  $P_{300}$  latency and RT to eliciting stimuli (Kutas, McCarthy, & Donchin, 1977; Karlin, Martz, & Mordkoff, 1970).

Various explanations have been advanced to account for effects such as those noted above. It has, for example, been suggested that  $P_{300}$  represents phasic arousal (Näätänen, 1975), the activity of a 'general purpose cognitive processor' (Donchin et al., 1973), 'template mismatch' (Hillyard, Squires, Bauer, & Lindsay, 1971), response set (Hillyard et al., 1973) and decision processes following stimulus evaluation (Kutas et al., 1977). No adequate explanation exists which accounts for all the findings relating to  $P_{300}$ , although it is now clear that this component is not, as earlier suspected, simply the resolution of the negative-going pre-stimulus expectancy wave (contingent negative variation (Cohen, 1974)), as the two phenomena can be dissociated (Donchin, Tueting, Ritter, Kutas, & Heffley, 1975; Hillyard, 1971). Further discussion of this component will be presented in section 2d and a more detailed discussion will be found in chapters 9 and 10.

The conclusion to be drawn from the present section is that outside the investigative paradigms concerned with ER indices of lateral asymmetries of processing there is ample evidence that differences in ERs may be related to differences in the cognitive activities associated with eliciting stimuli.

2d The relationship between ERs and lateral asymmetries of processing:

i) Introduction: The purpose of this section is to review studies to date which have employed ER techniques to investigate cerebral asymmetries, with an emphasis on those studies which have utilised visual evoked responses as these are particularly relevant to the studies to be presented in the following chapters. Other recent reviews of this field have been made by Callaway, 1975; Butler and Glass, 1976; Donchin, McCarthy and Kutas, 1977, Donchin, Kutas and McCarthy, 1977; and Marsh, 1978.

ii) Methodological considerations: Apart from the general methodological problems of ER studies there are a number peculiar to studies of lateral asymmetry. These have been considered in detail by Donchin, Kutas and McCarthy (1977) and much of the present discussion is drawn from the comments of these authors. Donchin et al. note that nearly all studies investigating an EEG parameter of asymmetric processing employ the same general paradigm; an independent variable is defined in terms of a task or tasks given to the subject and the dependent variable is taken as some parameter of the EEG activity recorded during task performance. It should be noted that a minimum requirement for studies of this type to be valid is that EEG recordings should be made simultaneously from homotopic scalp areas; claims of evidence of asymmetry based on recordings from different scalp areas at different times must be treated with scepticism as many uncontrolled factors might have intervened in the time between recordings.

Donchin et al. also discuss the importance of using validated tasks in studies of this type. They point out that many studies have not used tasks previously shown differentially

to engage the cerebral hemispheres, nor did they take steps to ensure that subjects were task involved and performed at an adequate level. To these points might be added the comment that it is insufficient simply to ensure that subjects are task involved and that performance level is adequate; care must be taken to maximise the probability of subjects utilising appropriate (from the experimenter's point of view) cognitive strategies. It is also important to ensure that any electro-physiological differences found between tasks are not attributable to differential task difficulty. Another important factor is the cerebral laterality of subjects. It is obviously necessary to ensure that subjects are lateralised with respect to cognitive ability in an homogeneous, known, fashion. For this reason the most appropriate population from which to draw subjects is that of dextrals, of whom over 95% have language lateralised to the left hemisphere (Levy, 1974a).

The choice of electrode montage has been discussed previously with respect to the optimal position of the reference electrode (section 2b). Donchin et al. also note, for the same reasons as those outlined previously, the inadequacy of single non-equidistant or separate reference sites and reject the use of bipolar linkages on the grounds that such electrode arrangements minimise the likelihood of changes being observed due to the common-mode rejection characteristics of differential amplification. They conclude that appropriate references are linked equidistant sites (ears or mastoids), the chin, or an active midline site. As previously noted it is arguable that the latter is often the best choice of reference for studies of lateral asymmetries in ERs. The choice of the site of exploring electrodes is

dependent on the aims of the experiment; for instance, investigations of modality-specific ER components will require the placement of electrodes which maximally record activity from the appropriate modality-specific regions of the cortex, these being different to the optimal sites for recording long-latency modality non-specific components.

Consideration must also be given to methods of data analysis. The absence of detected asymmetries in ERs in a study designed to observe them may not mean that they are not present but that the measurement techniques employed were either too insensitive or inappropriate. The finding of such asymmetries must be treated with caution unless it can be demonstrated that, in the same paradigm, the asymmetries can be modified by the utilisation of a different task hypothesised to engage the hemispheres in a different fashion to that giving rise to the originally observed asymmetries. This is because there are a number of artefactual sources of such asymmetries, e.g., skull thickness (Leissner, Lindholm, & Petersen, 1970). It is also important that the measurement of asymmetry is reported in a way which allows the elucidation of the locus of any changes in asymmetry which may be observed. For this reason the use of ratio indices of asymmetry (e.g., R.hem/L.Hem) or other proportional measures should be avoided as a change in such a measure cannot, in the absence of other data, indicate the contribution made by each hemisphere to the effect.

It will become apparent that many studies which have attempted to relate differences in ERs to lateral asymmetries in processing are open to criticism with respect to one or more of the issues discussed above.

iii) Auditory ERs (AERs): It is not the purpose of this section fully to review studies relating AERs to lateral asymmetry of function but some comment on the studies central to the field (and often widely cited in the literature) is relevant. There is much debate as to whether simple auditory stimuli presented so as to require little cognitive effort on the part of the subject result in asymmetric AERs when monaurally presented (see Donchin, McCarthy, & Kutas, 1977, for a review of this area). Asymmetries might be expected in view of the more predominant projections which exist between each ear and the contralateral, compared to the ipsilateral, auditory cortex but findings have been equivocal (cf., Vaughan & Ritter, 1970; Peters & Mendel, 1974). It may be the case that an overlooked factor in studies of this nature is the strategy subjects adopt to deal with the supposedly neutral stimuli. It has been demonstrated in a dichotic listening paradigm that ear advantages with respect to the detection of certain types of stimuli, e.g., vowels, may depend upon whether subjects are processing the stimuli in a linguistic or non-linguistic context (Spellacy & Blumstein, 1970). Thus, the mental set of the subject may be an important mediating variable for AERs even when these are elicited by simple stimuli. Support for this contention is given by the study of Shucard, Shucard and Thomas (1977), who demonstrated that asymmetries in AERs to tones were dependent on the nature of the subjects' on-going task.

To investigate AER asymmetries which may be related to cognitive processing, investigators have typically used linguistic and non-linguistic eliciting stimuli and compared AERs recorded from homotopic scalp areas overlying the auditory cortex. A number of studies have reported AER

asymmetries in such a paradigm (e.g., Cohn, 1971; Matsumiya, Tagliasco, Lambroso, & Goodglass, 1972; Molfese, 1978a; Molfese, Freeman, & Palermo, 1975; Morrell & Salamy, 1971; Neville, 1974; Wood, Goff, & Day, 1971; Wood, 1975). A number of the early studies were the subject of a critical review by Friedman, Simson, Ritter and Rapin (1975a) who themselves were unable to demonstrate task dependent asymmetries in AERs elicited by speech and non-speech sounds in either a passive listening condition or a condition requiring discriminative responses. These authors criticised the study of Morell and Salamy (1971) on the grounds that no non-speech control was used, thus making it impossible to determine whether the reported asymmetries to phonemic stimuli were stimulus or task-dependent. A replication and extension of the study of Morell and Salamy by Grabow and Aronson (1977) found no asymmetries in the AERs elicited by either phonemes or tones. The study of Cohn (1971) was criticised on the grounds that the stimulus-dependent ER activity was seen at a very short latency (a positive wave at 14 msec was observed over the right hemisphere for click but not verbal stimuli) and might therefore reflect differences in the physical parameters of the two types of eliciting stimuli rather than any differences in cognitive processing. It should further be noted that Cohn presented no quantitative data nor even representative waveforms to support the validity of his findings. The use of bipolar electrode linkages by Matsumiya et al. (1972) leads to the criticism by Friedman et al. (1975a) that the results of this study are uninterpretable, in that it is impossible to determine the reason (e.g., activity at one or both electrode sites) for the reported asymmetries. Finally Wood (1971) is criticised on the grounds that the significant

differences between portions of ER waveforms emerge from a series of 256 separate Wilcoxon tests on the sampling points of each subject's AERs. Thus the chance of type 1 error is very high. The conclusion of Friedman et al. (1975a) was that, at that time, no evidence existed which strongly supported the contention that lateral asymmetries of processing were reflected in AERs. This was the conclusion also of Galambos, Benson, Smith, Schulman-Galambos and Osier (1975). This study utilised as stimuli consonants and tones. In the linguistic condition subjects were required to listen to a stimulus sequence which consisted of the repetition of one of the consonants with the occasional presentation of one other, the task being to count the number of times the rare stimulus was presented. In the non-linguistic condition an analogous situation obtained for the two tones. On the basis of finding no task dependent components in ERs to either the frequent or rare stimuli (the ERs to these latter stimuli had a large P<sub>300</sub> component) Galambos et al. concluded that such effects probably do not exist. It should be noted, however, that it is arguable the extent to which a task involving 100 repetitions of the same consonant with an occasional intrusion which must be discriminated remains, for very long, a linguistic task. There are, presumably, a number of non-linguistic cues which might be utilised in such a situation. Moreover, although no mention is made of the performance level of the subjects it would seem likely that the tasks employed were of a low standard of difficulty and required little processing capacity on the part of the subjects, in which case it is possible that any asymmetrically localised mechanisms were not fully engaged. It is certainly the case that the pessimism of Galambos et al. is not justified on the grounds of this study.

Of the studies not reviewed by Friedman et al. (1975a) there are a number which appear to be immune from the criticisms voiced in that paper. Neville (1974) demonstrated asymmetries in AERs elicited by dichotically presented digits which were absent in ERs to dichotic clicks. The early components of the AERs to the digits showed a greater amplitude when recorded from the left hemisphere and the later components from this hemisphere were of a shorter latency. These results were interpreted as evidence for left hemisphere involvement in this task, this being supported by the behavioural data which showed that subjects had displayed the usual right ear - left hemisphere advantage in the recall of the digits. No such advantage was observed for the reporting of the number of clicks heard in each ear. Neville further reported that no ER effects were observed with the monaural presentation of the stimuli suggesting that, under some circumstances, at least, ER asymmetries may not be observed unless subjects are subjected to a high task loading.

Molfese, Freeman and Palermo (1975) reported that in infants, children and adults speech stimuli (syllables and words) elicited larger AERs ( $N_1$ - $P_2$  components) from the left hemisphere and non-verbal stimuli (chords and noise) caused the same effect with respect to the right hemisphere. These effects occurred in the absence of any task instructions, subjects merely listening to the stimuli, and have been replicated and extended by Molfese, Nunez, Seibert and Ramanaiah (1976) and Molfese (1978b). Molfese (1978a) has reported that AER differences associated with differences in the linguistic, as opposed to the acoustic, parameters of the eliciting stimuli occur only in AERs recorded from the left hemisphere. Once again, no task requirement other than



listening was required on the part of the subjects. It should be noted that ERs in this study (i.e., Molfese, 1978a) were based on only 16 repetitions of each stimulus type, rather a lower number than is normally utilised. As only line tracings of ERs are shown in the figures it is impossible to evaluate whether they were adequately separated from background EEG. Wood (1975) replicated and extended the finding of Wood et al. (1971) that differences in AERs from the left hemisphere were associated with whether subjects were required to perform linguistic or acoustic analysis of the eliciting consonant-vowel stimuli. Unfortunately ER analysis in this second study proceeded as in the first, by the use of serial statistical tests over all sampling points of ER pairs, meaning that the criticisms applied to Wood et al. (1971) apply also to Wood (1975). In contrast to the studies noted above neither Tanquay, Taub, Doubleday and Clarkson (1977) nor Haaland (1974) could find the hemisphere asymmetries which might have been expected to occur with the use of linguistic eliciting stimuli. Neither of these studies, however, employed non-linguistic control stimuli.

A number of studies have reported AER effects associated with semantic and syntactic factors. For example, Brown, Marsh and Smith (1973) reported that ERs to ambiguous words which were disambiguated by their context differed according to their contextual meaning and that these differences were greater over the left hemisphere. Teyler, Roemer, Harrison and Thompson (1973) reported that AERs to click stimuli differed according to whether the clicks were temporally related to nouns or verbs. Using tone stimuli as 'probes' Shucard et al. (1977) reported that AERs to these are of a larger amplitude from the left hemisphere when presented to subjects during

performance of a verbal task and are larger from the right during a musical task. As noted previously, this study demonstrates the importance of controlling subjects' cognitive set even when using simple, supposedly neutral stimuli.

In spite of the important methodological issues raised by Friedman et al. (1975a) and others (e.g., Donchin, Kutas, & McCarthy, 1977) a consideration of the major findings to date leads to the conclusion that there is evidence to support the contention that lateral asymmetries in AERs may be associated with lateral differences in information processing. Discussion of possible explanations of these effects will be reserved until after a review of studies which have utilised visual evoked responses (VERs) as a dependent variable.

iv) Visual ERs (VERs):

Unstructured stimuli to central vision: There is some disagreement as to whether centrally presented 'neutral' or unstructured stimuli (e.g., strobe flash) give rise to VERs which are symmetrical across the hemispheres. For example, Vaughan, Katzman and Taylor (1963) and Kooi, Guvener and Baghi (1965) both reported that flash ERs were symmetrically distributed in normal subjects. This was also the conclusion of Harmony, Ricardo, Otero, Fernandez and Valdes (1973) whose study analysed the VERs of 139 subjects. Richlin, Weisinger, Weinstein, Gianninia and Morganstern (1971) reported that in 6 normal dextral children the middle latency components of their VERs were larger and the latency shorter over the right occipital region. This study is difficult to evaluate as it was reported very poorly; for example, no representative waveforms were shown. Subsequently, Richlin, Weinstein and

Weisinger (1976), in a similar study, replicated the above-mentioned results with respect to the amplitude but not the latency asymmetry. Interestingly, in both of these studies the pattern of results in retardate subjects differed from that of normals. These results have been further replicated in children by Beck, Dustman and Lewis (1975) and Sobotka and May (1977). Thus, there is some support for the contention that at least in children VERs may be asymmetrically distributed over the hemispheres. There are also reports of VERs having a larger amplitude from the right hemisphere in adult subjects (Rhodes, Obitz, & Creel, 1975; Perry & Childers, 1969) although it should be noted in the case of Perry and Childers (1969) that whilst widely cited as evidence for the contention that VERs are asymmetrical (e.g., Donchin et al., 1977a,b) these authors offer no evidence whatever to support their statements on this matter (see Perry & Childers, 1964, p.54, p.64). Blatt and Offner (1966) have reported that the latencies of VERs recorded from the left hemisphere of dextral subjects were delayed compared to those of VERs from the right hemisphere.

At present it is not possible to resolve the issue of the extent to which VERs elicited by centrally-viewed stimuli exhibit systematic hemisphere asymmetries. It may be the case that an important factor, as noted with respect to analogous AER studies, is the mental set of the subjects. Unless this is controlled it is difficult to know the extent to which any VER asymmetry is the result not of structural differences between the hemispheres, as suggested by those investigators finding this effect, but of the influence of asymmetrical cognitive set or processing. Cognitive processing presumed

primarily to engage only one hemisphere has been reported to influence the asymmetry of VERS elicited by neutral 'probe' stimuli (Rasmussen, Allen & Tarte, 1977; Galin & Ellis, 1975). The confirmation, if it occurs, that centrally viewed stimuli do elicit larger VERS (possibly of a shorter latency; see Richlin et al. (1971), Blatt & Offner (1966)) from the right hemisphere, when cognitive set is controlled, could be interpreted as lending support to Bryden and Allard's (1976) hypothesis that the right hemisphere is specialised for early visual processing.

Lateralised stimuli: Several investigators have taken advantage of the almost perfect decussation of the visual pathways to direct stimuli to the individual hemispheres. Among the first investigators to do this was Eason who with his co-workers has reported a series of experiments in which individual VFs were stimulated with flash stimuli and recordings made from homotopic occipital regions referenced to ipsilateral ear lobes (Culver, Tanley, & Eason, 1970; Eason, Groves, & Bonelli, 1967; Eason & White, 1967; Eason, Groves, White, & Oden, 1967). As would perhaps be expected on anatomical grounds one finding was that VERS recorded from the hemisphere contralateral to the VF stimulated (the directly stimulated hemisphere) were of a larger amplitude and shorter latency than those from the ipsilateral hemisphere (Eason et al., 1967a). This effect was reported (Eason et al., 1967b) to be modified by the handedness of the subject such that only left-handers were reported as showing, overall, larger VERS from the right hemisphere. It should be noted that some aspects of the methodology of this study are weak, particularly with respect to the means by which stimuli were presented. Each lateral VF was stimulated separately in a discrete block of trials. Thus, on any run of trials, subjects

knew which VF was to be stimulated and in spite of this no attempt was made to monitor subjects' fixation to ensure that stimulation of both VFs did not occur. Culver et al. (1970) using exclusively female subjects (Eason et al. (1967b) utilised males) were unable to replicate the previous study. They reported that for both right and left-handed subjects right hemisphere VERS were greater than those from the left hemisphere when the LVF was stimulated but that VERS were symmetrical to RVF stimulation. Similar methodological criticisms to those voiced above apply to this study also, however. Gott and Boyarsky (1972) carried out a similar study to those discussed above. Using male subjects these investigators reported that the VER from the hemisphere contralateral to subjects' preferred hands was delayed, relative to the ipsilateral hemisphere, when each was stimulated directly. Gott and Boyarsky also reported that no VF-dependent amplitude asymmetry occurred in the VERS of right-handed subjects whereas for left-handers the response from the right hemisphere was greater than that from the left when stimulation occurred in the LVF. As in the case of Eason et al. (1967b) the stimuli were presented to each VF in separate blocks and subjects' fixation was not monitored. As noted by Butler and Glass (1976) the results of the experiments of Eason and his associates and Gott and Boyarsky are puzzling in that, although left-handers are a heterogeneous group with respect to brain organisation, no reflection of this was found in the VERS of left-handed subjects in these studies. The interpretation of their results by Gott and Boyarsky was that the delayed latency in the VERS from the hemisphere contralateral to the preferred hand reflected the involvement of that hemisphere in the control of the hand. This explanation

does not account for the finding of Culver et al. (1970) that no such differences were found between left- and right-handed females, nor for the finding in Gott and Boyarsky's study that only left-handers exhibited a VF dependent asymmetry. In spite of the doubts expressed by Butler and Glass (1976) the possibility that these results reflect differences between dextrals and sinistrals and between the sexes with respect to brain organisation cannot be ruled out. However, in view of the methodological inadequacies of the studies thus far performed in this area a replication of the results using more adequate methodology, prior to a detailed attempt to account for them, would be of benefit.

Andreassi, Okamura and Stern (1975) reported two experiments in which VERs were recorded from homologous occipital regions during stimulation of the retina at different lateral eccentricities. A small cross was used as an eliciting stimulus and subjects were required to count the number of times it appeared during each block of stimulus presentations. It was reported that whilst no VER asymmetries were present to midline stimulation significant asymmetries in VER latency occurred when stimuli were presented to the lateral VFs. VERs with components of the shortest latency were recorded over the hemisphere contralateral to the stimulated VF. In the second experiment reported by these investigators an amplitude asymmetry was also observed; VERs with the larger amplitude were recorded over the contralateral hemisphere. The explanation offered for these effects was that the hemisphere contralateral to the stimulated VF received afferent stimulus information directly whereas the ipsilateral hemisphere received the information via the extra indirect pathway of the

splenium, leading to a delayed and possibly degraded response. Andreassi et al. omit to mention other possible sources contributing to the electrical activity observed from the ipsilateral hemisphere. These include contributions from the extra-geniculate visual system (Eason et al., 1967b) and from the passive propagation of electrical activity generated in the contralateral hemisphere.

Buchsbaum and Drago (1977) report an experiment in which individual VFs were stimulated (flash stimuli) while subjects either attended to the stimuli or performed mental arithmetic. All subjects were right-handed females and recordings were made between homotopic occipital and 'Wernicke's region' sites referenced to ipsilateral ear lobes. When subjects attended to the stimuli the hemisphere contralateral to the field of stimulation gave rise to the VERS with the larger amplitudes, this effect being strongest for the middle latency (116-152 msec) negative component. This amplitude asymmetry was largest in the occipital leads, as might be expected if the VERS were being generated primarily in the occipital region. Also of note is the finding that when comparing VERS elicited by direct (contralateral VF) stimulation of each hemisphere those from the left hemisphere were larger, a result contradicting that of Culver et al. (1970). Unfortunately, no peak latency measures were presented in the report of this study. The effect of mental arithmetic was to eliminate all the hemisphere differences that had been observed when subjects attended to the stimuli and to depress the amplitude of all VERS relative to those recorded in that condition. The effects of mental arithmetic on VERS was greatest in those recorded from the left hemisphere when stimulation occurred in the right visual field; this is

congruent with the suggestion (Butler & Glass, 1974a) that mental arithmetic primarily engages the left hemisphere.

As previously noted, the studies of Eason's group and that of Gott and Boyarsky (1972) are difficult to interpret, not least because of the methodological shortcomings of these experiments. It seems clear, however, that stimulation of lateral VFs can give rise to VER distributions which to a large extent reflect the anatomical arrangements of the retino-cortical visual pathways. The study of Buchsbaum and Drago (1977) illustrates that, in some circumstances, subjects' cognitive activity may have a significant modifying effect on VERs elicited in such paradigms.

Using pattern-reversal stimulation Halliday and his co-workers have reported the apparently paradoxical result of half-field stimulation giving rise to a larger VER from the hemisphere ipsilateral to the field of stimulation (Barrett, Blumhardt, Halliday, Halliday, & Kriss, 1976a,b; Blumhardt, Barrett, & Halliday, 1977; Halliday, Barrett, Blumhardt, Halliday, & Kriss, 1977). These results contradict those of a similar experiment by Cobb and Morton (1970) who reported that pattern-reversal stimulation of an individual half-field gave rise to a VER almost wholly confined to the contralateral hemisphere. However, as elegantly demonstrated by Barrett et al. (1976a) this result was due to Cobb and Morton's use of bipolar electrode linkages, which resulted in a spurious effect. The explanation of Halliday's group for their results is that the neuronal generators of the pattern-reversal ER lie within the calcarine fissure and are oriented so as to propagate activity predominantly towards the contralateral scalp area, meaning that electrodes over this area are best



placed to detect such activity. This explanation was disputed by Beauchamp, Mathews, Small and Stein (1976) who argued that the first detectable VER to half-field pattern-reversal stimulation was over the hemisphere contralateral to the stimulated VF. They argued that the findings of Barrett et al. (1976a,b) were due to the first positive wave in the VER (the component showing the paradoxical effect) from the ipsilateral hemisphere seeming to be bigger because it started from a more negative baseline. The hypothesis of Barrett et al. received support through the demonstration that in a subject who had undergone a unilateral occipital lobectomy direct stimulation of the intact hemisphere gave rise, as in normal subjects, to a larger VER over the hemisphere ipsilateral to the VF of stimulation (Blumhardt et al., 1977).

To date, the effect reported by Halliday's group has only been shown to occur with pattern-reversal stimulation of quite large ( $16^{\circ}$  semi-circle) areas of the VF. That it may be restricted to pattern-reversal stimulation is suggested by the study of Biersdorf and Nakamura (1971) who, using flash stimulation extending semi-elliptically into individual half-fields ( $7.5^{\circ} \times 15^{\circ}$ ), reported that largest VERs were recorded from the hemisphere contralateral to the field of stimulation in all subjects. The results of studies such as those discussed above suggest that it is not always justified to assume that an electrode will maximally register activity from the region of cortex directly beneath it. However, the results of those studies which have used stimuli subtending a small visual angle at moderate lateral eccentricities (e.g., Andreassi et al., 1975) are interpreted most parsimoniously by assuming that the active electrodes detected activity

principally in the hemisphere over which they were situated.

Vella, Butler and Glass (1972) reported a study in which individual VFs were stimulated by an illuminated checkerboard stimulus ( $15^{\circ}$  square at an eccentricity of  $14^{\circ}$ ). VEs from the right hemisphere were found to be larger than those from the left in all conditions and particularly when comparing VEs from each indirectly stimulated hemisphere. The control conditions, when the stimulus was viewed centrally or VEs were elicited by diffuse flashes of the same overall dimensions as the stimulus, resulted in no asymmetries. The results were interpreted as reflecting the specialisation of the right hemisphere for the processing of visuo-spatial stimuli. This being the case it is not clear why the same effect was not observed when the stimulus was viewed centrally. The interpretation of the observed asymmetries is made difficult by the fact that they were observed maximally in homologous bipolar channels (occipital-temporal) rather than in the channels recorded with a common reference (occipital-midline occipital). Vella et al.'s suggestion that this was because it is the visual association cortex, rather than the primary cortex, which is functionally specialised cannot be evaluated with this electrode montage. The interpretation of the results of this study are further complicated by the findings of Barrett et al. (1976a,b), discussed previously, which demonstrate that lateralised pattern-reversal stimulation over large retinal areas may give rise to paradoxical effects. It is not clear the extent to which this may have occurred in Vella et al.'s study.

Studies using meaningful stimuli: A number of studies have elicited VEs with psychologically meaningful stimuli

with the aim of indexing the asymmetrical processing of such stimuli. Buchsbaum and Fedio (1969) used verbal and non-verbal stimuli in such a study. The stimuli were equated for size and brightness and consisted of words, random dot patterns and structured dot designs, presented in central vision. Recordings were made from occipital regions referred to ipsilateral ear lobes. Verbal and non-verbal stimuli were mixed within each block of stimulus presentations. The five right-handed subjects were given no task instructions other than to 'observe the stimuli'. One finding was that the latency of the first positive peak (190-280 msec) of the VERS to the verbal stimuli was shorter than that of the VERS to the non-verbal stimuli (in their discussion section the authors claim that this effect was greatest in VERS from the left hemisphere, but no evidence is presented to support this contention). A complex correlational analysis yielded the finding that VERS to the verbal stimuli were more similar to one another than they were to the VERS elicited by the design stimuli; in view of the latency differences between these two sets of VERS this is not surprising. This effect was reported to be significantly greater between VERS recorded from the left hemisphere. The results of this experiment were interpreted as demonstrating that the perception and decoding of the verbal information took place in the left hemisphere as it responded to the verbal and design stimuli with more disparity than did the right hemisphere. Friedman et al. (1975a) have criticised the study on the grounds that the large numbers of t-tests performed on the peak latency values and on the correlational indices meant that the risk of type 1 error was very high. Also, the lack of a task means that the cognitive activity of the subjects was largely uncontrolled and it is not possible

to be certain that subjects processed the stimuli in the manner assumed by the investigators (the behavioural data presented by Buchsbaum and Fedio (1969) were obtained from a group of subjects whose VERS were not recorded).

Buchsbaum and Fedio (1970) reported an experiment almost identical to that described above with the exception that the stimuli were lateralised to individual VFs. All VER analyses involved the correlational analysis of VERS. It was reported that, as in the study of Buchsbaum and Fedio (1969), most discrepancy between the VERS to the two kinds of stimuli occurred in the left hemisphere and that this discrepancy was greatest when the left hemisphere was directly stimulated. It was further reported that VERS from the hemispheres when each was directly stimulated were more consistent than those recorded from the indirectly stimulated hemispheres. On the basis of these results Buchsbaum and Fedio suggested that the left hemisphere had primarily been the one involved in the verbal analysis of the stimuli. Subsequently, Fedio and Buchsbaum (1971) replicated this study using as subjects unilateral temporal lobectomy patients. The results of this study were essentially the same as those of Buchsbaum and Fedio (1970) with the additional finding that in left-lesioned patients VERS elicited by words were less consistent morphologically than those to the non-verbal stimuli and that the opposite result obtained for right-lesioned patients, i.e. greatest consistency was observed in the VERS elicited by the verbal stimuli. This result is congruent with the well established findings relating to unilateral brain lesions (see section 1b).

It is pertinent to note that in the three studies

discussed above (Buchsbaum & Fedio, 1969, 1970; Fedio & Buchsbaum, 1971) subjects passively observed the eliciting stimuli, with a concomitant lack of control of cognitive activity. In the latter two studies no attempt was made to analyse specific components of the VER and thus the source of the observed VER differences is not known. Taken as a whole, however, these studies suggest that it is possible to index differential hemisphere engagement with VERs elicited by psychologically meaningful eliciting stimuli.

Seales (1976) elicited VERs with letter pairs to which subjects made discriminative responses on the basis of, in one condition, whether letters were of the same size and, in another condition, whether the letters had the same name. VERs were recorded from homotopic occipital and temporal regions and no component from either placement exhibited task-dependent asymmetries. Poon, Thompson and Marsh (1976) performed an experiment similar to that of Seales (1976) in which subjects responded either as soon as the stimuli appeared or on the basis of whether the letters shared a common linguistic feature (e.g., both vowels). VERs were recorded from temporal regions, and showed an asymmetry in the amplitude of an early negative component (80-100 msec) only in the verbal condition, when this component was larger in the left hemisphere. Unfortunately, as no analogous non-verbal task was employed, it is impossible to determine whether this asymmetry reflects differences in the information processing or response requirements between the two conditions.

A number of other studies have elicited VERs with complex or structured lateralised stimuli. Gott et al. (1975, 1977) reported a study in which subjects were right-handed normals and commissurotomed patients. Stimuli consisted of words

which had to be examined for a rhyming match with a constantly-present test word or of shapes which had to be examined for a physical match with a reference shape. The stimuli were presented bilaterally or unilaterally to the lateral VFs and VERs were recorded from homotopic occipital and parietal sites referred to the left ear. VERs were analysed using correlational techniques and the results presented in an extremely unclear manner. A main finding was that VERs from the two hemispheres were less similar when elicited by unilateral, as compared to bilateral stimuli, as might be expected in the light of the review of studies employing lateralised stimuli. Gott et al. also reported that the two subject groups showed similar patterns of correlations between VERs when verbal stimuli were delivered to the left hemisphere but dissimilar ones to right hemisphere stimulation with these stimuli. These results, along with a qualitative analysis of the VER data, were interpreted by the authors as demonstrating a left hemisphere specialisation for the processing of the verbal stimuli. It is of interest to note that the patient group showed a higher interhemispheric correlation between VERs to bilateral verbal stimulation than did the normals, suggestive perhaps of a more extensive bilateralisation for language capacities (see section 1b). It is also noteworthy that bilateral VERs were observed in the commissurotomed group to the unilaterally presented stimuli. As all callosal connections are missing in these patients this result provides compelling evidence that VERs recorded from the hemisphere ipsilateral to a stimulated half-field are not entirely the result of the transmission of the stimulus information across the splenium.

Neville (1978) conducted a study employing as subjects normal and congenitally deaf children. Stimuli consisting of drawings of common objects were presented to the right or left VFs with the task requirement being to choose from a selection a picture representing the stimulus which had just been exposed. VERs were recorded from left and right temporal regions referenced to linked ears and were formed only from stimuli to which correct behavioural responses were given. In normal subjects, in the absence of any behavioural asymmetries relating to field of stimulus presentation, a right hemisphere latency advantage was observed for the first three components of the VER irrespective of VF of stimulus presentation. This effect was associated with larger amplitudes in the later components of the VERs recorded from the right hemisphere. The deaf children showed a different pattern of results in that asymmetries in the amplitudes of their VERs varied with VF of stimulus presentation such that the larger amplitude was observed in VERs from the hemisphere contralateral to the field of stimulus presentation. Further analysis revealed a tendency for the deaf subjects who used a sign language to show an asymmetry reversed with respect to that found in the normal subjects. These results were interpreted as indicating a right hemisphere specialisation for the experimental task in the normal children and a lack or reversal of this asymmetry of processing ability in deaf children, possibly as a result of their lack of verbal language abilities. Although this study is of great interest the interpretation given by Neville would be more convincing if a linguistic task had also been utilised and had resulted, in the normal children, in an asymmetry reversed with respect to that found in the VERs elicited by the

picture stimuli.

Krynicky (unpublished study, cited in Donchin, McCarthy & Kutas, 1977) conducted a study similar to that of Neville (1978) using adult subjects. He demonstrated, using behavioural responses, that a polygon matching task resulted in a RVF superiority if a simple physical match was required and a LVF superiority if a mental rotation prior to matching was demanded. According to Donchin et al. VERs elicited by polygons associated with each type of task showed gross hemisphere asymmetries in that the VER from the hemisphere supposedly superior in the performance of each task was large and consisted of a number of separate components whereas that from the opposite hemisphere consisted of one slow component. As full details of this study are not available it is impossible to evaluate it. The results would appear to provide a convincing demonstration of the ability of VERs to index asymmetric cognitive processing.

In a study performed by Lehmann and Julesz (1977) random dot stereograms were presented unilaterally to the two VFs. It was reported that a VF asymmetry in the form of a larger VER from the contralateral hemisphere was observed, the VER from the ipsilateral hemisphere being not only smaller but of a reversed polarity. These asymmetries were reported to exist for up to 300 msec, providing, in the view of the investigators, evidence of independent data handling in the two hemispheres. Although fusion of random-dot stereograms has been reported to be impaired by right hemisphere lesions (Carmon & Bechtoldt, 1969), Lehmann and Julesz report no VER effects which might be associated with such an asymmetry of function.



Consideration of the results of studies which have used meaningful eliciting stimuli leads to the conclusion that VER asymmetries may be the result of asymmetries in subjects' processing of the stimuli. This is particularly evident in the case of unilateral presentation of the eliciting stimuli; asymmetries caused by 'anatomical' factors may be substantially modified by stimulus processing mediated asymmetrically between the hemispheres.

Use of 'probe' stimuli: Instead of eliciting VERs with meaningful, task-relevant stimuli some investigators have done so with task-irrelevant stimuli while subjects were engaged in some pre-defined cognitive activity; the so-called 'probe' paradigm. The rationale of this approach is that any task-dependent asymmetries in hemisphere activity may be indexed by a differential response on the part of the two hemispheres to a neutral stimulus. Galin and Ellis (1975) recorded flash ERs from parietal and temporal sites (referenced to an active midline site) while subjects performed verbal (writing from memory) or spatial (Kohs blocks) tasks. The performance of these tasks was reported to be associated with different levels of EEG alpha activity from the hemispheres. The ratio of right hemisphere to left hemisphere activity (the R/L ratio) was significantly lower during the spatial task and this was interpreted as indicating that the two tasks produced the expected differential hemisphere engagement. R/L ratios of the integrated power of the VERs recorded during task performance were found to be task-dependent in a similar fashion in that they were smaller in the spatial condition. Analysis of individual VER components yielded the findings that the R/L ratios of two peak-to-peak amplitude measures demonstrated the same effect

and that no systematic peak latency changes occurred. These results were considered to demonstrate that the VER amplitudes were measuring some aspect of 'hemispheric excitability' which varied with engagement in cognitive activity. The use of ratio measures to present the data means that it is impossible to determine how the task-dependent changes actually came about and thus to evaluate effectively different putative mechanisms underlying the changes. Donchin, Kutas and McCarthy (1977) considered that the study demonstrated that VERs were directly influenced by the spectral characteristics of the background EEG; this use of correlational data to impute direction of causality is, of course, invalid. It is possible that both EEG and VER characteristics were influenced by some common regulatory mechanism.

In a partial replication of Galin and Ellis (1975) Mayes and Beaumont (1977) were unable to find any task dependent asymmetries in VERs to the probe stimuli. They criticised the study of Galin and Ellis for its lack of control of several factors including eye movements, amount of attention paid to the probe stimuli and the influence of other EEG components on the VER. Whilst these criticisms are all valid the most likely reason for the failure of Mayes and Beaumont's replication attempt lies in the fact that they employed bipolar electrode linkages (occipital to parietal). It is possible that the use of such a montage resulted in these investigators missing task-dependent asymmetries because the effects occurred equally at both (closely spaced) electrodes of one or both channels. In a subsequent study Beaumont and Mayes (1977) were again unable to demonstrate task-dependent VER asymmetries. Although common reference derivations were

employed the investigators chose to use covert mental imagery tasks which were unvalidated with respect to their potency for differentially engaging the hemispheres. Although the finding of task-dependent differences between VERS suggested that differential processing occurred it is possible that this did not include differential hemisphere engagement.

Rasmussen, Allen and Tarte (1977) investigated asymmetries in flash ERS recorded from central derivations. The two conditions employed required subjects either to attend to the eliciting flashes or to perform mental arithmetic, a task considered to be mediated primarily by the left hemisphere. The R/L amplitude ratio of the middle latency components was reported to be larger in the mental arithmetic condition and this was considered to be the result of relatively more left-hemisphere involvement in this condition compared with the control situation. As noted previously, the use of ratio measures in the absence of other data means that it is not possible to determine the cause of the task-dependent changes. However, Caperall and Shucard (1977) have reported that VERS to flash stimuli were attenuated from the left hemisphere when subjects performed mental arithmetic and from the right hemisphere during a musical task compared to VERS elicited during a 'relaxation' task.

Other than the studies of Mayes and Beaumont (1977) and Beaumont and Mayes (1977) there would appear to be some consensus that VERS to visual 'probe' stimuli reflect asymmetrical cognitive activity, possibly through the relative attenuation of the VERS generated in the hemisphere primarily engaged in the task. The results of the study of Buchsbaum and Drago (1977) can be interpreted in this light in that

their mental arithmetic condition caused most attenuation in VERS from the directly stimulated left hemisphere. As previously noted, these effects provide convincing evidence for the need to control subjects' cognitive activities even when eliciting VERS with simple stimuli which are supposedly neutral with regard to the relative specialisations of the two hemispheres.

The 'background information probe' paradigm: In a series of publications Thatcher has reported studies in what he has called the 'background information probe' (BIP) paradigm (Thatcher & April, 1976; Thatcher, 1977a,b). It should be noted at the outset that in each of these reports the presentation of experimental results has been unsystematic and unclear in the extreme. The BIP method involves the presentation of a number of neutral control stimuli, followed by a meaningful stimulus (e.g., a letter), then a variable number of control stimuli and finally another meaningful stimulus which the subject must compare to the first according to some predefined set of criteria. Separate VERS are recorded to each stimulus in the presentation series. In a study in which letters were the meaningful stimuli and the subject's task was to determine whether the two letters in each presentation series were the same or not Thatcher reported a number of differences between VERS recorded to each stimulus, most notably that the late positive component of VERS to second letters which matched the first was larger than that of VERS to mismatches. According to Thatcher (1977b) some hemisphere asymmetries in VERS were also observed in some of the subjects but no systematic analysis of these effects was presented. As it was possible for subjects to perform this

task using either physical or name match strategies (all letters were upper-case) consistent asymmetries across subjects would perhaps not be expected (see section 1c). In a study involving the semantic matching of word stimuli (Thatcher & April, 1976; Thatcher, 1977b) significant hemisphere asymmetries were reported in the late positive component of VERs recorded from posterior derivations in that the amplitude of this component was larger in VERs from the left hemisphere. This effect was only observed to the second of the word stimuli in each presentation sequence. Interestingly, such an asymmetry was also observed in VERs to the control stimuli following the first word in each sequence, an effect which may be similar to that observed by investigators such as Galin and Ellis (1975) and was interpreted by Thatcher as reflecting covert rehearsal processes.

Although Thatcher's experimental paradigm and results are of interest the data analysis and presentation leave much to be desired and make a detailed evaluation of his results impractical. As noted by Thatcher (1977b) the possible causes of the observed VER asymmetries are unclear and may reflect cognitive processes associated with stimulus perception, memory rehearsal and memory retrieval. These issues would have been partially resolved by the use of experimental conditions in which the meaningful stimuli required non-verbal, spatial processing likely to engage predominantly the right hemisphere.

Studies involving the  $P_{300}$  component: Several investigators have searched for task-dependent asymmetries in the  $P_{300}$  component of ERs. As noted in section 2c, this component is highly sensitive to a number of psychological

variables and for this reason might be expected to be sensitive to asymmetries in cognitive activity. As noted above, Thatcher (1977a,b) has reported asymmetries in this component which might be related to verbal processing. Shelburne (1972) conducted an experiment in which subjects viewed series of three consecutively appearing letters the third of which determined whether the letters formed a word or nonsense trigram. VERs were recorded from occipital and parietal regions. In accord with its greater information content the third letter elicited a VER with an enhanced  $P_{300}$ . No VER asymmetries were observed in any component, however, and a replication of this experiment using children as subjects (Shelburne, 1973) yielded the same results.

Marsh and Thompson (1973) used as verbal and non-verbal stimuli words requiring recognition and lines the orientation of which had to be judged. VERs were recorded from temporal and 'angular gyrus' placements. Neither the CNVs prior to nor the  $P_{300}$ s elicited by the stimuli showed any signs of asymmetry. Friedman et al. (1975b) recorded VERs from temporal and parietal regions to sequentially presented words comprising a sentence. A  $P_{300}$  component was observed in the VERs to each word and was of a longer latency to the word which disambiguated the sentence wherever in the sentence the word occurred. The largest  $P_{300}$  was always in the VERs elicited by the last word in the sentence. Whilst these results indicated that  $P_{300}$  was in some way influenced by linguistic variables no hemisphere asymmetries were observed in this component. It is arguable that this result supports the view that  $P_{300}$  does not index the processing of stimulus information but the reaction of the organism to the results of that processing. Further

discussion of this point will be found in chapters 9 and 10. The results of the study of Friedman et al. (1975b) are consistent with those of Friedman et al. (1975a) who found no evidence of AER asymmetries to linguistic and non-linguistic stimuli. In a review of attempts to find task-dependent asymmetries in  $P_{300}$  these authors (Friedman et al., 1977) concluded that no such study has yet succeeded.

Preston, Guthrie, Kirsh, Gertman and Childs (1977) reported a study in which normal and dyslexic adults were employed. Recordings were made from occipital and parietal areas to stimuli consisting of passively viewed light flashes and word series in which target words had to be detected. In both groups of subjects the late positive component ( $P_{300}$ ) of their VERS was significantly larger when elicited by the word, as compared with the flash, stimuli. Moreover, in the VERS to words, both the previous positive peak ( $P_{200}$ ) and  $P_{300}$  were larger in the left hemisphere and the difference in  $P_{200}$  and  $P_{300}$  amplitude between flashes and words was greater in the left parietal electrode of the left hemisphere of the normals than in the dyslexics. These results were taken to reflect the superiority of the left hemisphere for the processing of the word stimuli, this superiority being less evident in dyslexics. The interpretation of the results would have been easier had the investigators employed a control condition more analogous to that of the verbal one. It is possible that observed VER differences between the conditions reflected differences in task demands other than those associated with the verbal processing of the words; in the case of the observed  $P_{300}$  enhancement in the verbal condition it is arguable that this reflected no more than the increased task-relevance of these stimuli compared with the light flashes. With respect

to the asymmetry observed in the  $P_{300}$  component it should be noted that  $P_{300}$  amplitude was determined by averaging the amplitudes from a baseline of the waveform at 250, 350, 450 and 550 msec. It is possible that the apparent finding of an asymmetrical  $P_{300}$  component reflects no more than the asymmetry in the  $P_{200}$  component and was caused by some of the  $P_{300}$  riding on a greater amount of positivity in the left hemisphere because of the larger  $P_{200}$  in that hemisphere. For the above reasons it is arguable that the study of Preston et al. does not conclusively demonstrate the existence of  $P_{300}$  asymmetries associated with verbal asymmetries.

v) ERs and lateral asymmetries of processing-discussion: In the cases both of auditory and visual ERs contradictions currently exist in the literature with respect to the distribution of ERs to 'neutral' stimuli. It would seem clear that one possible source of these contradictions is the lack of realisation on the part of investigators that ERs to neutral stimuli may be affected by subjects' ongoing cognitive activities. In the case of VERS it is also clear that the lateralisation of stimulus input gives rise to asymmetrical distributions of the type which might be expected on anatomical grounds but that these asymmetries are modified by the task associated with the eliciting stimuli. Indeed, a consideration of the studies (reviewed in this chapter) employing auditory stimuli, and those utilising centrally-presented and lateralised visual stimuli leads to the conclusion that in spite of methodological difficulties and failings evidence does exist to support the contention that hemisphere asymmetries in ERs can be associated with cerebral asymmetries in information processing. In



studies in which the loci of ER asymmetries have been reported it has nearly always been the case that the components most sensitive to these effects have been those in the middle latency range (approximately 80-200 msec), i.e., 'exogenous' components (see section 2c). Attempts to find such asymmetries in late, 'endogenous', ER components have met with relatively little success, suggesting that these components may be less sensitive than earlier ones to lateralised aspects of information-processing. The following chapters present data pertinent to these and other issues.

## CHAPTER 3

### Experiments 1 and 2

#### 3a Experiment 1

##### 3a(i). Introduction

The purpose of the first experiment was to investigate electrophysiological processes associated with the processing of stimuli in a VF experiment of the type discussed in section 1c. Verbal stimuli, in the form of letters, were associated with a task requiring a discrimination on the basis of the phonetic qualities of the letters. The task was similar to those shown by Cohen (1972), Geffen et al. (1972) and Nierderbuhl (1976) to result in a RVF/left hemisphere processing advantage in lateral VF experiments. In the present study the letters were exposed unilaterally in the lateral VFs and VERs recorded from each hemisphere to stimuli exposed in each VF. Thus, the experiment was similar to that of Andreassi et al. (1975) who stimulated individual hemi-fields with a small cross as an eliciting stimulus. In the present study, however, subjects were required to process the eliciting stimuli in a manner considered to be mediated by asymmetrical cognitive activity. The study is also similar to the verbal condition of Buchsbaum and Fedio (1970), the principal difference to this study being that subjects were

required to adopt specific task sets rather than being allowed passively to observe the stimuli.

3a(ii). Method:

Ten adults, five of each sex, served as subjects all of whom reported themselves to be strongly right-handed. The task requirement was to fixate on a small dot at the centre of a VR14 computer oscilloscope (green phosphor) and to attend to two series of briefly-appearing letters which were exposed to one or other VF.<sup>1</sup> Subjects were instructed to respond as fast and as accurately as possible by slightly raising (4mm) their right index fingers (which were situated under a microswitch lever) when they saw a letter the name of which contained the sound 'ee'. Raising the finger activated the micro-switch which was connected to the Lab 8/e computer controlling the display and allowed subjects' RTs to the target letters to be computed. The subjects performed the task seated in a quiet, dark room with their heads resting on a chin-rest.

The stimuli consisted of upper-case letters approximately 6.5 mm across viewed from a distance of 500 mm. Examples of the letters are shown in Figure 4(i). On exposure, their inner edges subtended a visual angle of  $3^{\circ}36'$  and their outer edges one of  $4^{\circ}18'$ . The intensity of the letters was approximately 13 cd/m<sup>2</sup> and their exposure duration 60 msec.

Two blocks of 50 letters formed the series utilised, the letters being pseudo-randomly drawn from the alphabet. In each

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<sup>1</sup> Programs and additional technical details related to this and all subsequent experiments will be found in Appendix 1.

block the number of letters containing the sound 'ee' was 18. For both blocks exposure of each letter to either the left or right VF was randomly determined, as was the inter-stimulus interval, which was either 2 or 3 sec. The two blocks were presented to subjects with a short break in between them. Thus, for both blocks of stimuli each subject saw the same sequence of letters with a unique pattern of lateralisation.

Subjects' EEGs were recorded using silver/silver chloride electrodes filled with 'Neptic' jelly and affixed with collodion cement. They were positioned at homotopic left and right sites 25% of the distance from the occipital ( $O_1, O_2$ ) to the posterior temporal ( $T_5, T_6$ ) placements of the 10-20 system (Jasper, 1958).  $C_z$  served as a common reference and the right mastoid was grounded. All inter-electrode impedances were below 5 K $\Omega$ . The position of the exploring electrodes was chosen to allow the detection of activity in the visual cortex and the adjacent association cortex, particularly that in the region around the angular gyrus (this region is implicated in the mediation of the processes involved in visual to verbal translation (see section 1b and Geschwind, 1961)). The EEG signals were led into two matched channels of a Devices high-gain A.C. amplifier with low-pass settings 3 dB down at 25 Hz and time-constant 0.3 sec. The gain of each channel was 20 K and their outputs, along with event-marking pulses, were recorded on separate channels of a Racal F.M. tape-recorder prior to off-line analysis. For every subject the amplifier channels used to record left and right EEG channels were alternated between the blocks of stimuli to counter-balance any residual differences between the channels.

Analysis of the EEG records was carried out using a Lab 8/e

computer with a system software averaging program and was performed on the EEG samples pooled from the two blocks. For every subject the 500 msec of EEG following each stimulus onset was digitised at the rate of 400 Hz and a VER from each exploring electrode was calculated for each channel x visual field of stimulus presentation combination. As the foci of interest in this study were the middle latency components of the VER separate averages were not made for the target and non-target stimuli, which would have allowed analysis of any enhanced late positive component to the rarer target stimuli. The electrode montage employed was such that this component would have been very small, even to the target letters, as it would have been almost equipotential at all three recording electrodes (Simson et al., 1977a,b).

### 3a (iii). Results:

The mean number of stimuli presented to each VF was 50, with a range across subjects of 47-53. Four components of the VER were readily identifiable by visual inspection in all but one subject's records and all subsequent analyses were performed on the records of the other nine subjects. Figure 3(i) illustrates representative waveforms from two subjects.

The identifiable components consisted of a positive peak at a latency of around 140 msec ( $P_1$ ), a negative peak around 190 msec ( $N_1$ ), a further positive peak around 250 msec ( $P_2$ ) and a small negative component around 300 msec ( $N_2$ ). The latencies of these were measured from stimulus onset and amplitudes were measured peak-to-peak ( $P_1-N_1$ ,  $N_1-P_2$ ,  $P_2-N_2$ ). Mean latencies and amplitudes of these components are shown in Tables 3(i) and 3(ii). All analyses were performed on

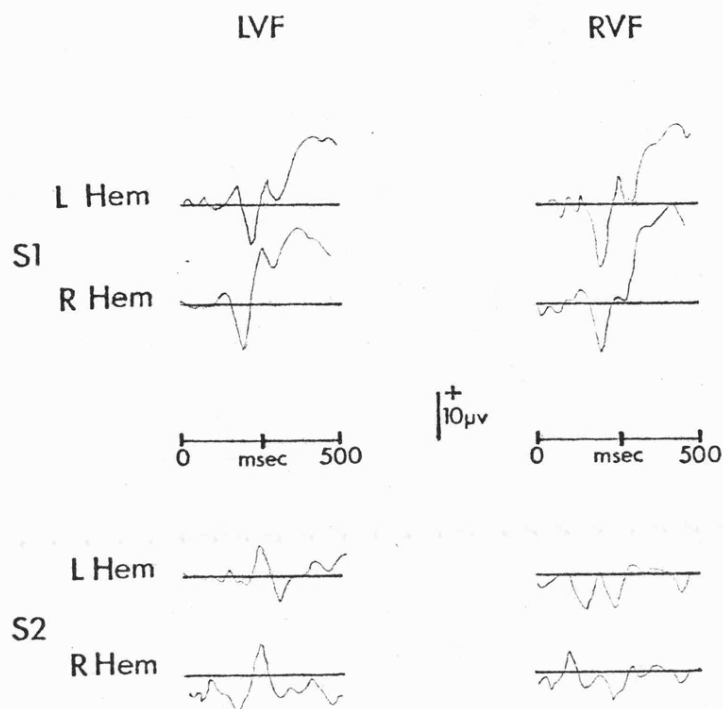


Figure 3(i). VERs from two subjects recorded from the left and right hemispheres to stimuli presented in the left and right visual fields.

(Experiment 1)

Table 3(i). Mean latencies and standard deviations of VER components from left and right hemispheres with left and right visual field stimulus presentation. (Experiment 1)

		L. vis. field		R. vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
P <sub>1</sub>	Mean	147.88	126.66	131.17	149.88
	S.D.	19.80	19.89	19.17	19.51
N <sub>1</sub>	Mean	193.22	183.22	193.66	203.22
	S.D.	23.20	24.45	19.78	28.77
P <sub>2</sub>	Mean	245.88	245.55	252.33	253.88
	S.D.	25.63	27.73	19.39	20.81
N <sub>2</sub>	Mean	311.00	304.55	247.33	293.22
	S.D.	11.40	13.13	31.23	18.15

Table 3(ii). Mean peak to peak amplitudes ( $\mu\text{V}$ ) and standard deviations of VER components from left and right hemispheres with left and right visual field stimulus presentation. (Experiment 1)

		L. vis. field		R. vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
$P_1-N_1$	Mean	4.05	5.05	5.77	5.72
	S.D.	2.02	2.54	3.55	4.04
$N_1-P_2$	Mean	4.76	7.00	6.24	5.72
	S.D.	2.64	5.01	4.26	5.04
$P_2-N_2$	Mean	5.23	5.59	5.09	5.36
	S.D.	2.72	3.08	2.61	3.23



individual components using two-way ANOVAs with repeated measures. The two factors were VF of stimulus presentation and hemisphere.

Analysis of the latencies of each component revealed no significant differences in the latencies either of  $P_2$  or  $N_2$ . In the cases of  $P_1$  and  $N_1$  significant hemisphere x VF of stimulus presentation interactions were revealed ( $P_1$ :  $F_{1,8} = 58.07$ ,  $p < 0.001$ ;  $N_1$ :  $F_{1,8} = 20.32$ ,  $p < 0.005$ ). Inspection of the means reveals that these effects are due to the fact that in both conditions of stimulus presentation the hemisphere contralateral to the visual field stimulated produced these components at a latency shorter than those produced by the ipsilateral hemisphere.

Of the ANOVAs carried out on the amplitudes only the analysis of those relating to the  $N_1$ - $P_2$  component revealed significant effects. In the case of this component a significant hemisphere x visual field of stimulus presentation interaction was obtained ( $F_{1,8} = 10.87$ ,  $p < 0.025$ ). Inspection of the relevant means indicates that this was because the hemisphere contralateral to the field of stimulus presentation gave rise to this component with a greater amplitude than that from the ipsilateral hemisphere, this effect occurring in both conditions.

There was no significant difference in the mean RT to the target letters in each VF. Mean RT to stimuli in the LVF was 582.8 msec (SD = 72.5) and to those in the RVF 601.6 msec (SD = 103.1).

### 3a(iv). Discussion:

The hemisphere x visual field of stimulus presentation interactions observed with respect to the latencies of  $P_1$  and  $N_1$  and the amplitude of  $N_1$ - $P_2$  partially replicate the study of Andreassi et al. (1975), who reported a similar pattern of results in such a paradigm. The interpretation of the results in the light of the hypothesised asymmetrical processing of the eliciting stimuli requires a consideration of data obtained in the same experimental paradigm with a non-linguistic task likely to engage predominantly the right hemisphere. These data were provided by a second study and it is in the light of the results of this second experiment that the results reported above will be discussed.

### 3b Experiment 2

#### 3b(i). Introduction:

This experiment was carried out in order to allow a comparison of the results obtained in Experiment 1 with those obtained in an experiment which utilised a non-verbal, visuospatial task which might be expected primarily to engage the right hemisphere. The task employed required a discriminative response on the basis of the physical characteristics of letters and thus allowed the use of the same stimuli as were employed in Experiment 1. Nierderbuhl (1976) has demonstrated in a lateral VF paradigm that letter stimuli associated with such a task are processed more quickly when presented to the LVF and thus the right hemisphere.

#### 3b(ii). Method:

A further ten right-handed subjects, five of each sex, were employed as subjects. The method of this experiment

was identical in every respect to that of Experiment 1 with the exception that subjects were required to respond to letters containing a right-angle instead of those with an 'ee' sound. Twenty-four of the letters out of each block of 50 had this characteristic.

### 3b(iii). Results:

A mean of 50 stimuli (range 40-60) were presented to each VF in this experiment. Subjects' VERS were very similar in morphology to those from Experiment 1 and, as in the first experiment, the data from one subject were rejected on the grounds that the VERS did not show clearly recognisable components. Representative waveforms from subjects in this experiment are shown in Figure 3(ii). Mean latencies and amplitudes are shown in Tables 3(iii) and 3(iv). The components of the VERS obtained in this experiment occurred at somewhat shorter latencies than those in the previous experiment,  $P_1$  occurring at around 110 msec,  $N_1$  around 170 msec,  $P_2$  around 230 msec and  $N_2$  around 265 msec.

ANOVAs revealed no significant differences in the latencies of either  $P_2$  or  $N_2$ . Analysis of  $P_1$  and  $N_1$  revealed, in each case, significant hemisphere x visual field of stimulus presentation interactions ( $P_1$ :  $F_{1,8} = 45.56$ ,  $p < 0.001$ ;  $N_1$ :  $F_{1,8} = 14.21$ ,  $p < 0.01$ ). As in Experiment 1 these interactions were due to the hemisphere contralateral to the visual field stimulated giving rise to these components at a latency shorter than those from the ipsilateral hemisphere.

No significant effects were found with respect to the amplitudes of the  $P_1$ - $N_1$  component. In the case of  $N_1$ - $P_2$  a significant main effect of field of stimulus presentation

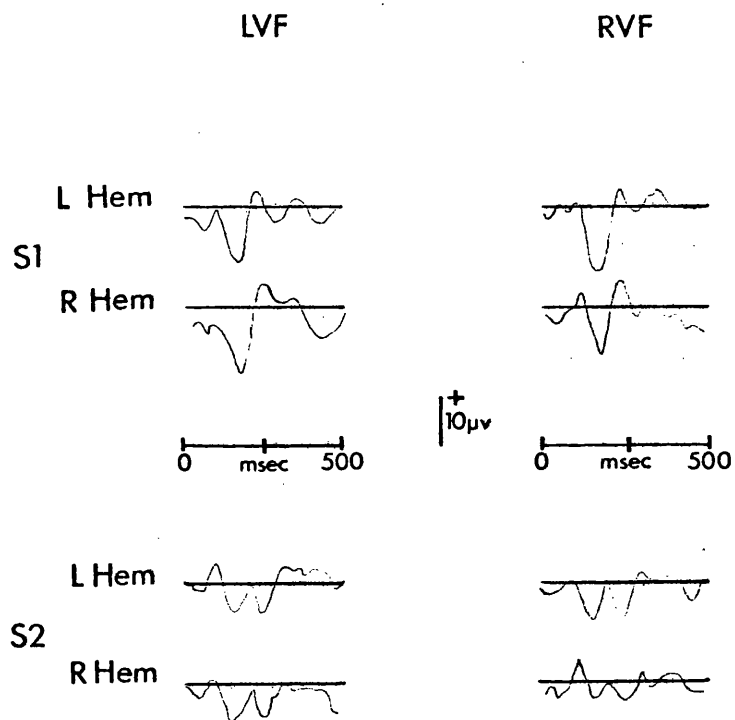


Figure 3(ii). VERs from two subjects recorded from the left and right hemispheres to stimuli presented in the left and right visual fields.  
(Experiment 2)

Table 3(iii). Mean latencies (msec) and standard deviations of VER components from left and right hemispheres with left and right visual field stimulus presentation. (Experiment 2)

		L. vis. field		R. vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
P <sub>1</sub>	Mean	109.22	100.77	103.88	117.22
	S.D.	8.49	7.01	11.47	14.63
N <sub>1</sub>	Mean	176.11	158.22	172.33	181.33
	S.D.	14.19	36.77	19.53	15.28
P <sub>2</sub>	Mean	233.44	230.77	228.44	231.22
	S.D.	17.85	19.14	19.59	18.02
N <sub>2</sub>	Mean	267.00	259.44	267.66	268.88
	S.D.	14.99	12.66	17.07	20.89

Table 3(iv). Mean peak to peak amplitudes ( $\mu V$ ) and standard deviations of VER components from left and right hemispheres with left and right visual field stimulus presentation. (Experiment 2)

		L. vis. field		R. vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
$P_1-N_1$	Mean	8.75	8.93	7.50	6.24
	S.D.	2.83	7.08	3.51	2.68
$N_1-P_2$	Mean	7.49	9.63	7.50	5.30
	S.D.	4.39	4.59	4.80	3.93
$P_2-N_2$	Mean	3.22	2.48	3.26	2.48
	S.D.	1.87	2.33	2.23	2.12

( $F_{1,8} = 31.82$ ,  $p < 0.001$ ) was found in conjunction with a significant hemisphere x visual field of stimulus presentation interaction ( $F_{1,8} = 15.58$ ,  $p < 0.01$ ). These effects are due to the different behaviours of the component in the two hemispheres. Whilst the amplitude of  $N_1$ - $P_2$  from the left hemisphere did not vary with field of stimulus presentation (LVF = 7.49  $\mu$ V, RVF = 7.50  $\mu$ V) that from the right hemisphere did do so (LVF = 9.63  $\mu$ V, RVF = 5.30  $\mu$ V).

Analysis of the  $P_2$ - $N_2$  component revealed a significant main effect of hemisphere ( $F_{1,8} = 10.31$ ,  $p < 0.025$ ). This was due to the component being of a larger amplitude in the left hemisphere irrespective of the field of stimulus presentation.

Mean RT to stimuli in the LVF was 569.1 msec (SD = 65.3) and to those in the RVF 571.8 msec (SD = 78.3). These means did not differ significantly.

### 3b(iv). Discussion:

As with Experiment 1 the results of this experiment replicate those of Andreassi et al. (1975) in as much as significant hemisphere x VF of stimulus presentation interactions were found in the latencies of  $P_1$  and  $N_1$ . However, a different pattern of results to those obtained in Experiment 1 was observed with respect to the amplitudes of  $N_1$ - $P_2$  and  $P_2$ - $N_2$ . These results will be discussed and compared with those obtained in Experiment 1 in the next section.

### 3c. Comparison and discussion of Experiments 1 and 2:

In neither experiment were RTs observed to vary with VF of stimulus presentation, as might have been expected on the

basis of the previous studies employing such stimuli and tasks. A possible reason for these results lies in the small number of stimuli requiring a response, an average of 18 in each VF in the first experiment and 24 in the second one. It is possible that this was too few a number reliably to show any differences due to the large amount of between- and within-subject variance inherent in RT studies of this nature. For instance, in contrast to the present study Rizzolatti et al. (1971) exposed 260 letter stimuli in each visual field of which half required a response.

In both experiments the analysis of the latencies of  $P_1$  and  $N_1$  replicates the findings of Andreassi et al. (1975). The latencies of these components from the hemisphere contralateral to the field of stimulus presentation were found to be shorter than those from the ipsilateral hemisphere. This effect would seem, as noted previously (see section 2d(iv)), to be accounted for by the anatomical arrangements of the human visual system. A fuller discussion of the implications of these results and more data pertaining to the issues involved will be found in Chapter 7.

The lack of VF-related asymmetries in the amplitudes of the earliest measured component,  $P_1-N_1$ , is puzzling in view of the currently held belief that the earlier ER components are most likely to be influenced by non-psychological parameters of the stimulus (see section 2c). This result suggests that factors other than those associated with the route of stimulus input may be more important in the determination of this VER component in the present studies, the nature of which remains to be elucidated. The pattern of asymmetries shown by the amplitudes of  $N_1-P_2$  suggests that the effects on the VER of



stimulus lateralisation, when present, can be modified by the type of stimulus processing subjects are engaged in. This concurs with the results of other similar studies, particularly that of Neville (1978; see section 2d(iv)). Figure 3(iii) illustrates the way in which  $N_1$ - $P_2$  from each hemisphere was observed to vary with VF of stimulus presentation in the two experiments. It can be seen that whilst the amount of variation in the amplitude of this component from the two hemispheres was similar in Experiment 1 (variation in the left hemisphere = 1.48  $\mu$ V, in the right hemisphere = 1.28  $\mu$ V) this was not the case in Experiment 2 in which practically no variation at all occurred in this component from the left hemisphere. In view of the non-verbal, visuospatial, nature of the task in the second experiment it is possible that this reflects differences in the left hemisphere's processing of the letter stimuli contingent on whether the stimuli were associated with a verbal or non-verbal task set. It is of interest to note that Buchsbaum and Fedio (1969, 1970) reported that VERS from the left hemisphere to verbal and non-verbal stimuli were more dissimilar than those from the right hemisphere.

The hemisphere asymmetry observed in the component  $P_2$ - $N_2$  in Experiment 2 is also suggestive of asymmetrical cerebral processing. The left hemisphere was found to give rise to this component with the larger amplitude, suggesting that asymmetrically distributed verbal processing was occurring. The presence of this asymmetry only in the experiment in which a non-verbal task set was emphasized is puzzling and suggests that even in these circumstances verbal processing of the stimuli might occur. These results are discussed more

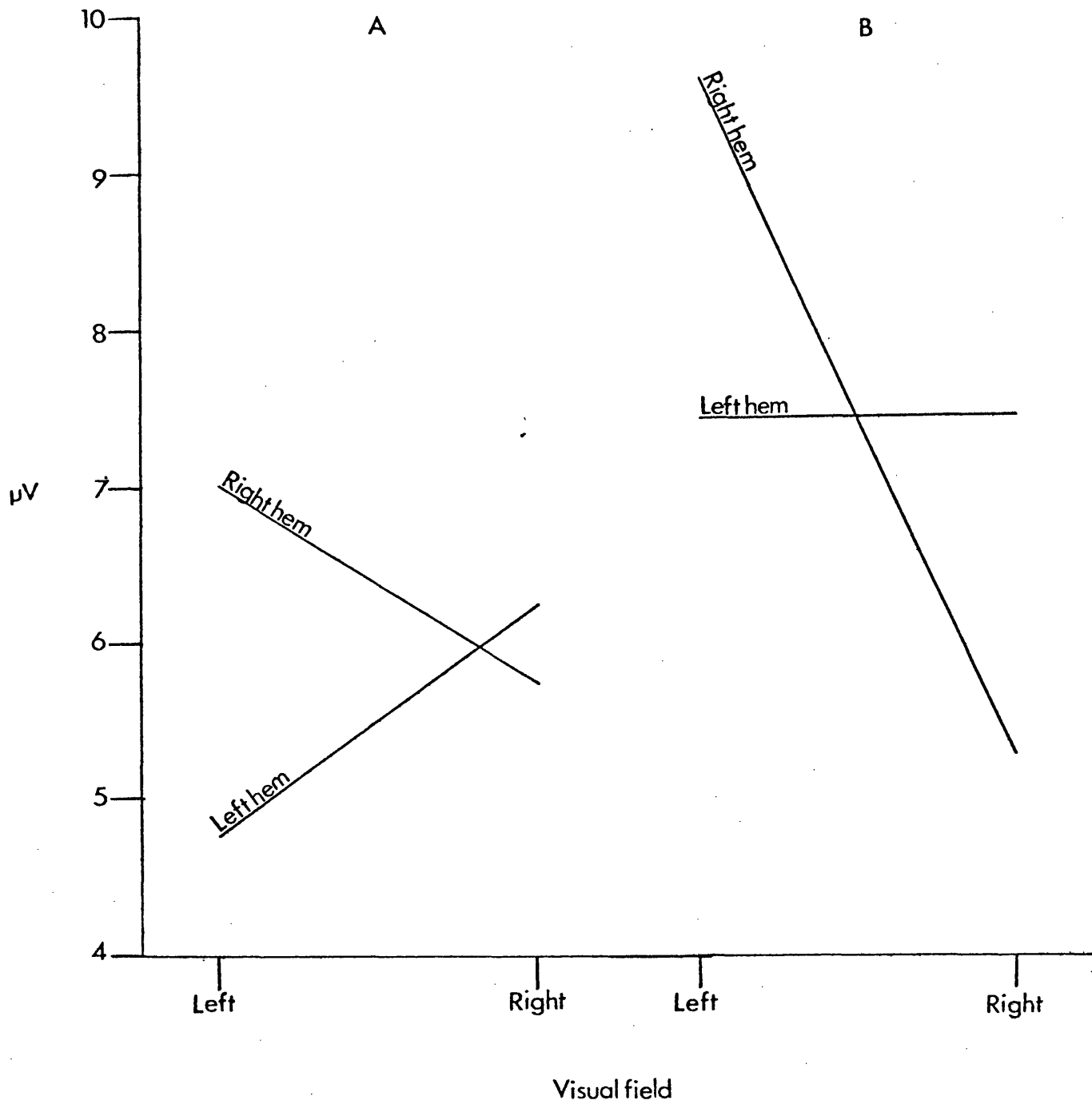


Figure 3(iii). Mean amplitude of the N<sub>1</sub>-P<sub>2</sub> component in VERs recorded from each hemisphere to stimuli presented in each visual field in Experiment 1 (A) and Experiment 2 (B).

fully in Chapter 5 in the light of other data bearing on this issue.

That evidence of asymmetrical processing of stimuli was found in the absence of any behavioural indices of such an asymmetry demonstrates that, as suggested in section 1c, one of the problems of relying on an 'output' measure of asymmetrical processing may be that in some circumstances it is too gross a measure of information-processing to detect such effects. Congruent with the results obtained in an RT paradigm by Cohen (1972) and Geffen et al. (1972) the present findings provide convincing evidence of the need for the careful control of subjects' task sets in such experiments. Differences between the patterns of results in the two experiments described above were due only to a change in the manner in which subjects processed the same stimuli. It is clear that if subjects are allowed passively to observe the eliciting stimuli (and hence invent their own task) or a task is used which can be accomplished by more than one manner of information-processing, it is possible that this will be reflected in the heterogeneity of subjects' ERs.

To summarise: the results of Experiments 1 and 2 add weight to previous findings that unilateral stimulation of the VFs gives rise to asymmetrical VERs, probably as a result of the anatomical arrangement of the visual system. Different patterns of results with respect to the interhemispheric differences in the amplitudes of the  $N_1-P_2$  and  $P_2-N_2$  components of the VERs obtained in each experiment suggest that these components indexed the differential processing of the eliciting stimuli.

## CHAPTER 4

### Experiment 3

#### 4a Introduction:

This experiment follows directly from Experiments 1 and 2. Other than incorporating some methodological improvements the main difference between it and the previous two studies is that the stimuli were of a non-verbal nature. The purpose of the use of such stimuli was to facilitate clarification of the extent to which the hemisphere asymmetries observed in Experiments 1 and 2, particularly the asymmetry observed in the  $N_1$ - $P_2$  component in Experiment 2, were dependent on the use of stimuli of an explicitly verbal nature. The stimuli in the present study were associated with a task considered likely to be processed more efficiently by the right hemisphere. They consisted of superimposed letters (see Figure 4(i)) and were very similar to those used by Nierderbuhl (1976). This author reported that the use of such stimuli with a task which required subjects to discriminate between the stimuli on the basis of a set of physical features gave rise to a LVF advantage for RT.

The methodological differences between the present and previous studies consisted of (i) not including in the averaging process EEG samples following stimuli to which a

A B C D E F G H I  
 J K L M N O P Q R  
 S T U V W X Y Z

W X Y Z  
 A B C D E F G H  
 I J K L M N O P

Figure 4(i). Letter and pattern stimuli of the types  
 utilised in Experiments 1-6 and 8 and 9.

response was required, thus minimising the possibility of movement-related artefacts, and (ii) complementing the RT performance measure with accuracy indices.

#### 4b    Method:

Ten right-handed adults, five of each sex, were employed as subjects. The experimental situation was almost identical to that described for Experiments 1 and 2 with the exception of the stimuli and task requirement. They were required to fixate on a dot at the centre of a VR14 oscilloscope and to attend to two series of stimuli in each of which the stimuli were exposed unilaterally in one or other VF. Subjects were instructed to respond as fast and as accurately as possible by slightly raising their index fingers on observing a stimulus which was symmetrical about the vertical axis. This response closed a microswitch connected to the Lab/8e computer controlling the experiment and allowed the calculation of subjects' RTs to the target stimuli exposed in each VF as well as the number of hits and false positive responses. Prior to the experimental runs subjects were shown each of the stimuli on the oscilloscope screen. This was done to minimise the extent to which subjects became more familiar with the stimuli during the course of the experiment, this being a possible source of intra-subject variance.

The stimuli consisted of pairs of upper-case letters exactly superimposed on one another, and giving rise to non-verbal geometrical patterns with identical parameters of intensity and size to the letters utilised in Experiments 1 and 2 (see Figure 4(i)). As in the previous experiments they

were viewed from a distance of 500 mm, but with an exposure duration of 100 rather than 60 msec, this longer duration being required to allow subjects to perform at a reasonably high level of accuracy (approximately 80%).

Two blocks of 100 patterns were formed, these being pseudo-randomly chosen from a pool of 20 (5 of which were symmetrical) with the constraint that 20 of the patterns in each block were symmetrical about their vertical axis. In each block exposure of the patterns to the left or right VF was in a pre-determined random order with the constraint that 10 symmetrical stimuli were exposed in each VF. The inter-stimulus interval in each block varied randomly and was either 2 or 3 sec.

All details of EEG recording were the same as in Experiments 1 and 2. EEG data from each block were pooled prior to averaging and VERS were formed from the 500 msec of EEG following each non-target (asymmetrical) stimulus with a sampling rate of 400 Hz. Thus, VERS elicited by stimulation of each VF were obtained from each hemisphere.

#### 4c Results:

The VERS obtained in this study were very similar in form to those obtained in Experiments 1 and 2,  $P_1$  occurring at a latency of around 105 msec,  $N_1$  around 175 msec,  $P_2$  around 250 msec and  $N_2$  around 280 msec. Representative waveforms are shown in Figure 4(ii). Latency and amplitude measurements were made in the same way as in Experiments 1 and 2 and mean latencies and amplitudes are shown in Tables 4(i) and 4(ii).

Analysis of the latencies of  $P_2$  and  $N_2$  revealed no significant effects. That of the latencies of  $P_1$  revealed

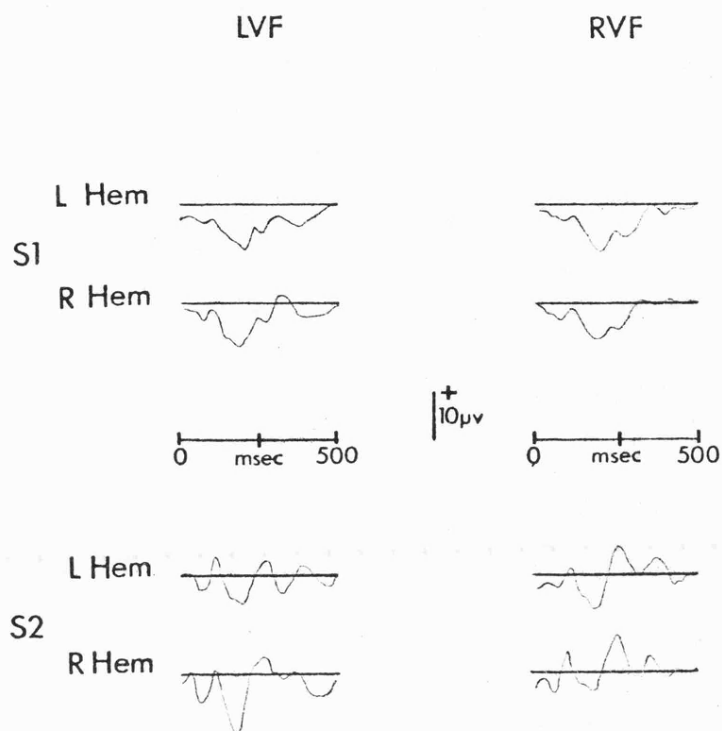


Figure 4(ii). VERs from two subjects recorded from the left and right hemispheres to stimuli presented in the left and right visual fields. (Experiment 3)



Table 4(i). Mean latencies (msec) and standard deviations of VER components from the left and right hemispheres with left and right visual field stimulus presentation. (Experiment 3)

		L. vis. field		R. vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
P <sub>1</sub>	Mean	108.91	97.43	111.18	111.14
	S.D.	10.74	11.01	11.26	10.20
N <sub>1</sub>	Mean	177.66	169.35	174.52	181.67
	S.D.	20.23	16.21	12.19	15.68
P <sub>2</sub>	Mean	253.94	249.30	249.52	251.86
	S.D.	29.84	29.41	45.13	39.23
N <sub>2</sub>	Mean	280.21	277.23	285.47	282.42
	S.D.	29.55	34.81	39.72	38.69

Table 4(ii). Mean peak to peak amplitudes ( $\mu$ V) and standard deviations of VER components from the left and right hemispheres with left and right visual field stimulus presentation. (Experiment 3)

		L. vis. field		R. vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
$P_1-N_1$	Mean	7.37	8.11	8.02	7.00
	S.D.	3.96	4.50	4.50	4.44
$N_1-P_2$	Mean	7.96	9.61	8.62	7.40
	S.D.	5.66	6.46	7.69	7.03
$P_2-N_2$	Mean	2.03	1.72	2.21	2.09
	S.D.	1.99	1.62	1.83	2.14

significant main effects for visual field of stimulus presentation ( $F_{1,9} = 14.42$ ,  $p < 0.01$ ) and hemispheres ( $F_{1,9} = 22.96$ ,  $p < 0.001$ ). These effects are presented graphically in Figure 4(iii) and are caused by the right hemisphere producing this component with the shorter latency when the stimuli were presented in the LVF and with the same latency (as the left hemisphere) when they were presented in the RVF. Analysis of the latencies of  $N_1$  revealed a significant visual field of stimulus presentation x hemisphere interaction ( $F_{1,9} = 7.66$ ,  $p < 0.025$ ). This was caused by each hemisphere producing this component with the shorter latency when stimulated directly (stimulation in the contralateral VF).

Analysis of the amplitudes of  $P_1-N_1$  and  $P_2-N_2$  revealed no significant effects. That of  $N_1-P_2$  revealed a significant visual field of stimulus presentation x hemisphere interaction ( $F_{1,9} = 12.54$ ,  $p < 0.01$ ). This was caused by the component being larger from the hemisphere contralateral to the VF of stimulation in both conditions. The extent of this variation with visual field differed between the hemispheres to a significant extent (variation in the left hemisphere =  $0.66 \mu V$ , in the right hemisphere  $2.21 \mu V$ ;  $t_9 = 3.10$ ,  $p < 0.02$ ).

Mean RTs to the target stimuli and mean number of hits and false positives are shown in Table 4(iii). The only performance index differing significantly with respect to visual field of stimulus presentation was that of false positives, there being significantly more to stimuli in the LVF ( $t_9 = 4.36$ ,  $p < 0.002$ ).

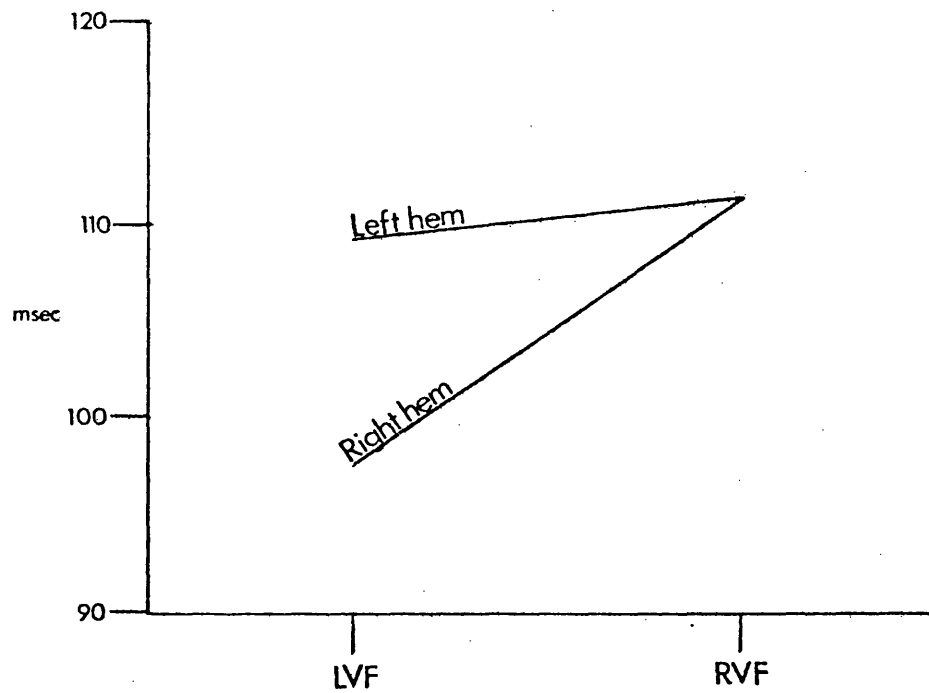


Figure 4(iii). Mean latency of the P<sub>1</sub> component of VERs recorded from each hemisphere to stimuli presented in each visual field in Experiment 3.

Table 4(iii). Mean R.T. (msec) to targets, hits and false positive responses to stimuli presented in left and right visual fields. (Experiment 3)

		L. vis. field	R. vis. field
R.T.	Mean	645.52	663.11
	S.D.	80.15	102.80
Hits	Mean	16.10	16.00
	S.D.	2.92	3.74
False +ves	Mean	8.60	4.90
	S.D.	4.48	3.80

#### 4d Discussion

As in Experiments 1 and 2 no asymmetries were observed in RT to the target stimuli, possibly for the same reasons as noted with respect to analogous results in Experiments 1 and 2. Neither did the number of hits vary with visual field of stimulation. However, significantly more false positive responses were elicited by stimuli presented in the LVF. This result concurs with that of Bryden (1976) who, using another task hypothesized to be mediated primarily by the right hemisphere (dot localisation), found the same effect. It would appear that under some circumstances the right hemisphere employs a weaker criterion than its fellow with respect to the initiation of responses, although it is not obvious why this should be. Whilst it is tempting to relate this effect to those associated with the simultaneously recorded VERs, particularly the finding (discussed below) that the right hemisphere gave rise to VERs with the shorter latency of the  $P_1$  component, it is not at all clear what the nature of such a relationship might be.

The pattern of latency variation observed with the component  $P_1$  differs from those observed in the previous experiments. In the present study the directly stimulated right hemisphere gave rise to this component with a shorter latency than did the left hemisphere when it was directly stimulated. Moreover, there was no difference in the latencies of  $P_1$  from the two hemispheres when the left one was stimulated directly. These results suggest that the task and stimuli used in this study may have caused an asymmetrical engagement of the hemispheres resulting in the

right hemisphere reacting more quickly than the left when directly stimulated. Furthermore, the lack of a difference between the latencies of  $P_1$  from the directly stimulated left hemisphere and indirectly stimulated right hemisphere suggests that the inter-hemisphere transfer of the stimulus information from the left to the right hemisphere was extremely efficient. The relatively large inter-hemispheric difference in the latency of the  $P_1$  recorded when the right hemisphere was directly stimulated suggests that the transfer of stimulus information from the right to the left hemisphere occurred at a slower rate or was in some way delayed. These findings indicate that at least the early stages of stimulus processing may have been mediated primarily by the right hemisphere. They are similar to those of Neville (1978), who reported that in normal children a right hemisphere latency advantage obtained in the VEPs elicited by visuospatial stimuli regardless of the VF of stimulus presentation. She concluded that even though there was an absence of a behavioural index of asymmetrical processing in her study the right hemisphere was pre-eminent in the processing of the eliciting stimuli.

The visual field of stimulus presentation x hemisphere interaction found with respect to the latencies of  $N_1$  is the result of a pattern of asymmetries in this component very similar to those found in Experiments 1 and 2. It suggests that in the later stages of stimulus processing the two hemispheres may have shared stimulus information in a more equitable manner, indicating perhaps that even when a task engages the hemispheres asymmetrically stimulus information may still be processed bilaterally (although the results of such processing in one or other hemisphere may be largely

task irrelevant).

The amplitudes of  $N_1$ - $P_2$  were found to vary in a manner very similar to that observed in Experiment 2, in that this component showed the greater amount of variation with visual field of stimulus presentation when recorded from the right hemisphere. As in Experiment 2 this effect may be related to differences in the way in which the hemispheres processed the stimuli, possibly reflecting a relative lack of task-involvement on the part of the left hemisphere.

As in Experiment 1 no asymmetries were observed in  $P_2$ - $N_2$ . This suggests that the asymmetry observed in this component in Experiment 2 was related to the combination of a non-verbal task and verbal stimuli. This effect is further investigated in the experiments reported in the next chapter.

The experiment reported in this chapter provides further evidence that asymmetries in VEPs which are the result of purely anatomical factors may be modified by appropriate conditions of task and stimulus. The use of a visuospatial task and non-verbal stimuli would appear to have resulted in the engagement primarily of the right hemisphere, at least in the early stages of stimulus processing, and to have eliminated the  $P_2$ - $N_2$  asymmetry observed in Experiment 2. This latter result would seem to be due to the fact that, although similar tasks were utilised in this and the previous study, the non-verbal nature of the stimuli in the present experiment meant that no verbal processing was initiated in the left hemisphere. This issue is taken up at greater length in the next chapter.



## CHAPTER 5

## Experiments 4 and 5

5a Experiment 4

## 5a(i). Introduction:

The aim of this experiment was to investigate task and stimulus effects on the VER using eliciting stimuli presented in central vision. The results of Experiments 1-3 strongly suggest that the VER technique employed in those studies has the ability to index asymmetries of cerebral processing. The use of the technique with stimuli presented on the visual midline allows an assessment of possible asymmetries of processing associated with verbal and spatial stimuli when these are transmitted simultaneously to each hemisphere, a situation much more akin to individuals' normal viewing conditions (and not amenable to behavioural investigation) than that of the asymmetrically directed input employed in Experiments 1-3. A similar study has been reported by Buchsbaum and Fedio (1969). These investigators employed nonsense words and dot patterns as eliciting stimuli and reported the occurrence of differences in the VERs to the (passively observed) stimuli, these being greater in the left hemisphere. The present study utilised the stimuli and tasks previously employed in Experiments 1 and 3 as a means

of providing verbal and visuospatial conditions and thus, unlike the study of Buchsbaum and Fedio (1969), allowed the monitoring of subjects' performance.

5a(ii). Method:

Ten right-handed subjects were employed, five of each sex. As in the previous experiments the stimuli were presented on a VR14 display oscilloscope. Two sets of stimuli were employed, one set consisting of upper-case letters of the alphabet and the other of geometrical patterns as described previously (see section 4b and Figure 4(i)). As in the previous experiments the stimuli were approximately 6.5 mm across and were viewed from a distance of 500 mm. They subtended a visual angle of 32' across the visual midline on exposure, the duration of which was 60 msec. Stimulus intensity was approximately 13 cd/m<sup>2</sup>.

Two blocks of each stimulus type were formed. Each block consisted of 50 stimuli randomly chosen from the appropriate pool of stimuli with the constraint that 10 of those included should be targets. In the case of the letters a target was defined as any letter containing the sound 'ee'. For the patterns targets were those stimuli which were symmetrical about the vertical axis. Inter-stimulus intervals in each block varied randomly, being either 2 or 3 seconds. Subjects were seated in a darkened room with their heads resting on a chin rest. They were instructed to fixate constantly on a small central fixation dot which was present on the VR14 screen in the absence of a stimulus and, as in the previous experiments, were required to respond by slightly raising the right index finger, this activating a micro-switch. Prior to the experimental runs subjects were shown each of both

types of eliciting stimuli to allow some familiarisation to occur. The Lab/8e computer controlling the display computed the RT to target stimuli in each block, the number of hits and the number of false positives. The four stimulus blocks were presented in an ABBA design counterbalanced across subjects with short rest intervals between the blocks.

EEGs were recorded in a manner identical to that described for Experiments 1-3 with the exception that the amplifier channels were counterbalanced over subjects rather than blocks of stimuli. The samples of EEG associated with each stimulus type were pooled and VERs from each hemisphere formed from the 500 msec of EEG following each target stimulus; the number of eliciting stimuli was thus 80 for each VER.

#### 5a(iii). Results:

The data from one subject were rejected on the grounds that her VERs showed no clearly recognisable components. Four components were consistently recognisable in the VERs of the remaining nine subjects. These consisted of a positive peak around 75 msec ( $P_1$ ), a negative peak around 155 msec ( $N_1$ ), a further positive peak around 230 msec ( $P_2$ ) and finally a late negative peak around 265 msec ( $N_2$ ). Representative waveforms are illustrated in Figure 5(i) and mean latencies and peak to peak amplitudes are shown in Tables 5(i) and 5(ii).

Separate two-way ANOVAs with repeated measures (factors of hemisphere and stimulus type) were performed on the latencies of each component. The analysis of the latencies of  $P_1$  revealed a weakly significant effect of hemisphere

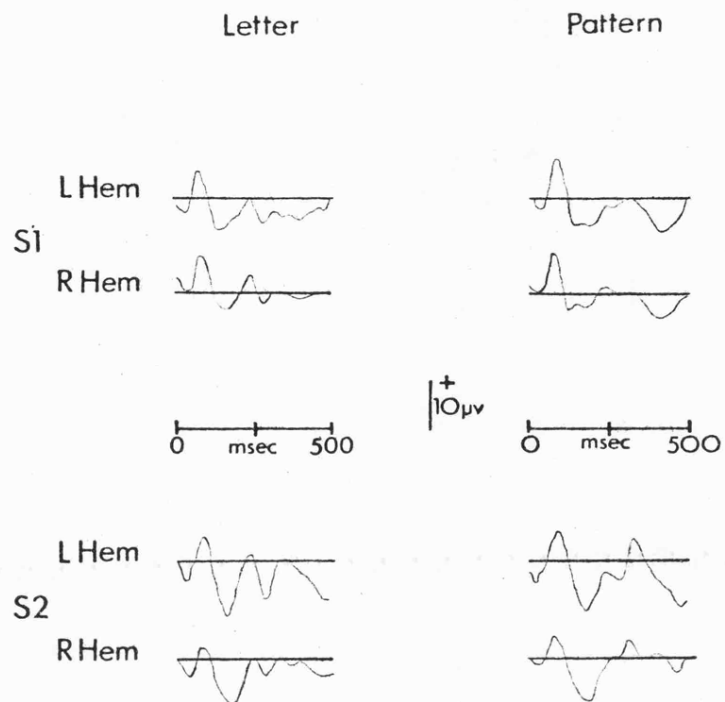


Figure 5(i). VERs from two subjects recorded from the left and right hemispheres to letter and pattern stimuli. (Experiment 4)

Table 5(i). Mean latencies (msec) and standard deviations of VER components from the left and right hemispheres elicited by pattern and letter stimuli. (Experiment 4)

		Pattern stimuli		Letter stimuli	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
P <sub>1</sub>	Mean	77.31	75.26	80.41	72.95
	S.D.	5.92	7.58	11.06	8.90
N <sub>1</sub>	Mean	154.00	151.82	155.14	154.32
	S.D.	15.47	19.28	11.49	20.20
P <sub>2</sub>	Mean	237.56	234.92	231.11	228.77
	S.D.	26.81	25.22	24.49	23.73
N <sub>2</sub>	Mean	264.46	261.14	266.87	263.16
	S.D.	16.42	16.48	19.83	23.84

Table 5(ii). Mean peak to peak amplitudes ( $\mu V$ ) and standard deviations of VER components from the left and right hemispheres elicited by pattern and letter stimuli. (Experiment 4)

		Pattern stimuli		Letter stimuli	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
$P_1-N_1$	Mean	14.23	14.28	13.10	13.49
	S.D.	4.58	5.70	4.02	5.98
$N_1-P_2$	Mean	7.67	8.41	8.35	7.78
	S.D.	4.59	5.41	4.20	4.38
$P_2-N_2$	Mean	1.52	1.35	4.01	3.35
	S.D.	1.58	1.12	2.58	1.78

( $F_{1,8} = 5.32$ ,  $p < 0.05$ ) in the absence of other effects.

This was caused by the latency of  $P_1$  from the right hemisphere being shorter than that from the left in both conditions. No other component's latencies differed significantly.

With respect to the amplitude data only the analysis of  $P_2-N_2$  gave rise to any significant effect. This was for tasks ( $F_{1,8} = 21.46$ ,  $p < 0.002$ ) and was due to this component being larger in the VERs elicited by the letter stimuli compared with that in the VERs to the patterns.

The means of the three recorded performance measures are shown for each task in Table 5(iii). No significant differences between any of the pairs of means were found. The large but non-significant difference between tasks in the means of the false positive responses is due to the inordinately large number of such responses (30) made by one subject when responding to the pattern stimuli.

#### 5a(iv). Discussion:

The behavioural data indicate that the tasks associated with the different stimulus types did not differ in difficulty. Thus the difference in the VERs elicited by the different stimuli are unlikely to be due to the factor of task difficulty.

The analysis of component latencies revealed that  $P_1$  from the right hemisphere showed a significantly shorter latency compared with that from the left and a similar result has been reported by Blatt and Offner (1966) and Richlin et al. (1975) using flash stimuli. This effect may be interpreted as revealing the pre-eminence on the part of the right hemisphere for the initial stages of visual processing whether the task associated with the stimulus information

Table 5(iii). Mean R.T. (msec) to target stimuli, hits and false positive responses to pattern and letter stimuli. (Experiment 4)

		Patterns	Letters
R.T.	Mean	615.23	621.84
	S.D.	59.38	66.51
Hits	Mean	16.64	17.32
	S.D.	3.23	1.23
False +ves	Mean	8.00	1.02
	S.D.	9.06	3.24



is verbal or non-verbal. This explanation is supported by the finding of Bryden and Allard (1976), who demonstrated in an RT paradigm that the normally reliable RVF advantage for letter recognition could be reversed by using unfamiliar type-faces. They interpreted this as demonstrating the pre-eminence of the right hemisphere for all visual processing, this pre-eminence overshadowing the left hemisphere advantage for verbal processing when the visual processing was of more than a certain level of complexity. The occurrence in the present study of a right hemisphere latency advantage in the earliest VER component suggests that such an asymmetry of processing may exist at a relatively low-level of stimulus processing, possibly in the modality-specific visual cortex. This would support the argument of Meyer (1976) who, on the basis of a VF asymmetry in the McCollough illusion (found to be stronger in the LVF/right hemisphere) suggested that asymmetry of processing existed at the level of the primary visual cortex. Davidoff (1975) has reported a hemisphere asymmetry in another 'low-level' visual operation, that of brightness perception, and found that the right hemisphere perceives stimuli as being darker than does the left. This too was interpreted as evidence for a right hemisphere superiority at a low level of stimulus processing.

An alternative explanation of the asymmetry observed in  $P_1$  latency is that it reflected a peripheral bias towards the RVF on the part of the subjects. Were this, for whatever reason, to be the case then stimulation thought to be on the visual midline would in fact be distributed mainly within the LVF and might be expected to result in VERs the components of

which showed the typical pattern of latency asymmetries that is associated with unilateral stimulation of a VF (see, for example, Andreassi et al., 1975). The lack of asymmetry in any component other than  $P_1$  militates against this explanation which cannot, however, be conclusively rejected without the use of extremely sophisticated eye-movement monitoring apparatus. The eccentricity of bias which might lead to such an effect is very small, in the region of less than  $1.3^\circ$  (Andreassi et al., 1975) and thus outside the resolution of standard EOG techniques. It should be noted, however, that there is no obvious reason why a consistent peripheral bias should occur across subjects in an experiment of this type.

Analysis of the amplitude data revealed no task dependent lateral asymmetries in the peak-to-peak components. Of interest, however, is the finding that the longest-latency component consistently observed,  $P_2-N_2$ , was of a considerably greater magnitude in VERs elicited by the letter stimuli compared with those elicited by the patterns. As this component occurred quite late in the VER it is highly unlikely that this effect reflects differences in the physical nature of the two sets of eliciting stimuli (see section 2c) and is thus likely to be a reflection of subjects' different modes of information-processing, i.e., verbal compared with visuospatial. It is of great interest to note that the analogous components in the VERs obtained in Experiments 1-3 also appeared to be sensitive to this factor. Comparison of the amplitudes of this component as observed in Experiments 1 and 3 (these experiments employed the same stimuli and tasks as the present study) reveals that a task-dependent difference

was observed identical to that observed in the present study (see Figure 5(ii)). Across hemispheres and conditions the mean amplitude of this component was 5.31  $\mu$ V in Experiment 1 and 2.01  $\mu$ V in Experiment 3, a difference of more than 60%. Combined with the results of the present study, this strongly suggests that  $P_2$ - $N_2$  is sensitive to differences in the processing of the eliciting stimuli and is larger when elicited by stimuli requiring verbal, as opposed to visuospatial, processing.

The results of Experiment 2, in which subjects were required to perform a spatial analysis of the same letter stimuli as used in Experiment 1, add a complicating factor. In this experiment a hemisphere asymmetry (left greater than right) was observed in  $P_2$ - $N_2$ . This suggests that under the conditions of Experiment 2 the cognitive processing giving rise to  $P_2$ - $N_2$ , considered on the basis of the results of Experiments 1, 3, and 4 to be related to verbal processing, was localised asymmetrically predominantly to the left hemisphere. It is suggested that under circumstances in which eliciting stimuli have strong verbal associations some form of verbal processing always occurs. When the task demands associated with the stimuli are verbal, as in Experiment 1 and the verbal condition of Experiment 4, then the verbal processing giving rise to  $P_2$ - $N_2$  occurs in both hemispheres. When the task demands are non-verbal and instead spatial, as in Experiment 2, then such processing is confined to the left hemisphere and is not mediated also by the more task-involved right hemisphere.

This hypothesis was subjected to further test in Experiment 5, in which the same stimuli and task as were

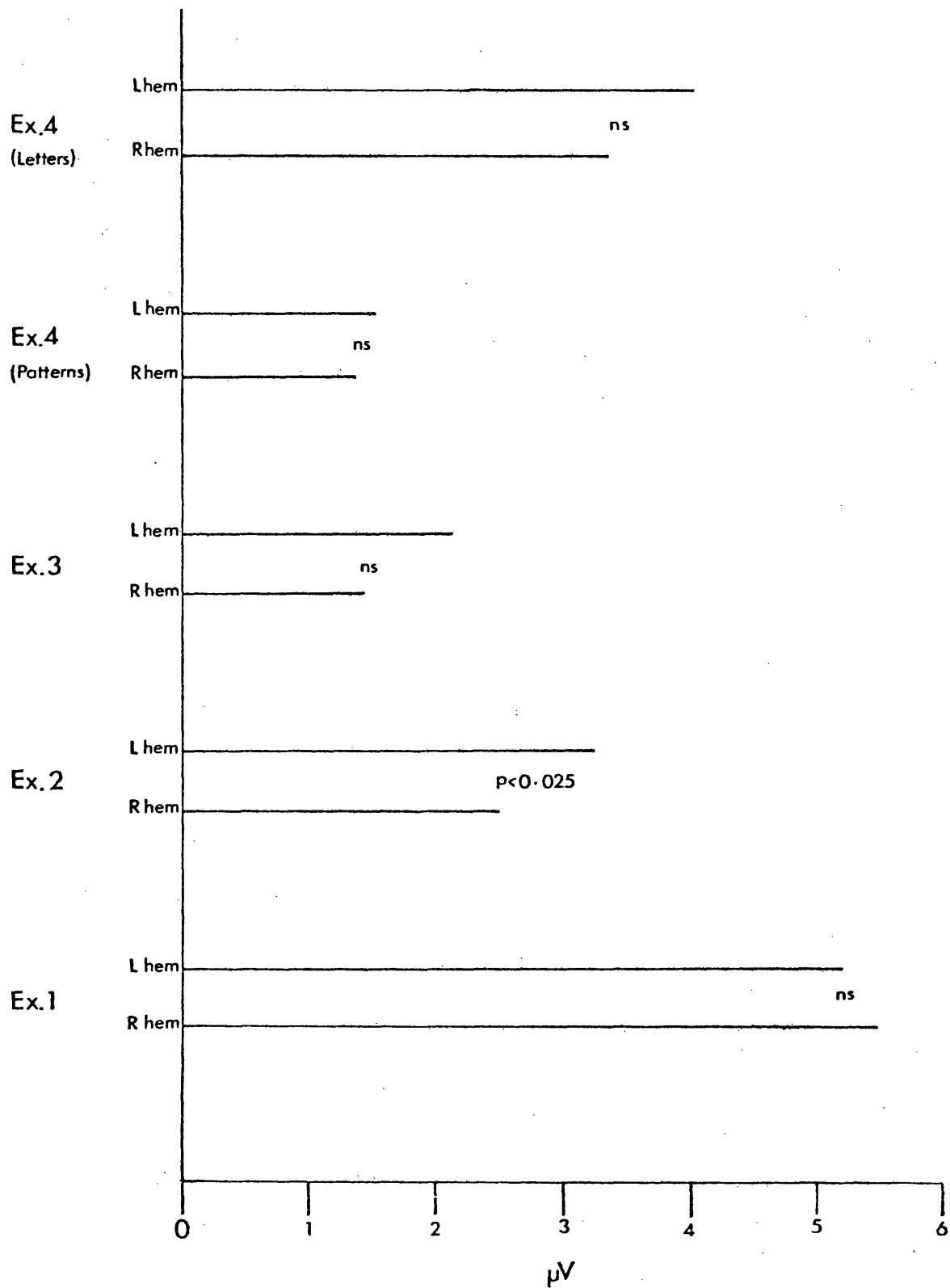


Figure 5(ii). Mean amplitude of the P<sub>2</sub>-N<sub>2</sub> component of subjects' VERS recorded from each hemisphere in Experiments 1-4 (averaged across visual fields for Experiments 1-3).

employed in Experiment 2 were utilised. In this case, however, the stimuli were exposed to the visual midline, as in Experiment 4. It was predicted that under these circumstances  $P_2-N_2$  would exhibit a hemisphere asymmetry in the form of the component being larger in the left hemisphere and thus replicating the results of Experiment 2 with respect to this component.

## 5b Experiment 5

### 5b(i). Method:

Ten right-handed adults, 6 male and 4 female, were employed as subjects. The task requirement and experimental procedures were almost identical to those of Experiment 4, the exception being that only one experimental condition was employed, in which subjects were required to view upper-case letters and respond as fast as possible to those which contained a right angle; a task identical to that employed in Experiment 2. The physical parameters and viewing conditions of the stimuli were identical to those used in the previous experiment with the exception that the luminous intensity of the stimuli was slightly less, approximately  $10 \text{ cd/m}^2$  instead of the  $13 \text{ cd/m}^2$  used previously. Two blocks with 50 stimuli in each were formed for the experiment, each block containing 10 target stimuli and having randomly determined inter-stimulus intervals which were either 2 or 3 sec. The blocks were presented to subjects consecutively, separated by a short rest interval. RT to the target stimuli, hits and false positive responses were recorded.

The recording of subjects' EEGs and the subsequent formation of their VERs proceeded exactly as described for

Experiment 4 with the exception that a different amplification system was used. In the present study the EEG channels were amplified using Neurolog NL103 AC pre-amplifiers and Kemo active filters, giving a system with the following characteristics: gain 10 K per channel, low pass 3 dB down at 30 Hz and time-constant 1.61 sec. Amplification to 20 K was obtained by setting the input amplifiers of the F.M. tape-recorder to a gain of 2. The amplification channels used to record left and right EEG channels were counterbalanced over blocks for each subject.

#### 5b(ii). Results:

As in previous experiments four components were consistently observed in subjects' VERs, these consisting of two positive and two negative peaks.  $P_1$  occurred at a latency of around 115 msec,  $N_1$  around 170 msec,  $P_2$  around 235 msec and  $N_2$  around 275 msec. Representative waveforms are illustrated in Figure 5(iii) and mean latencies and peak-to-peak amplitudes are shown in Tables 5(iv) and 5(v). Performance indices are reported in Table 5(vi).

The latencies and amplitudes of each component from each hemisphere were analysed with separate t-tests. This analysis revealed a significant difference only with respect to the latency of  $P_1$  ( $t_9 = 2.81$ ,  $p < 0.02$ ) and indicated that this component occurred with the shorter latency in the right hemisphere. The critical comparison of this experiment, that of  $P_2$ - $N_2$  amplitude from each hemisphere, was only marginally significant ( $t_9 = 2.10$ ,  $p < 0.07$ ). Inspection of the means reveals that this result was caused by this component having a higher amplitude in the left hemisphere and inspection of the subjects' raw scores shows that 8 out of 10 subjects

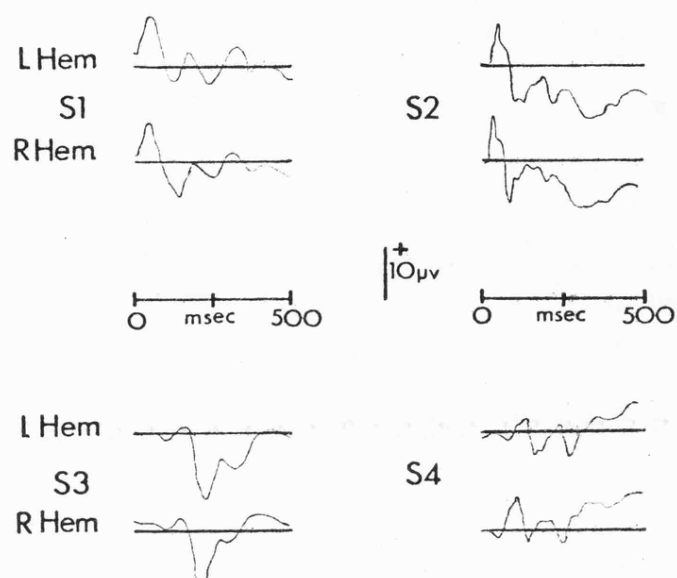


Figure 5(iii). VERs of four subjects recorded from the left and right hemispheres in Experiment 5.

Table 5(iv). Mean latencies (msec) and standard deviations of each VER component from the left and right hemispheres. (Experiment 5)

Component		L. Hem	R. Hem
P <sub>1</sub>	Mean	116.91	110.60
	S.D.	22.92	25.00
N <sub>1</sub>	Mean	172.21	171.64
	S.D.	32.86	33.70
P <sub>2</sub>	Mean	235.38	231.54
	S.D.	29.80	31.51
N <sub>2</sub>	Mean	280.57	269.52
	S.D.	28.76	28.35



Table 5(v). Mean peak to peak amplitudes ( $\mu$ V) and standard deviations of each VER component from the left and right hemispheres.  
(Experiment 5)

Component		L. Hem	R. Hem
P <sub>1</sub> -N <sub>1</sub>	Mean	10.84	11.12
	S.D.	3.98	4.21
N <sub>1</sub> -P <sub>2</sub>	Mean	5.95	6.01
	S.D.	3.35	3.60
P <sub>2</sub> -N <sub>2</sub>	Mean	3.70	2.43
	S.D.	2.81	1.72

Table 5(vi). Mean R.T. (msec) to target stimuli, hits  
and false positive responses. (Experiment 5)

R.T.	Mean	567.90
	S.D.	62.20
Hits	Mean	17.00
	S.D.	1.55
False +ves	Mean	9.60
	S.D.	9.32

manifested a larger  $P_2-N_2$  component in the left hemisphere whilst the 2 subjects who did not showed large ( $>1 \mu V$ ) reversals of this asymmetry.

#### 5b(iii). Discussion:

The observation of the shorter latency of  $P_1$  from the right hemisphere replicates the effect observed in Experiment 4. It adds further weight to the suggestion that this asymmetry may be reflecting the specialisation of the right hemisphere for early visual analysis.

Although of only marginal statistical significance the finding that  $P_2-N_2$  exhibited a greater amplitude in the left hemisphere supports the hypothesis, outlined in section 5a(iv), that this component reflects verbal processing which is confined mainly to the left hemisphere when the task demand associated with the stimulus is visuospatial. The significance of this is discussed in the next section.

#### 5c General discussion

The results of Experiment 5 support the notion that  $P_2-N_2$  may, under the appropriate conditions, reflect verbal processing irrelevant to the performance of the task associated with the eliciting stimulus. This finding is of interest as it suggests that even under circumstances in which the mediation of a task necessitates the allocation of the processing capacities of only one hemisphere the other may still process the stimulus information, perhaps in a parallel fashion. Thus a possible explanation of the asymmetry observed in Experiments 2 and 5 in the  $P_2-N_2$  component is that the highly verbal nature of the stimuli resulted in an

'automatic' allocation of the left hemisphere's processing capacity irrespective of the nature of the task. The finding that  $P_2$ - $N_2$  amplitude, although high, did not exhibit asymmetries in Experiment 1 or in the verbal condition of Experiment 4 suggests that this component reflects a form of processing which may be bilaterally mediated under conditions in which such processing is task-relevant. A recent review concerning right hemisphere language capacities (Searleman, 1977) has convincingly argued that the receptive language capacities of this hemisphere have been heavily underestimated and are, in fact, quite extensive. This being the case the suggestion that the verbal processing indexed by  $P_2$ - $N_2$  can under some circumstances be mediated bilaterally is not unreasonable, although the precise nature of this processing remains to be elucidated.

Finally, it is relevant at this point to note that neither in Experiment 4 nor 5 were any asymmetries observed in the amplitude of the  $N_1$ - $P_2$  component of subjects' VERs. In Experiments 1-3 asymmetries in this component thought to result from the lateralisation of stimulus input were observed to be modified by task and stimulus factors. It might have been expected that in the absence of a lateralisation of stimulus input these components would retain their sensitivity to such factors. One interpretation of the lack of such effects is that the processing of stimuli presented to central vision is distributed between the hemispheres in a less asymmetrical fashion than when the same stimuli are received via lateralised input channels. This would support the contention (Beaumont, 1978b) that VF studies of hemisphere asymmetries of processing may give a false picture of the way in which visual input is usually processed in the cortex.

## CHAPTER 6

## Experiment 6

6a Introduction

In all the experiments reported so far each block of eliciting stimuli has been associated with only one task. Thus the nature of the stimuli and of the cognitive operations required to facilitate a response were known to the subjects in advance of each stimulus presentation. In such circumstances it is arguable that any task-dependent differences observed in subjects' VERS reflect not only differences in the processing of the different stimuli but also aspects of what might be described as specific preparatory factors, such as attentional bias or set (Näätänen, 1975; Kinsbourne, 1973). To elucidate the extent to which this is the case it is necessary to employ an experimental condition in which subjects cannot predict in advance the nature of each stimulus that they are required to process. The present study utilised blocks of stimuli which consisted of random sequences of letters and patterns to which different types of discriminative response were required.

When the 'mixed stimulus' paradigm has been employed by investigators studying preparatory effects on behavioural indices of asymmetries of processing (e.g., Berlucchi, 1975; Cohen, 1972; Geffen et al, 1972; see section 1d for a fuller

discussion) it has consistently been reported that asymmetries of processing remain present when stimuli and associated tasks are intermixed. This has been interpreted as supporting a 'structural' model of asymmetric VF effects. However, these results do not elucidate the extent to which electrophysiological asymmetries reflect structural as opposed to preparatory factors. The 'mixed-stimulus' paradigm has been employed in VER studies by Buchsbaum and Fedio (1969, 1970) who reported the existence of stimulus-dependent VER differences in such circumstances. In these studies random sequences of shapes and nonsense words were utilised as eliciting stimuli. As subjects were not required to perform any stimulus-related tasks these studies are not comparable to the present one, in which subjects were required to become heavily task-involved, although they do suggest that some task- or stimulus-dependent effects in VERs are independent of preparatory factors.

Other than eliminating possible task-specific preparatory effects the experimental paradigm of the present experiment also changes the nature of the tasks facing the subjects from those in the previously reported experiments. In this experiment subjects were effectively required to perform two tasks; firstly to discriminate between the two types of stimulus and subsequently to discriminate between targets and non-targets according to the criteria (verbal or visuospatial) associated with each stimulus type. In view of the results obtained in Experiments 4 and 5 it was expected that the visual processing required to accomplish the task of stimulus recognition would be mediated predominantly by the right hemisphere and that this would be reflected in subjects' VERs. It was also predicted that if preparatory set was not a necessary condition for the task-dependent VER differences

observed in previous experiments then this should at the very least be reflected in an enhanced  $P_2$ - $N_2$  component to the letter stimuli compared with the patterns, replicating the effects observed with respect to this component in the previously reported experiments.

#### 6b Method

Ten subjects were employed, five of each sex. Two blocks with 100 stimuli in each were utilised, the stimuli consisting of 50 upper-case letters and 50 patterns formed from super-imposed letters. The physical parameters and viewing conditions of the stimuli were identical to those described with regard to Experiment 4 (section 5a(ii)). In each block the two stimulus types were exposed in a random order with 10 of each type as targets (letters whose name contained an 'ee' sound and patterns which were symmetrical about the vertical axis). Inter-stimulus intervals varied randomly as either 2 or 3 sec.

Prior to the experimental runs subjects were shown each of the stimuli to facilitate familiarisation with them and were instructed to respond as fast and as accurately as possible by raising their right index fingers on observing either of the two types of target stimulus. The blocks of stimuli were presented under identical conditions to those employed in previous experiments with a short rest in between them.

EEGs were recorded in exactly the same manner as in Experiment 4 with the exception that the amplifier channels used to record left and right channels were counterbalanced across stimulus blocks for each subject. Separate VERS were formed to the 80 non-target stimuli of each type. As in all

previous experiments VERNs were formed from the 500 msec of EEG from each hemisphere following stimulus onset at a digitisation rate of 400 Hz.

### 6c Results

Subjects' VERNs were morphologically very similar to those observed in the previous experiments, consisting of 2 prominent components of each polarity. The VERNs of one subject did not contain a clear late negative component ( $N_2$ ) and analysis of this component was performed on the data from the other nine subjects. Representative waveforms are shown in Figure 6(i) and the mean latencies of each component and their peak-to-peak amplitudes are shown in Tables 6(i) and 6(ii).

The latencies and amplitudes of each component were analysed using 2-way ANOVAs with repeated measures, the factors being stimuli (letter vs. pattern) and hemispheres (left vs. right). Analysis of the latency of  $P_1$  revealed a significant effect of hemispheres ( $F_{1,9} = 18.41$ ,  $p < 0.002$ ) which was caused by this component occurring with the shorter latency in the right hemisphere. A significant effect of hemispheres was also found to occur with respect to the latencies of  $N_1$  ( $F_{1,9} = 8.69$ ,  $p < 0.025$ ) and was also the result of the right hemisphere producing the component with a shorter latency than the left. Analysis of the latencies of  $P_2$  revealed a significant hemisphere x stimulus interaction ( $F_{1,9} = 11.36$ ,  $p < 0.01$ ) which was due to the fact that although the latency of this component barely differed between the hemispheres when elicited by the letter stimuli it was produced with much the shorter latency by the right hemisphere when elicited by the pattern stimuli. No significant effects were elicited by the



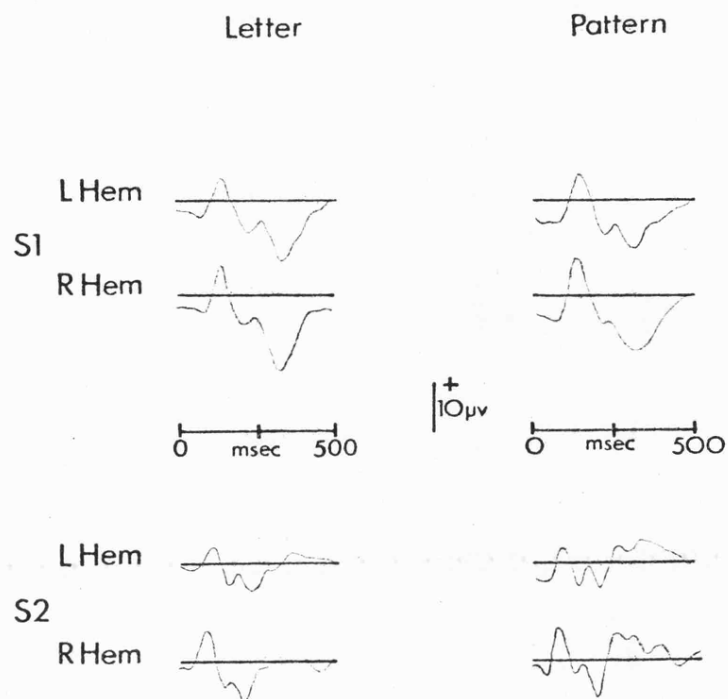


Figure 6(i). VERs from two subjects recorded from the left and right hemispheres to letter and pattern stimuli. (Experiment 6)

Table 6(i). Mean latencies (msec) and standard deviations of VER components from the left and right hemispheres elicited by patterns and letters. (Experiment 6)

		Pattern stimuli		Letter stimuli	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
P <sub>1</sub>	Mean	115.12	107.80	116.62	107.49
	S.D.	14.00	14.15	14.92	16.72
N <sub>1</sub>	Mean	183.48	179.41	183.90	178.27
	S.D.	26.42	28.53	23.81	20.76
P <sub>2</sub>	Mean	280.46	271.43	274.18	273.97
	S.D.	18.44	19.81	12.71	16.83
N <sub>2</sub>	Mean	311.69	310.11	315.71	312.54
	S.D.	29.67	28.31	22.60	23.36

Table 6(ii). Mean peak to peak amplitudes ( $\mu\text{V}$ ) and standard deviations of VER components from the left and right hemispheres elicited by patterns and letters. (Experiment 6)

		Pattern stimuli		Letter stimuli	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
$P_1-N_1$	Mean	12.17	15.36	11.70	15.75
	S.D.	4.86	8.25	4.69	6.47
$N_1-P_2$	Mean	9.90	11.69	9.17	11.40
	S.D.	6.59	8.30	5.86	8.13
$P_2-N_2$	Mean	2.37	3.35	2.75	3.71
	S.D.	3.70	5.41	3.06	4.05

analysis of  $N_1$ .

Analysis of the peak-to-peak amplitudes revealed a significant hemisphere effect for  $P_1-N_1$  ( $F_{1,9} = 7.73$ ,  $p < 0.025$ ) and a marginally significant effect of hemispheres in the case of  $N_1-P_2$  ( $F_{1,9} = 5.02$ ,  $0.05 > p > 0.06$ ). In each case these were caused by the right hemisphere producing the components with the larger amplitude. No effects were revealed by the analysis of  $P_2-N_2$ , the between-subject variance of which was very large.

The RTs to the two sets of target stimuli did not differ significantly. There were, however, significant differences in the number of hits ( $t_9 = 3.35$ ,  $p < 0.01$ ) and the number of false positives ( $t_9 = 4.55$ ,  $p < 0.002$ ) to each stimulus type. These results indicated that more hits and less false positive responses were made to the letter stimuli. (See Table 6(iii).)

#### 6d Discussion

Subjects' RTs to both stimulus types were considerably longer than those found in any previous experiment, this presumably reflecting the longer processing time required by subjects to perform the two discriminations required prior to a decision regarding whether or not to respond. The behavioural data indicate that the task associated with the pattern stimuli was the more difficult, subjects responding to fewer of the targets and more of the non-targets of this stimulus type. The interpretation of any task-dependent effects must be made with this factor in mind.

The latencies of both  $P_1$  and  $N_1$  were observed to be of a shorter latency in VERs from the right hemisphere and this was associated with larger right hemisphere amplitudes of both

Table 6(iii). Mean R.T. (msec) to target stimuli, hits and false positive responses to pattern and letter stimuli. (Experiment 6)

		Patterns	Letters
R.T.	Mean	761.64	671.50
	S.D.	103.92	105.38
Hits	Mean	11.30	17.00
	S.D.	4.32	2.10
False +ves	Mean	15.10	4.90
	S.D.	6.52	3.20

$P_1-N_1$  and, marginally,  $N_1-P_2$ . A possible interpretation of these asymmetries is that they reflect the fact that the right hemisphere was pre-eminent in the visual processing of the stimuli (as predicted in section 6a) and, since this processing was more complex than in previous similar experiments (i.e., Experiments 4 and 5), it was reflected more widely in the VER. In this context it is of interest to note that this is the first experiment in which the amplitude of the component  $P_1-N_1$  has demonstrated an asymmetry of any kind. This asymmetry may reflect the increased involvement of the right hemisphere in the processing of the eliciting stimuli in this experiment in response to the greater demands (compared with previous experiments) placed on subjects' information-processing capacities.

An alternative explanation for the effects discussed above is that they reflect the fact that subjects consistently biased their point of fixation towards the RVF, leading to the stimuli falling predominantly into the LVF and the concomitant asymmetries in latency and amplitude produced by such circumstances. As noted in section 5a(iv), whilst there is no obvious reason why this should occur the small magnitude of the bias which conceivably could produce such effects precludes its control by the use of any but the most sophisticated eye-monitoring techniques. However, the finding that the component  $P_1-N_1$  exhibited a hemisphere asymmetry suggests that factors other than just lateralisation of stimulus input were operating. This is because in previous experiments in which eliciting stimuli were unilaterally presented (Experiments 1-3) the amplitude of this component was found to be insensitive to the factor of visual field of stimulus presentation, in contrast to the amplitude of the

component  $N_1-P_2$  and the latencies of  $P_1$  and  $N_1$ , all of which parameters were highly sensitive to this factor. This would suggest that in the present study at least the asymmetry in  $P_1-N_1$  may reflect differences in processing between the hemispheres other than those caused solely by peripheral factors, there being no obvious reason why this component should be sensitive in this experiment to peripheral factors when it was not in previous studies.

Whether or not the hemisphere asymmetries discussed above are manifestations solely of peripheral artefacts, the hemisphere x stimulus interaction observed in the latencies of  $P_2$  is of interest. The effect was caused by the component having a shorter latency in the right hemisphere only when elicited by the pattern stimuli and is further evidence that task-dependent differences in stimulus processing may be reflected in VERS when the possibility of the existence of differential preparatory factors is eliminated. The interpretation of this effect is, however, difficult. A possible explanation is that it reflects the fact that the right hemisphere pre-eminence for the earlier processing of the stimulus information is maintained when the information derived from such processing is related to stimuli which require further visuospatial processing, an operation for which the right hemisphere is suitably specialised, whilst information derived from the verbal stimuli is transferred to the left hemisphere prior to the verbal processing. It should be noted that to subject this speculative account to experimental test would require considerable ingenuity. An alternative explanation for this effect is that it may reflect differences in the processing of the stimuli caused by the relative levels of difficulty of the associated tasks, that

associated with the pattern stimuli appearing, from the behavioural data, to have been the more difficult and thus perhaps to have been more likely to engage lateralised functions more fully.

The results of the present study offer no support for the prediction that the verbally processed letter stimuli would elicit a  $P_2-N_2$  component that was enhanced relative to that elicited by the patterns. This component was of a similar amplitude in both conditions. This result suggests that an important factor in the experiments in which this component was observed to be sensitive to different modes of information-processing may have been the preparatory set of the subject. Another possible explanation for the lack of task-specificity of  $P_2-N_2$  in the present study is that the complexity and difficulty of the tasks led subjects to adopt processing strategies which did not include the type of cognitive operations to which  $P_2-N_2$  is sensitive. In any case, the study demonstrates that  $P_2-N_2$  amplitude is not necessarily correlated with a simple verbal/visuospatial processing distinction. The finding that  $P_2$  latency exhibited task-specific hemisphere asymmetries suggests however that in this study, as in the previous ones, this region of the VER was sensitive to differences in the information processing associated with the two types of stimuli.

The results of this experiment add further weight to the contention that the initial processing of visual input is a cognitive operation for which the right hemisphere is specialised relative to the left. The results also suggest that task-dependent asymmetries may be found in the absence of task-specific preparatory sets on the part of the subject. Finally, the present findings do not support the hypothesis that the



different modes of information processing required to perform verbal as opposed to visuospatial discriminations constitute a factor sufficient to cause the modulation of the amplitude of  $P_2-N_2$ .

## CHAPTER 7

### Experiment 7

#### 7a   Introduction

The effects on the VER of the unilateral presentation of eliciting stimuli would appear to be clear. The early and middle latency components of the VER recorded from the hemisphere contralateral to the visual field of stimulus presentation are frequently of a shorter latency and occasionally of a larger amplitude than those recorded from the ipsilateral hemisphere (Andreassi et al., 1975; chapters 3 and 4). It has previously been argued (section 2d(iv) and 3b(iv)) that these effects reflect the fact that the retino-cortical pathways are arranged such that the hemi-retinae subserving each visual field are connected directly (via the lateral geniculate nucleus) with the occipital cortex contralateral to the visual fields, the route to the ipsilateral occipital cortex involving an additional pathway across the splenium of the corpus callosum. Thus, the delay in the VERs recorded from the ipsilateral hemisphere reflects the time required to process and transmit stimulus information over the corpus callosum. If this explanation is correct then it is reasonable to interpret variations in the delay of the ipsilateral VER relative to the contralateral one as reflecting to some extent

differences in the efficiency with which the contralateral hemisphere performs this transmission function; this interpretation is at the root of the explanation of the latency effects observed in Experiment 3 (section 4d).

If it is the case that the VER observed from the hemisphere ipsilateral to the visual field of stimulation is produced as the result of input, via the corpus callosum, from the contralateral hemisphere, then this is of interest at an anatomic as well as a neuropsychological level. The very similar morphologies of VERs recorded from homotopic sites to unilateral stimulation suggest strongly that they are the result of very similar generative mechanisms. It would seem that the nature of the afferent input to the VER generators<sup>1</sup> in the directly stimulated (contralateral) hemisphere was to a large extent unmodified by that hemisphere prior to callosal transmission, and that this transmission preserved the nature of the original input. Moreover, the generative mechanisms of the ipsilateral hemisphere appear not to distinguish between afferent input originating from the visual pathways and the corpus callosum.

Evidence exists which indicates that the early and some middle-latency components of VERs elicited by stimulus onset are generated in the striate cortex. For instance, Bodis-Wollner, Atkin, Raab and Wolkstein (1977) have demonstrated that large and consistent VERs may be recorded in humans in the absence of any pre-striate cortex and on the basis of topographical studies of VERs to pattern-onset in which

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<sup>1</sup> The term 'generators' does not imply that it is being assumed that VER electrogenesis is the result of the operation of discrete neural entities; it is in this context a purely functional term.

different retinal areas were stimulated Jeffreys (1971) and Jeffreys and Axford (1972a) concluded that the early components of these VERS were generated in the primary visual cortex within the calcarine fissure. It is thus likely that at least the first component of the VERS observed in Experiments 1-3 was generated in this region of the cortex. The results of these experiments therefore suggest that the striate cortices representing the lateral visual fields at an eccentricity of approximately  $4^{\circ}$  (the eccentricity of the stimuli in Experiments 1-3) are callosally interconnected. This contradicts other evidence, derived mainly from animal studies (for reviews see Berlucchi, 1972; Selnes, 1974) which suggests that only the first  $1^{\circ}$ - $1.5^{\circ}$  of the striate cortices representing each hemi-field are callosally interconnected.

The means of determining directly the extent to which the striate cortices are callosally interconnected in man would appear to be possible using VER techniques. It might be predicted that VERS recorded from homotopic sites to unilateral stimulation will maintain their morphological similarity only as long as they are being generated at homologous anatomic loci by similar mechanisms. It follows that, when an area of a hemi-retina the striate representation of which is not callosally interconnected is stimulated, this will be detectable in the VERS so elicited (assuming they are generated at the striate level in the directly stimulated hemisphere) in that they will be more dissimilar morphologically than those elicited by stimulation of retinal areas whose representation is callosally interconnected.

An experiment based on the argument developed above was performed. Subjects' visual fields were unilaterally

stimulated at varying eccentricities and the VERs so elicited were recorded from homotopic occipital sites. It was hypothesized that the stimulation of areas of the hemi-retinae which sent efferents to striate cortex which was callosally interconnected would result in morphologically more similar pairs of VERs than would the stimulation of areas with no such interconnection. It was hoped that the occurrence of this effect would allow the elucidation of the extent of striate-striate pathways in the cortex.

## 7b Method

Four subjects, two of each sex, were employed. Stimuli were presented on a VR14 computer oscilloscope and consisted of squares of light which, at the 500 mm viewing distance, subtended a visual angle of 7.5' x 7.5' with a luminous intensity of 8.6 cd/m<sup>2</sup>. A small circular fixation dot with a diameter of 1.5' visual angle and a luminous intensity of 1.72 cd/m<sup>2</sup> was present at the centre of the screen. The use of small eliciting stimuli was intended to minimise the possibility of artefacts caused by reflected light, a common problem in studies of this nature (Regan, 1972).

Subjects were seated facing the oscilloscope with their heads on a chin-rest. They were instructed to maintain fixation on the dot at the centre of the screen and, in each condition, to count the number of stimulus repetitions. Eleven conditions of stimulus presentation were employed, these differing only with respect to the site of retinal stimulation. Each condition consisted of 80 stimulus repetitions with a stimulus exposure duration of 60 msec and an inter-stimulus-interval of 1.5 sec. The conditions were:

- 1 & 2      Stimulation at 2° eccentricity in each VF
- 3 & 4      Stimulation at 4° eccentricity in each VF
- 5 & 6      Stimulation at 6° eccentricity in each VF
- 7 & 8      Stimulation at 8° eccentricity in each VF
- 9 & 10     Stimulation at 10° eccentricity in each VF
- 11         Stimulation at 0° eccentricity in each VF

The 11 conditions were presented in a different random order to each subject. To minimise fatigue and boredom subjects were allowed to rest for as long as they wished between conditions.

EEGs were recorded using silver/silver chloride electrodes from the 10-20 sites O<sub>1</sub> and O<sub>2</sub> referred to F<sub>Z</sub>. The exploring sites were chosen to maximise the detection of activity in the visual cortex and the reference to minimise the contribution of any vertex response whilst maintaining a symmetrical cephalic reference site. The EEG channels were amplified with Devices high-gain AC amplifiers with a gain of 20 K, low pass setting 3 dB down at 25 Hz and a time-constant of 0.3 sec. Amplifier channels used to record from the left and right hemispheres were counterbalanced across subjects. Their outputs, along with event markers, were recorded on separate channels of FM tape prior to off-line analysis. To ensure that subjects' gaze did not deviate systematically from fixation and to allow detection of time-locked eye-movement artefacts (frontal electrode placements are particularly sensitive to EOG artefacts because of their proximity to the eyes) the EOG was recorded from Beckman miniature electrodes positioned on the outer canthus of and above the left eye. This signal was amplified by a Devices AC amplifier with a gain of 5 K, low-pass 3 dB down at 25 Hz

and time-constant 10 sec. It was recorded on a separate channel of FM tape.

The 250 msec of EEG and EOG following each stimulus onset were averaged (digitisation of 500 Hz) to produce VERS and an average EOG for each condition of stimulation.

### 7c Results and discussion

Waveforms obtained from two subjects are shown in Figure 7(i). It can be seen that there are no consistently recognisable components between these two subjects' VERS and this was the case for the other subjects also. This lack of morphological stability between and, to a lesser extent, within subjects is possibly the result of the small size and relatively low intensity of the eliciting stimuli and precludes the use of quantitative analytic techniques. Visual inspection indicates that the VERS elicited by stimulation at the more peripheral eccentricities are no more dissimilar than those elicited by stimulation at smaller eccentricities or at the midline. The results provide no indication, therefore, of the discontinuity of similarity that would, it was hypothesised, index the limits of callosal interconnectivity in the visual cortex. This does not mean, however, that these findings necessarily indicate that such interconnectivity exists in the areas of striate cortex which receive input from the lateral visual fields at a  $10^{\circ}$  eccentricity. It is possible that the poorly-defined VERS recorded in the present study contained substantial contributions for sources of neural activity other than the striate cortex, most notably the richly interconnected prestriate regions of the visual cortex, and also possibly

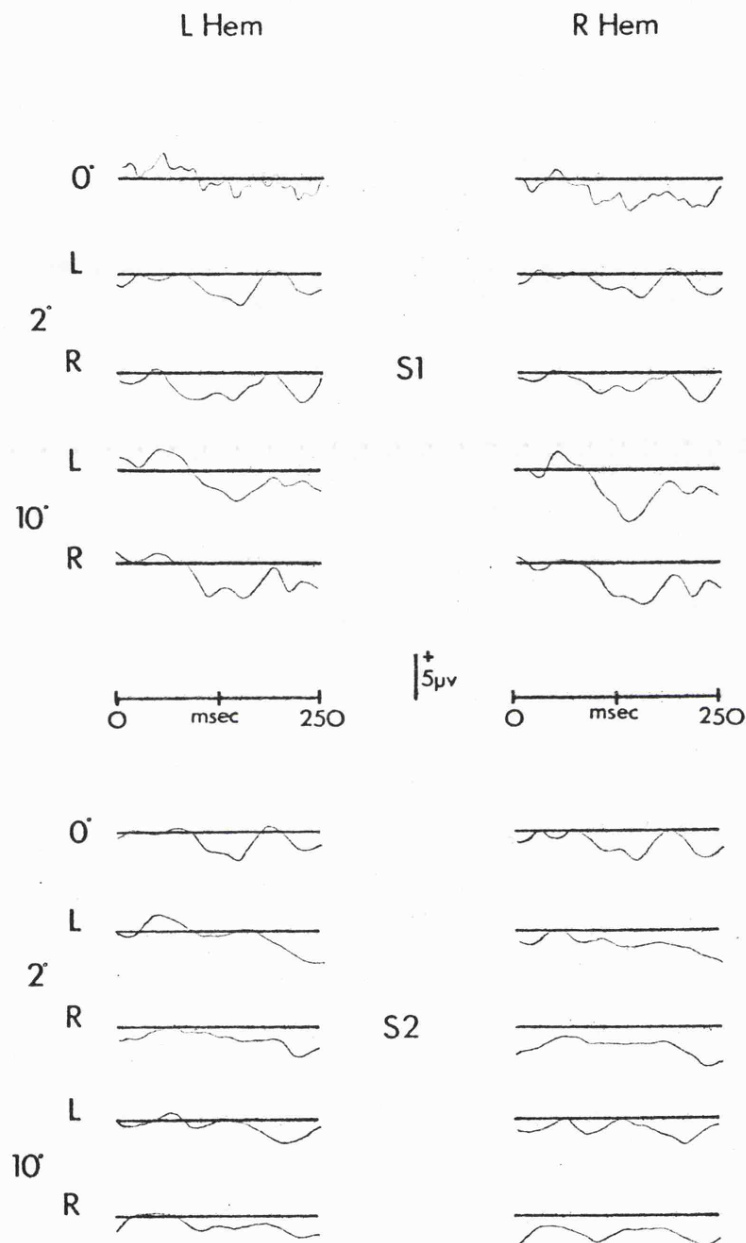


Figure 7(i). VERS from two subjects recorded from the left and right hemispheres to stimuli presented at 0°, 2° left and right and 10° left and right of fixation. (Experiment 7)



from sub-cortical activity. The present results can be considered as no more than suggestive. Future studies in this paradigm would benefit from the use of eliciting stimuli which whilst allowing accurate localisation on the retina produce VERs with a component the electrogenesis of which is known to occur in the striate cortex.

## CHAPTER 8

### Discussion of Experiments 1-7

#### 8a Introduction

Although the VER differences observed in the experiments reported so far have been ascribed to information processing differences related to the employment of different stimuli and tasks no systematic attempt has been made to elucidate the processes by which these factors manifested themselves in subjects' VERs. This has been the case also in nearly every report published with respect to VER correlates of asymmetries of processing; little attempt has been made to relate the results obtained either to the results of ER studies in other areas of enquiry (most notably selective attention) or to current theories of the mechanisms which underly cerebral asymmetries of processing. The present chapter discusses the possible causes and ramifications of the effects observed on the VER in the experiments reported in the previous five chapters.

#### 8b Amplitude differences

Interpretation of amplitude variations in averaged ER components are always to some extent ambiguous on account of the fact that such amplitudes are highly sensitive to the

inter-trial variability of the component in question. A high level of variability will give rise to a smaller averaged component than will the averaging of trials which occur within a more restricted range of latency variation. Using conventional averaging techniques it is not possible to estimate the degree to which differences in 'latency jitter' are responsible for any variations in ER amplitude which may be observed, this estimation requiring the use of single-trial ER analyses (for the application of such analysis to the estimation of latency jitter see Coppola, Taber, & Buchsbaum, 1978).

With respect to studies attempting to show ER correlates of selective attention Näätänen (1975) has identified a number of possible factors which might affect the amplitude of ER components and all of which are relevant to the amplitude effects described in the experiments reported in Chapters 3-6. The first, and, he argues, the most common source of ER amplitude variation is that of differential arousal caused by differential preparation to stimuli of different degrees of 'relevance'. By 'arousal' or 'activation' Näätänen (and other investigators) would appear to be referring to the level of ANS and CNS responsiveness as indicated, for example, by variables such as skin conductance, pupillary dilation and alpha desynchronisation. These are assumed largely to co-vary and index the general level of organismic arousal or activation. The concept is, however, poorly defined. Callaway (1975) reviews studies relevant to the issue of the effects of arousal on ERs, notes that the term is loosely defined and provides no more precise a definition himself than the fact that it has an inverse relationship with fatigue. It has been convincingly demonstrated that an increase

in a subject's level of arousal, as defined above, is invariably accompanied by an increase in the amplitude in concurrently recorded ERs, the effect being most prominent on middle-latency components (Callaway, 1975). This effect is of crucial importance in studies in which an attempt is being made to demonstrate ER differences contingent upon differences in information-processing of the eliciting stimuli. Näätänen (1967) has elegantly demonstrated that the enhancement of the amplitude of ERs to 'attended' compared with 'unattended' stimuli, an effect once considered conclusively to demonstrate differences in stimulus processing (e.g., Spong, Haider, & Lindsley, 1965), may be a non-specific effect caused by differences in arousal preceding the two types of stimuli. Näätänen demonstrated that in circumstances in which the subject could not know in advance whether an eliciting stimulus was going to be 'relevant' no differences in ER amplitude were observed. The relevance of the factor of differential activation to ER studies of hemisphere asymmetry lies in the fact that it has been hypothesized (Kinsbourne, 1970; see also section 1d) that one effect of the differential engagement of the cerebral hemispheres in cognitive processing is that it is accompanied by asymmetric levels of cortical arousal<sup>1</sup>, the hemisphere which is most task-involved is also more highly aroused. In view of the relationship between arousal and ER amplitude it is therefore

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<sup>1</sup> The use of the terms 'activation' or 'arousal' by Kinsbourne refer to levels of cortical responsiveness as controlled by brain-stem mechanisms (Kinsbourne, 1973, discusses this model). It is assumed by the model that these levels are, within wide limits, independently determined in each cerebral hemisphere.

arguable that ER asymmetries in the form of amplitude differences may be no more than a reflection of this phenomenon.

In experimental situations in which differential preparedness (and thus arousal) is eliminated differences in the amplitude of ERs to the different eliciting stimuli may still be the result of 'non-specific' rather than 'stimulus-specific' effects. Näätänen (1975) has argued that amplitude differences occurring in middle-latency and late components of the ER are occurring at latencies which are longer than the time required by subjects to determine whether any eliciting stimulus is relevant and to become more or less aroused as a result. It is possible, Näätänen argues, that ER amplitude differences may reflect these phasic changes of state rather than processes specific to the processing of the stimuli; the 'reactive-arousal' hypothesis (Karlin, 1970). In the context of Kinsbourne's model of hemisphere function it is arguable that in circumstances in which the hemispheres are at an equal level of arousal (e.g., awaiting the arrival of equi-probable verbal or visuospatial stimuli) task-dependent ER amplitude asymmetries may reflect the phasic increases in arousal of each hemisphere as it is engaged by the stimuli which, by virtue of the task demands of the situation, it is specialised to process.

The final 'non-specific' source of ER amplitude variation discussed by Näätänen is that of differential CNV resolution. He argues that even in situations in which the pre-stimulus CNV amplitude is likely to be constant both for 'relevant' and 'irrelevant' stimuli larger positive going components in ERs to 'relevant' stimuli may reflect the fact

that the resolution of the CNV following such stimuli was more complete than that to 'irrelevant' stimuli, and that this positive-going wave may sum with the ER to produce an apparently enhanced positivity in otherwise similar ERs. The relevance of CNV effects to ER studies of hemisphere asymmetries is two-fold. In circumstances in which subjects are aware of the nature of the tasks confronting them CNVs which develop whilst the subjects await the task-relevant stimuli are reported to be larger over the hemisphere hypothesized to be potentially the more task-involved (Donchin, Kutas, & McCarthy, 1977; Butler & Glass, 1974b). The ERs elicited by the stimuli thus ride on asymmetrical levels of negativity, the resolution of which may cause asymmetrical distortion of some components. In situations in which subjects are unable to form differential preparatory sets the possibility remains that any CNV which is present (symmetrically distributed in the pre-stimulus period) will be differentially resolved, more completely perhaps in the hemisphere for which the stimuli have the greater 'relevance' (greater CNV resolution to 'relevant' as opposed to 'irrelevant' stimuli has been demonstrated by Wilkinson and Lee (1972)).

It should be noted that in spite of the factors discussed above it is still possible that ER amplitude changes may result from stimulus-specific differences in information-processing operations in the cortex; i.e., they may reflect the neuronal events associated with the processing of the eliciting stimuli. Whilst this explanation of ER amplitude asymmetries is commonly implied in the discussions of studies of hemisphere asymmetries of processing it is clear that the

effects of the non-specific processes discussed above must also be taken into account. It would be of benefit if future studies were designed in a way which facilitated the discrimination between these various potential sources of ER amplitude variation.

Although a detailed discussion of the possible contributions of specific and non-specific factors to the amplitude effects reported in Chapters 3-6 would be highly speculative and of doubtful worth consideration of some of the more important points is relevant. In the first instance it should be noted that the relevance of the 'differential preparation' and 'reactive arousal' explanations of ER amplitude effects rests largely on the extent to which Kinsbourne's (1970) hypothesis is correct in its assertion that asymmetrical cerebral processing is associated with asymmetrical levels of cortical arousal or activation. Direct evidence for this element of the hypothesis is difficult to come by (and is made none the easier by the vagueness with which the hypothesis has been formulated). The most compelling supportive evidence arises from studies of the distribution of EEG alpha activity across the cerebral hemispheres. Alpha desynchronisation or attenuation is widely regarded as an index of cortical arousal (Marsh, 1978; Lindsley & Wicke, 1974). When the EEG recorded from each hemisphere whilst subjects performed verbal and spatial tasks has been subjected to power and frequency analysis task-dependent alpha asymmetries (in the form of relatively less alpha from the putatively task-involved hemisphere) have consistently been reported to occur (see, for example, Beaumont, Mayes, & Rugg, 1978; Osborne & Gale, 1976; Butler & Glass, 1974a; Doyle, Ornstein, & Galin, 1974; Morgan,

McDonald, & Hilgard, 1972). This could be interpreted as reflecting the tonic asymmetries of cortical activation assumed by the Kinsbourne hypothesis to be associated with differential hemisphere involvement. However, the relationship between these EEG indices of asymmetries of arousal and ERs is far from clear. Eason, Aiken, White, and Lichenstein (1964) have reported that VERs elicited by light flashes and recorded during periods either of relaxation or mental activity were enhanced in the latter condition, a finding attributed to the arousing effect of the mental activity. In the context of VER studies, however, Caperall and Shucard (1977), Rasmussen et al. (1977) and Galin and Ellis (1975) have all reported that VERs to task irrelevant stimuli are, relative to those in the uninvolved hemisphere, attenuated in the task-involved (and supposedly more aroused) hemisphere, the latter investigators presenting data showing that VER attenuation was correlated with degree of EEG alpha suppression. The situation is made more confusing by the finding of Shucard et al. (1977) that if AERs to tone pairs are elicited from subjects engaged in verbal or musical tasks the ER to the second tone in the pair is larger in the more task-involved hemisphere. This effect was attributed to the fact that the greater level of activation of this hemisphere caused it to have a faster 'recovery cycle' than its fellow. It should be clear from this discussion that the relationships between hemisphere asymmetries of processing, concomitant asymmetries of cortical arousal, and asymmetries of ER amplitude are at present unclear and likely to prove complex. It would be a challenging and probably impossible task to attempt to explain the effects observed in Experiments 1-6 in such terms.



The extent to which pre-stimulus slow-waves may have influenced the VERs obtained in Experiments 1-6 is also problematic. It should be noted that because CNV phenomena are of a maximal voltage over the vertex and of a low voltage over the posterior scalp (McAdam, 1974) they would appear as a positive offset in the EEG channels used in these experiments (the montage in these studies consisted of homotopic occipital electrodes with a common vertex reference). Consequently, CNV resolution would appear as a negative-going component. In this context it is noteworthy that in Experiments 1-5  $P_2-N_2$  was observed to be highly task- and stimulus-specific. The possibility that this negative-going component was influenced by task-specific CNV factors cannot be discounted, particularly in view of the fact that when the possibility of differential preparation (and therefore differential CNVs) was eliminated (Experiment 6), the effects previously associated with this component were not observed.

### 8c Latency differences

The interpretation of variations in component latencies is not troubled by problems analogous to that of 'latency jitter' in amplitude measurements. Assuming a relatively unskewed distribution of the latencies of single trials, then the central tendency of these is adequately reflected by the use of the mean, i.e., measurement of the latencies of the components of the averaged waveform.

To the author's knowledge no study to date has reported the latency of ER components to be affected by non-specific factors of the type discussed in section 8b. The sensitivity of the latencies of the early- and middle-latency components of the VER to the peripheral factor of retinal site of

stimulation has been discussed in Chapter 7, where it was concluded that these effects were related to the directness of the pathways between the retina and the cortical generators of the VER. The right-hemisphere latency advantages observed in VER components in Experiments 3-6 were, however, ascribed to non-peripheral factors. It was assumed that component latencies were a direct measure of the speed with which the cortex processed the eliciting stimuli and that the latencies of different components indexed the speed of different stages of information processing. It was further assumed that the hemisphere manifesting a particular component with the shorter latency was the one most efficiently engaged in the information-processing underlying the electrogenesis of that component. On the basis of these two assumptions the finding that certain VER components occurred with a shorter latency in the right hemisphere was taken to indicate a right-hemisphere pre-eminence for the visual processing of the eliciting stimuli. Neither assumption is free from problems. The assumption that component latency may index the speed of processing of the eliciting stimuli is true only to the extent that the components of an ER are closely coupled to the processing of the eliciting stimulus; the less the extent to which this coupling occurs then the less valid is the assumption. Given that this first assumption is true, the second does not necessarily follow. It is for instance conceivable that the reason for the shorter latency of the VERs from the right hemisphere in the experiments mentioned above is that the right hemisphere is not specialised to process the eliciting stimuli and that because of this the time taken in stimulus processing is less than

that taken by the relatively more specialised left hemisphere, which is engaged in more extensive processing due to the fact that it is extracting more information from the stimulus input (for such an interpretation of latency asymmetries, see Gott & Boyarsky, 1972).

It is clear from the above discussion that the assumptions underlying the interpretation of ER latency differences, while perhaps intuitively attractive, are not unchallengeable. In as much as they allow a parsimonious explanation of the variation in the latencies of components in different conditions then they are of value. It would, however, be of benefit if they were to be subjected to critical tests rather than simply applied in a post hoc manner.

#### 8d    General discussion

Consideration of the issues raised in sections 8b and 8c makes it clear that the detailed interpretation of the VER effects described in Experiments 1-7 is fraught with difficulty. In spite of these problems it is arguable that a number of general conclusions may be drawn in the light of these experiments, although it should be noted that they all rest to some extent on assumptions which have been questioned in the preceding two sections.

From the results of Experiments 1-3, it would seem clear that the effect of route of stimulus input (LVF or RVF) interacts both with the nature of the stimulus and the associated task. Thus, the pattern of asymmetry in the latency of  $P_1$  in Experiments 1 and 2 (in which the same stimuli but different tasks were employed) was very similar while the

patterns of asymmetry shown by  $N_1$ - $P_2$  amplitude differed. In contrast, in Experiments 2 and 3 (in which different stimuli and similar tasks were utilised) different patterns of asymmetry were observed in  $P_1$  latency and similar patterns in  $N_1$ - $P_2$  amplitude. The results of these three experiments also suggest that the attempts to explain behavioural asymmetries associated with lateralised visual input in terms of one of the models<sup>1</sup> described in section 1c may be grossly oversimplifying the way in which information is processed in and shared between the cerebral hemispheres. The way in which these processes occur appears, on the evidence of these experiments, to be related to factors other than that of the nature of the task associated with the required behavioural response, e.g., whether or not the stimulus has a high level of verbal association.

Whatever the origins of the  $P_2$ - $N_2$  component observed in Experiments 1-6 its pattern of occurrence in these experiments suggests that it was associated with the verbal processing of the eliciting stimuli. The pattern of asymmetries of this component in the experiments further suggests that when verbal processing of the stimuli was task-relevant some aspect of this processing gave rise to bilateral involvement of the hemispheres. That this aspect of verbal

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<sup>1</sup> One model proposes that unilaterally presented stimuli were processed in the hemisphere to which they were presented and that VF asymmetries represented the relative specialisations of the two hemispheres for the stimuli in question. The other model proposes that stimuli are processed in the appropriately specialised hemisphere. With this model VF asymmetries index the extra time and degradation of stimulus input during transfer which occurs when a stimulus is directed to the hemisphere unspecialised for the required task.

processing is not necessarily bilateral, and that the hemispheres may be capable of independent processing, is suggested by the finding that when a verbal stimulus necessitated visuospatial processing prior to a response an enhanced  $P_2-N_2$  was observed only in the left hemisphere. These results further demonstrate the complex manner in which stimulus information and processing may be distributed between the hemispheres and suggest that the fact that a hemisphere may not be primarily responsible for the mediation of a task does not mean that it does not process the task-related stimuli to a significant degree. The possible importance of preparatory factors in these effects was demonstrated by the finding that when verbal and non-verbal stimuli were inter-mixed (Experiment 6) no stimulus-dependent  $P_2-N_2$  amplitude effects were observed.

Experiments 3-6 provide supportive evidence for Bryden and Allard's (1976) hypothesis that the right hemisphere is pre-eminent in the early stages of visual processing of all stimuli. This conclusion is derived from the finding that the right hemisphere gave rise to  $P_1$  with the shorter latency in each of these experiments, irrespective of whether the stimuli were verbal or not. That this effect occurred in the experiments in which subjects knew in advance the nature of each eliciting stimulus suggests that this asymmetry of processing is stable with respect to preparatory factors. The finding that not only  $P_1$  latency, but that of  $N_1$  and the amplitude of  $P_1-N_1$  all demonstrated a right hemisphere advantage in Experiment 6 suggests that this asymmetry may become more enhanced when more difficult visual processing is demanded.

On a more general level it is worth reiterating (see section 5b(iii)) that the lack of task- or stimulus-specific asymmetries in  $N_1$ - $P_2$  in the experiments in which the stimuli were presented to the visual midline, although such effects were observed with unilateral stimulation, suggests that the stimuli may have been subjected to processing which was distributed between the hemispheres in a different manner in each paradigm. Thus, the assumption that behavioural indices of the processing of unilaterally presented stimuli allow inferences which can be generalised to situations outside of this experimental paradigm (e.g., the processing of stimuli in central vision) may be in error.

## CHAPTER 9

## Experiments 8 and 9

9a Introduction

The focus of interest of the experiments reported and discussed in the previous chapters has been the effects of stimulus and task on the early- and middle-latency components of the VER. No attempt was made separately to analyse VERs elicited by the 'target' and 'non-target' stimuli employed in these experiments to determine whether asymmetries might exist in the late components of the VER associated with post-recognition processes (i.e.,  $P_{300}$ <sup>1</sup>; see section 2c). The reason for this, as noted in section 3a(iii) was that the electrode montage used in these experiments, whilst ideal for the analysis of possible asymmetries in modality-specific components of the VER, was inappropriate for the analysis of late components which would have been almost equipotential at all three electrodes. The experiments reported in this

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<sup>1</sup> In this and all subsequent discussion ' $P_{300}$ ' is used as a collective term for the late (greater than 250 msec) positive components observed to peak at varying latencies in different studies but considered to represent the same phenomenon. In the experiments reported in the present chapter and Chapter 10 the component assumed to represent  $P_{300}$  and observed in these particular experiments is labelled ' $P_3$ '.

chapter employed the same stimuli and tasks as used previously in association with recording and analysis techniques intended to facilitate the analysis of the late components of the VER.

## 9b Experiment 8

### 9b(i). Introduction:

Apart from being of interest within the paradigm of ER studies of cerebral asymmetries of processing this experiment is also of relevance in the wider context of research into the variables underlying the manifestation of  $P_{300}$ . The precise determinants and significance of this component are unclear. With simple stimuli and tasks (e.g., detecting dim 'targets' in a train of brighter flashes or discriminating a rarely occurring target letter from a more commonly presented one) the amplitude of this component is clearly associated with factors which relate to the subject's expectancy of whether the stimulus will occur (e.g., Duncan-Johnson & Donchin, 1977; Squires, Wickens, Squires, & Donchin, 1976; Sutton et al., 1965) and to the degree of salience or 'task-relevance' of the eliciting stimulus (Squires, Donchin, Herning, & McCarthy, 1977). When more complex stimuli and tasks are utilised this relationship becomes less clear, and factors such as the amount of cognitive activity required to process the stimuli (Rohbraugh, Donchin, & Eriksen, 1974) and the physical similarity between the different types of eliciting stimuli (Johnson & Donchin, 1978; Adams & Benson, 1973) are of importance.

On the basis of a correlational analysis between



subjects' RTs and the latencies of  $P_{300}$ s elicited by single stimuli, Kutas et al. (1977) have suggested that the latency of  $P_{300}$  indexes the amount of time a subject spends evaluating a stimulus prior to a decision regarding its salience. A similar suggestion has been made by Courchesne et al. (1977) who proposed that the latency of  $P_{300}$  may relate to the moment of recognition of a task-relevant stimulus. Supporting the general notion that  $P_{300}$  latency reflects time taken to process task-relevant information Adam and Collins (1978) have demonstrated that the latency of  $P_{300}$  varies with the amount of memory search required to decide whether the eliciting stimulus is a member of a previously presented set.

The hypothesis that the latency of  $P_{300}$  is associated with time taken to evaluate a stimulus is attractive in that it can account for conflicting reports on the question of whether RT and  $P_{300}$  are correlated (see, for example, Karlin, Martz, & Mordkoff, 1970; Wilkinson & Morlock, 1967) by postulating that a relationship will only obtain when response processes are closely coupled with stimulus evaluation. Thus, a stronger correlation is found between RT and  $P_{300}$  latency when subjects respond under 'accuracy' as opposed to 'speed' instructions (Kutas et al., 1977).

With reference to possible relationships between  $P_{300}$  and hemisphere asymmetries of processing it might be expected that stimuli which asymmetrically engage the hemispheres, and for which the task-relevant processing is confined primarily to one hemisphere, would elicit  $P_{300}$ s the asymmetries in which would reflect such factors. Such a finding has, to date, proven elusive (see Friedman et al., 1977; section 2d).

The present experiment compares VERs elicited by two different types of stimulus requiring different kinds of cognitive processing prior to a discriminative response, the cognitive processing of each type of stimulus being considered asymmetrically to engage the cerebral hemispheres. The stimuli and tasks employed are the same as those utilised in Experiment 4, and the present study is nearly identical to the former with the exception that the EEG recording and analysis were designed to facilitate the analysis of the late components of the VER. Apart from allowing the comparison of  $P_{300}$ s recorded from homotopic sites to the two types of stimulus the experiment also permits the comparison of  $P_{300}$  and performance measures of stimulus processing.

9b(ii). Method:

Ten right-handed subjects, five of each sex, were employed.

Two stimulus types were used to elicit VERs, these consisting of the upper-case letters and geometrical patterns utilised previously in Experiments 1-6. As in previous experiments the stimuli were viewed from a distance of 500 mm and, at this distance, subtended a visual angle across the midline of 42'. The luminance of the stimuli was approximately 10 cd/m<sup>2</sup> and their exposure duration 100 msec.

Four blocks of stimuli, two of each type, were employed. Each block contained 40 non-target stimuli, 4 each of a pool of 10, and 20 target stimuli, 4 each of a pool of 5. The order of targets and non-targets within a block was randomly determined. Thus, the a priori probability of the

exposure of a target in each block was 0.33. With regard to the letter stimuli targets were those letters the names of which contained the sound 'ee'. In the case of the patterns, targets were those stimuli which were symmetrical about the vertical midline. The stimuli were displayed at the centre of a Dec VR14 oscilloscope controlled by a Lab/8e computer. In each block the inter-stimulus intervals varied randomly between 1 and 4 sec (rectangular distribution).

Subjects were seated facing the oscilloscope in a darkened room with their heads resting on a chin rest. Prior to the experimental runs they were shown each of the targets and non-targets of each stimulus type and the experimental tasks were explained. They were instructed to maintain fixation on a small dot at the centre of the oscilloscope screen and to respond as quickly and as accurately as possible to targets by slightly raising their right index fingers (and thus activating a microswitch lever). On the basis of this response subjects' performances on each task, as measured by RT to the targets, number of hits and number of false positive responses, were calculated. The blocks of stimuli were presented in an ABBA design the order of which was counterbalanced across subjects.

Subjects' EEGs were recorded using silver/silver chloride electrodes on the scalp sites  $P_3$  and  $P_4$  of the 10-20 system referred to linked mastoids (Beckman miniature electrodes). Inter-electrode impedances were maintained below 5 K $\Omega$ . The EEG channels were amplified with Devices AC amplifiers and filtered with Kemo active filters to give a system with the following characteristics: gain 20 K in each

channel; low pass 3 dB down at 30 Hz; time-constant 1 sec. The channels used to record from each hemisphere were counterbalanced across subjects. In view of the sensitivity of slow ER components to eye-movement contamination (Hillyard, 1974) it was considered necessary concurrently to record subjects' EOGs. These were recorded with Beckman miniature electrodes placed on the outer canthus of and above the left eye. The signal was amplified by a Devices AC amplifier with a gain of 4 K, low pass 3 dB down at 25 Hz and time-constant 10 sec. A forehead ground was used for both EEG and EOG.

EEG, EOG and event markers were recorded on separate channels of a Racal FM tape-recorder prior to off-line analysis. VERS from each hemisphere were formed to the targets and non-targets of each stimulus type and the EOG associated with each pair of VERS was also averaged. Averaging took place over 600 msec epochs of EEG and EOG, starting 50 msec prior to stimulus onset and with a digitisation rate of 500 Hz.

#### 9b(iii). Results:

The data from one subject were rejected on the grounds that he performed extremely poorly on the experimental tasks (e.g., 22 false positive responses to the spatial stimuli) in contrast to the performances of the other subjects. Three components were consistently recognisable in subjects' VERS. These were a small positive peak around 150 msec ( $P_1$ ), a negative peak around 180 msec ( $N_1$ ) and a positive wave peaking around 400 msec ( $P_3$ ). In a few subjects' records a prominent positive peak was observed

around 250 msec ( $P_2$ ); as this was not seen consistently across subjects it was not subjected to analysis. In some of one subject's records neither  $P_1$  nor  $N_1$  could be recognised and this subject's data were excluded from the analysis of these components. The averaged EOGs associated with each pair of VERs were inspected for deviations associated with deflections in the VERs. In no case were such associations observed. Figure 9(i) illustrates representative waveforms.

Latencies of each component were measured from stimulus onset and amplitudes were measured with respect to a 50 msec pre-stimulus baseline. Mean latencies are shown in Table 9(i) and mean amplitudes are shown for the baseline to peak measures of  $P_1$ ,  $N_1$  and  $P_3$  and the peak to peak amplitude of  $P_1$ - $N_1$  in Table 9(ii). Three-way ANOVAs (factors: stimuli, letters vs patterns; targets vs non-targets; hemisphere, left vs right) with repeated measures were performed on the latencies and amplitudes of each component.

Analysis of the latencies of  $P_1$  revealed a significant effect of hemisphere ( $F_{1,7} = 42.44$ ,  $p < 0.001$ ) in the absence of any other effects and was due to this component having a shorter latency in all conditions when recorded from the right hemisphere. No effects were found for the latencies of  $N_1$ . Analysis of  $P_3$  latency revealed a significant effect of stimuli ( $F_{1,8} = 10.30$ ,  $p < 0.025$ ), this being caused by  $P_3$  occurring with a shorter latency when elicited by the letter stimuli.

Analysis of  $P_1$  and  $P_1$ - $N_1$  amplitudes revealed no significant effects. That of  $N_1$  revealed an effect of hemisphere ( $F_{1,7} = 13.91$ ,  $p < 0.01$ ) caused by this component having a

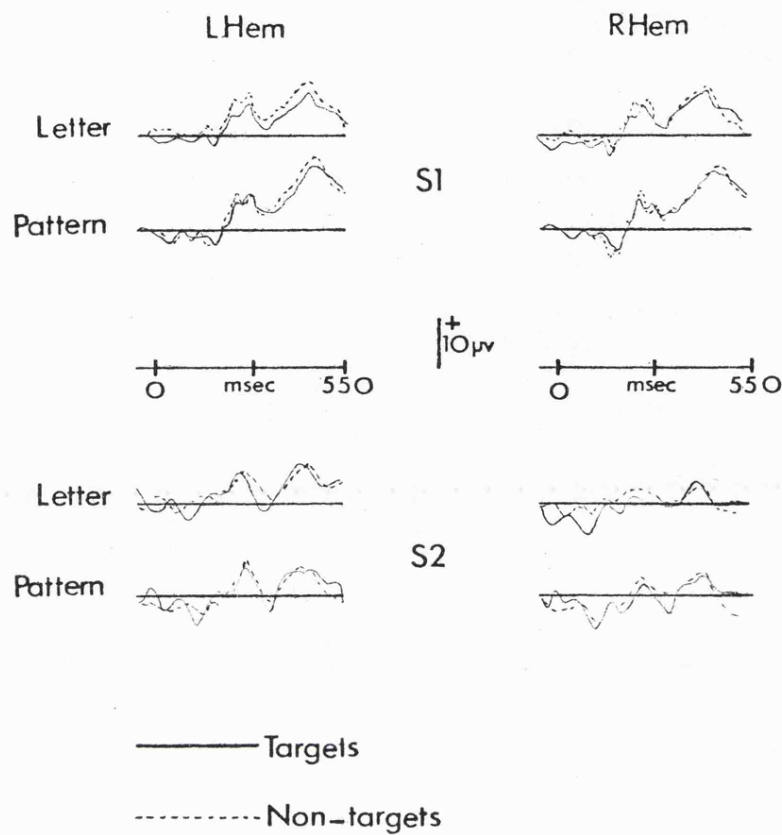


Figure 9(i). Two subjects' VERs recorded from the left and right hemispheres to letter and pattern targets and non-targets. (Experiment 8)

Table 9(i). Mean latencies (msec) and standard deviations of VER components from the left and right hemispheres elicited by pattern and letter target and non-target stimuli. (Experiment 8)

		Pattern stimuli				Letter stimuli			
		Targets		Non-targets		Targets		Non-targets	
Component		L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem
P <sub>1</sub>	Mean	153.12	144.25	146.50	141.17	157.30	134.80	148.60	133.45
	S.D.	24.25	23.21	28.30	27.96	14.69	11.01	16.87	15.13
N <sub>1</sub>	Mean	192.46	187.40	187.40	179.65	185.80	180.00	183.17	177.32
	S.D.	27.84	26.20	26.20	33.54	18.51	14.76	29.96	24.60
P <sub>3</sub>	Mean	414.66	401.93	401.93	390.66	392.26	368.70	379.06	367.39
	S.D.	40.17	37.56	37.56	35.44	53.62	47.94	46.26	39.85

Table 9(ii). Mean baseline to peak and peak to peak amplitudes ( $\mu V$ ) of VER components from the left and right hemispheres elicited by pattern and letter target and non-target stimuli. (Experiment 8)

		Pattern stimuli				Letter stimuli			
		Targets		Non-targets		Targets		Non-targets	
Component		L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem
P <sub>1</sub>	Mean	1.86	1.47	1.60	1.21	0.88	0.79	1.88	1.00
	S.D.	2.46	3.08	2.22	2.21	0.51	1.96	1.34	1.29
N <sub>1</sub>	Mean	-0.63	-3.05	-1.07	-3.68	-1.56	-3.25	-1.11	-3.80
	S.D.	1.38	1.98	1.94	2.21	1.52	2.48	2.49	3.21
P <sub>1</sub> -N <sub>1</sub>	Mean	2.50	4.53	2.93	4.90	2.44	4.04	3.00	4.80
	S.D.	2.05	4.30	1.59	3.04	1.42	3.25	1.39	3.54
P <sub>3</sub>	Mean	8.37	8.62	9.28	8.62	7.78	8.41	7.68	7.04
	S.D.	3.62	4.16	5.01	4.35	4.07	3.86	3.01	3.16



larger amplitude when recorded from the right hemisphere. Analysis of  $P_3$  amplitudes revealed an effect of stimuli ( $F_{1,8} = 6.15$ ,  $p < 0.05$ ), this component having a greater magnitude when elicited by the patterns.

Mean RTs, hits and false positive responses are shown in Table 9(iii). Mean RTs to the two types of stimulus were found to differ significantly ( $t_8 = 2.36$ ,  $p < 0.05$ ) indicating that subjects responded more quickly to the pattern stimuli. Neither the number of hits nor the number of false positives differed significantly. Subjects' accuracy was high, with a mean overall error rate of 1.75% to the letters and 3.98% to the spatial stimuli.

Correlation coefficients were calculated between subjects' mean RTs to the letter stimuli and the latency of  $P_3$  from each hemisphere. Neither coefficient was significant, this result also obtaining for the same analysis of the data relating to the spatial stimuli.

#### 9b(iv). Discussion:

The inter-hemispheric latency difference in  $P_1$  parallels that previously observed in Experiments 3-6 and is probably explicable in the same terms; i.e., it reflects a superiority on the part of the right hemisphere for the early stages of visual processing. The asymmetry observed in the amplitude of  $N_1$  may be explicable in terms of a right hemisphere superiority for the stimulus processing underlying the generation of this component. An alternative explanation however is that this asymmetry simply reflects the fact that any negativity closely following  $P_1$  and of the same latency in both hemispheres will ride on a greater amount of

Table 9(iii). Mean R.T. (msec) to target stimuli, hits and false positive responses to pattern and letter stimuli. (Experiment 8)

		Patterns	Letters
R.T.	Mean	509.67	545.28
	S.D.	51.22	56.45
Hits	Mean	38.11	39.56
	S.D.	1.90	0.73
False +ves	Mean	2.89	2.20
	S.D.	1.67	1.32

positivity when recorded from the left hemisphere (and hence appear smaller) because of the longer latency of  $P_1$  from this hemisphere.

No asymmetries were observed either in the latency or amplitude of the late positive component ( $P_3$ ) of subjects' VERs. This result is in keeping with other attempts to index asymmetrical hemisphere engagement with  $P_{300}$  and, along with these previous attempts, has implications for models of  $P_{300}$  generation. These implications, and the whole question of the relationship between  $P_{300}$  and hemisphere asymmetries of processing, are discussed in section 9d and in Chapter 10.

The dissociation observed between RT and  $P_3$  latency is of interest. While RTs to the pattern stimuli were faster than those to the letter stimuli the latencies of the  $P_3$ s elicited by the two types showed the reverse effect; those of the  $P_3$ s elicited by the pattern stimuli were longer. This dissociation suggests that even when response processes are closely coupled with stimulus evaluation or recognition (the high level of accuracy shown by subjects suggests that this was the case in the present study) the initiation of a response does not necessarily terminate the evaluating process, as implied by Kutas et al. (1977) and Courchesne et al. (1977). A possible explanation for the effect observed in this experiment is that the comparatively less familiar and more complex pattern stimuli initiated longer periods of stimulus processing on the part of the subject and that this was indexed by  $P_3$  latency, whilst RT indexed the amount of time required solely for task-relevant processing.

The finding that there was no difference in the amplitude

of  $P_3$  to the targets and non-targets of either type of stimulus is of great interest in view of the fact that the use of a relatively rare 'target' stimulus or class of stimulus deviating from more common background stimuli is regarded as a standard means of eliciting an enhanced  $P_{300}$  response (see, for example, Courchesne et al., 1977, 1978; Roth, Ford, & Kopell, 1978; Dunchan-Johnson & Donchin, 1977). This result suggests that the relative rarity of a particular class of stimulus is not sufficient to cause enhancement of  $P_{300}$  relative to another class of 'background' stimuli even though this might often be the result of such an experimental paradigm (see Courchesne et al., 1977, 1978). It may be that in this study, possibly because of the heterogeneous nature of the target and non-target stimuli, subjects did not form strong expectancies as to the nature of each successive stimulus and thus each elicited a relatively large  $P_3$ . This would be consistent with the suggestion of Donchin (1976) that when a subject holds a number of weak hypotheses about the environment the confirmation of any of them will give rise to a  $P_{300}$ . An alternative, if not unrelated explanation is that subjects regarded all of the stimuli as being of equal salience or task-relevance, irrespective of whether stimulus recognition demanded the emission or withholding of a response. The finding of Ritter and Vaughan (1969) that  $P_{300}$ s were elicited by both targets and non-targets when the discrimination between them was difficult is also of relevance, and suggests that a further factor giving rise to the observations in the present experiment may have been the degree of difficulty experienced by subjects in the discrimination of targets and non-targets.

It is also of interest to note that the amplitude of  $P_3$  was greater when it was elicited by the pattern stimuli. This result suggests that a determinant of  $P_{300}$  amplitude may be the nature of the stimulus and associated cognitive processing it initiates in the subject, as suggested also by Rohbraugh et al. (1974). It is possible that this amplitude difference may, in this instance, reflect the relative novelty of the pattern stimuli compared with the letters, the factor of novelty operating additively with that of task-relevance to produce an enhanced  $P_3$ . The finding of Courchesne, Hillyard and Galambos (1975) that novel stimuli elicit large  $P_{300}$ s supports this speculation, although it should be noted that no evidence exists at present to support the contention that the effects of stimulus novelty and task-relevance are additive.

As noted in section 8b the possibility that the observed variations in amplitude are the result of differential 'latency jitter' of individual trials must be borne in mind. This is a particular problem in  $P_{300}$  experiments due to the large variability which can occur in the latency of this component and, while there is no reason to suppose that such an effect should be differentially distributed among the different conditions of the present study this possibility cannot be ruled out.

The results of this experiment suggest that an important determinant of  $P_{300}$  is the nature of the cognitive activity, which may or may not be task-relevant, that the eliciting stimuli initiates in the subject. Furthermore, in keeping with the results of other studies in this paradigm (section 2d) the present findings provide no evidence that asymmetrical

cognitive processing may be indexed by either the latency or amplitude of  $P_{300}$ .

### 9c Experiment 9

#### 9c(i). Introduction:

The purpose of this experiment was to test the hypothesis that the latency and amplitude effects observed in Experiment 8 with respect to the  $P_3$  component observed in that experiment were the result principally of factors unrelated to the tasks associated with the eliciting stimuli. In the present experiment the stimuli and experimental situation were identical to those utilised in Experiment 8. In this case, however, the tasks associated with each stimulus type were identical. Thus, it was hypothesized, any differences in the  $P_3$  elicited by the two stimulus types would be attributable to processing differences contingent upon task-irrelevant factors.

#### 9c(ii). Method:

Eight subjects, five female and three male, were employed. All were right-handed.

The experimental and recording procedures were almost identical to those employed in Experiment 8. The only differences between the present experiment and the former one were that the blocks of letter stimuli were formed such that they each contained, in a random order, 20 letters which were symmetrical about the vertical axis (4 each of a pool of 5) and 40 asymmetrical letters (4 each of a pool of 10) and that the experimental instructions were identical with respect to each stimulus type, i.e., to respond as fast and as accurately

as possible to stimuli symmetrical about the vertical midline.

9c(iii). Results:

No components prior to  $P_3$  were consistently recognisable across subjects and conditions and thus only  $P_3$  was subjected to analysis. Representative waveforms are shown in Figure 9(ii) and mean latencies and amplitudes (measured in the same manner as in Experiment 8) are shown in Tables 9(iv) and 9(v).

Inspection of the means of the latencies in Table 9(iv) suggests that an ANOVA performed on these data might at the very least indicate a significant stimulus x target/non-target interaction, this reflecting the apparently large difference in latency between letter targets and non-targets. The effects indicated by the ANOVA as being significant were for hemispheres ( $F_{1,3} = 9.58$ ,  $p < 0.025$ ) and the interaction between stimulus type and hemisphere ( $F_{1,3} = 6.25$ ,  $p < 0.05$ ). These effects resulted from the fact that the left hemisphere produced  $P_3$  with a longer latency than did the right only when the patterns were the eliciting stimuli.

Analysis of the amplitudes of  $P_3$  revealed the existence of a significant stimulus x target/non-target x hemisphere interaction ( $F_{1,3} = 7.08$ ,  $p < 0.04$ ). Inspection of the means (Table 9(v)) shows that this was due to the fact that  $P_3$  amplitude was greater to the non-target stimuli compared to targets, this effect being greater in the left hemisphere when  $P_3$  was elicited by letters and in the right hemisphere when it was elicited by patterns. This interaction is illustrated graphically in Figure 9(iii).

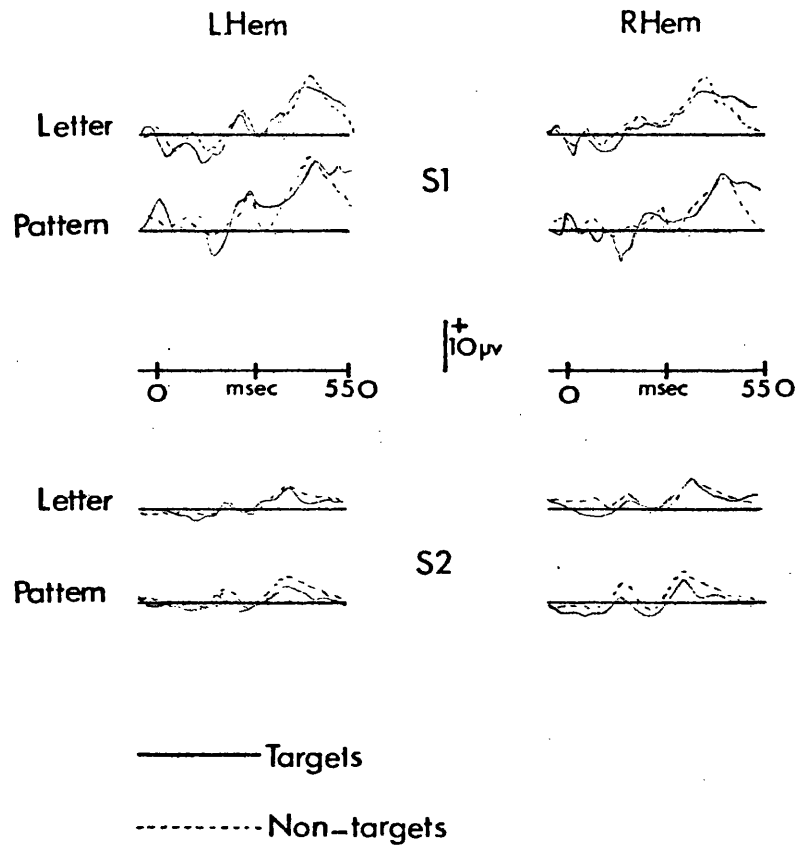


Figure 9(ii). Two subjects' VERs recorded from the left and right hemispheres to letter and pattern targets and non-targets. (Experiment 9)



Table 9(iv). Mean latencies (msec) of the P<sub>3</sub> component from the left and right hemispheres to target and non-target pattern and letter stimuli. (Experiment 9)

	Pattern stimuli				Letter stimuli			
	Targets		Non-targets		Targets		Non-targets	
	L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem
Mean	414.25	404.77	404.80	403.06	408.00	407.00	385.61	385.74
S.D.	45.08	41.66	42.43	43.22	34.47	32.77	34.39	34.49

Table 9(v). Mean baseline to peak amplitudes ( $\mu$ V) of the  $P_3$  component from the left and right hemispheres to target and non-target pattern and letter stimuli. (Experiment 9)

	Pattern stimuli				Letter stimuli			
	Targets		Non-targets		Targets		Non-targets	
	L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem	L. Hem	R. Hem
Mean	7.60	6.11	8.63	8.02	6.67	5.63	8.30	6.83
S.D.	3.24	3.23	2.39	2.07	2.63	2.81	2.76	3.35

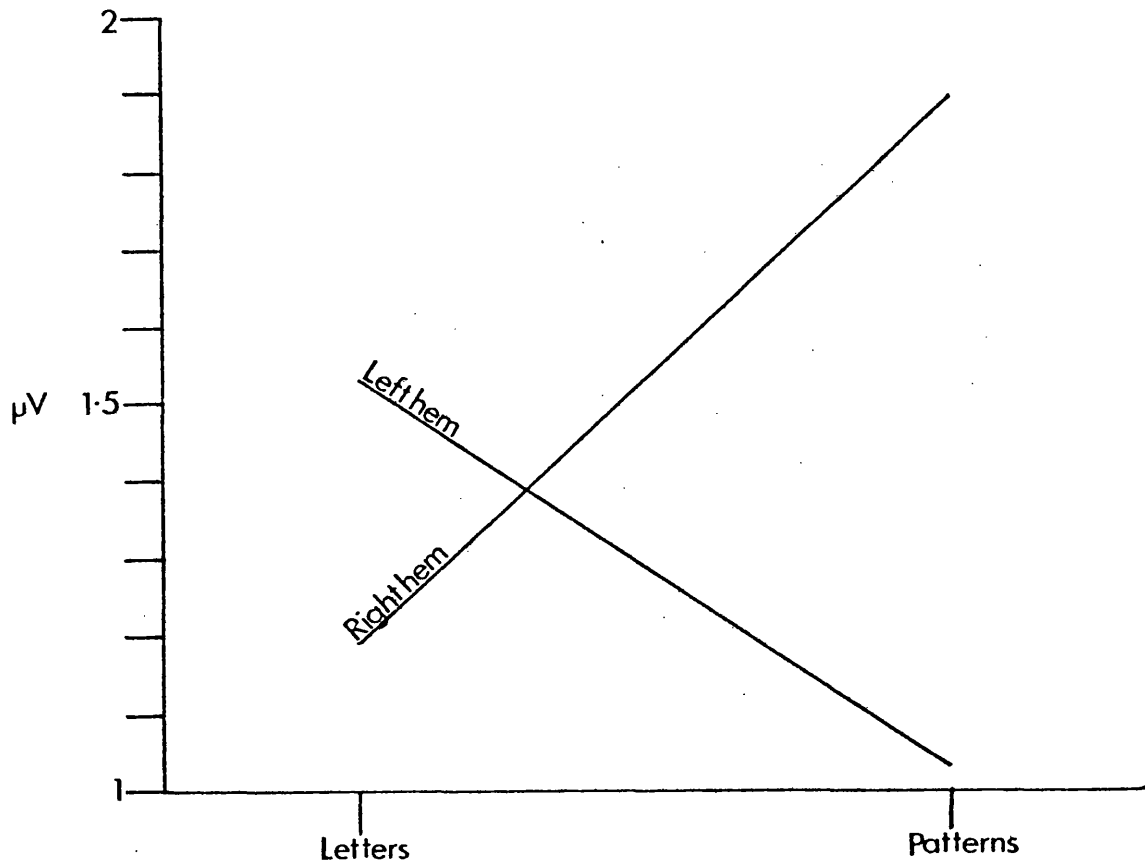


Figure 9(iii). The difference (non-targets - targets) in the amplitude of  $P_3$  from each hemisphere elicited by target and non-target letters and patterns in Experiment 9.

Table 9(vi) gives mean RTs, hits and false positive responses obtained to the letter and pattern stimuli. RTs to targets were found to differ significantly ( $t = 3.48$ ,  $p < 0.01$ ) as did the number of hits ( $t = 2.40$ ,  $p < 0.05$ ). The number of false positive responses to the two stimulus types did not differ significantly.

9c(iv). Discussion:

Unfortunately, this experiment has little utility in the testing of the hypothesis formulated in section 9c(i) as subjects' performance in this case was poor with respect to the pattern stimuli. Compared with the performance with regard to the letters, RTs were significantly longer and hits significantly less to the patterns whilst the number of responses to the pattern non-targets was greater to a nonsignificant extent. These findings strongly suggest that the subjects found the task considerably more difficult when it was associated with the patterns rather than the letters. Why there should be such a large difference between Experiments 8 and 9 in performance level on the same task utilising the same stimuli (cf. Tables 9(iii) and 9(vi), columns 2, 4 and 6) is inexplicable other than in terms of the sampling error between the two groups of subjects giving rise to populations with different levels of performance. Whatever the reason, the difference in performance levels shown by the two subject populations with respect to this task means that comparison of the patterns of  $P_3$  amplitude and latency obtained in this experiment and in Experiment 8 is of dubious value.

The results are, however, of interest in their own right. They confirm the finding of Experiment 8 that  $P_{300}$  amplitude

Table 9(vi). Mean R.T. (msec) to target stimuli, hits and false positive responses to pattern and letter stimuli. (Experiment 9)

		Patterns	Letters
R.T.	Mean	613.12	538.50
	S.D.	84.03	40.32
Hits	Mean	34.75	39.37
	S.D.	5.29	0.70
False +ves	Mean	5.12	1.87
	S.D.	5.18	2.52

to 'target' stimuli is not necessarily enhanced relative to more common background stimuli. Moreover, in this experiment, task-dependent asymmetries both of amplitude and latency were observed. It was found that the difference in the amplitude of  $P_3$  to targets and non-targets was greater in the left hemisphere with letter stimuli and the right hemisphere with the pattern stimuli. As the tasks associated with each stimulus were the same this finding suggests, as did those of Experiments 1-6, that verbal and non-verbal stimuli are processed differently irrespective of the similarity of the tasks with which they are associated. Why  $P_3$  should be smaller to the targets rather than the non-targets is puzzling; it would seem unlikely that subjects regarded the stimuli to which a response was required as being less task-relevant than those to which no response was needed. A possible explanation of this effect is that the  $P_3$ s to the target stimuli were the subject of more inter-trial variability (latency jitter) than were those to the non-targets. The hemisphere asymmetries noted above would then be explained as reflecting the fact that the hemisphere most concerned with the stimulus processing (whether or not this processing was task-relevant) exhibited this differential latency jitter to a greater degree than its fellow. The reasons for this effect, if indeed it occurred, are not immediately obvious.

As in Experiment 8, analysis of the latency data failed to show the relationship between  $P_3$  latency and RT which might have been expected from the hypothesis of Kutas et al. (1977). Although RTs to the two types of stimuli differed significantly,  $P_3$  latency did not. However, the relatively

poor level of performance to the pattern stimuli means that this result may have little significance other than reflecting the fact that subjects' responses to these stimuli were not closely coupled to the processes of stimulus evaluation. As with the amplitudes,  $P_3$  latencies in this study exhibited a task-specific asymmetry, in that the latency of  $P_3$  was longer in the left hemisphere when elicited by the patterns but not by the letters. A similar effect was found with respect to the  $P_2$  component observed in Experiment 7 in VEPs elicited by the same types of stimuli as used in the present experiment. On that occasion, the interaction was interpreted as reflecting the fact that the right hemisphere, which was pre-eminent for the earlier visual processing of both stimulus types, maintained this processing advantage with the pattern stimuli but not the verbal stimuli, the task-relevant processing of which necessitated a left-hemisphere contribution. It is doubtful whether this explanation is valid with respect to the present experiment as the task associated with both stimulus types was the same. However, it is clearly the case that some process was operative which caused a relative delay in the  $P_3$  elicited from the left hemisphere by the patterns. Given the hypothesis that  $P_{300}$  latency indexes the amount of time spent evaluating a stimulus (see sections 9b(i) and 9b(iv)) it is tempting to speculate that this delay reflected the fact that the left hemisphere took longer to process the patterns, perhaps because of its relative lack of specialisation for the associated task. The lack of such an asymmetry in the  $P_3$ s elicited by the letters might reflect the lack of difficulty experienced by subjects with the task-relevant processing of these stimuli or that the verbal nature of the stimuli in

some way speeded the processing of the stimuli in the left hemisphere.

The results of this experiment indicate that, for whatever reasons,  $P_3$  can be shown to demonstrate task and hemisphere effects which are suggestive of asymmetries of processing of the eliciting stimuli. The issue of why these effects should be observed in an experiment in which the tasks associated with each type of stimulus were identical, and not in the one in which the tasks might have been considered to necessitate differential asymmetries of processing, is discussed in the next section.

#### 9d Discussion of Experiments 8 and 9

Comparison of these two experiments leads to the problem of why stimulus-dependent asymmetries should be observed in  $P_3$  latency and amplitude in Experiment 9 but not in Experiment 8. One possible reason is that the subjects employed in Experiment 9 clearly found the experimental task associated with the pattern stimuli more difficult than did those in Experiment 8, and that a relatively high level of difficulty may be required fully to engage the hemispheres asymmetrically (cf., Bryden & Allard, 1976). This explanation has particular relevance to the latency asymmetry observed in Experiment 9, as this was found only with respect to the pattern stimuli. The absence of such an asymmetry in the  $P_3$ s elicited by the letters in Experiment 9, and by both sets of stimuli in Experiment 8, may indicate that as subjects did not find the tasks associated with these stimuli difficult the level of processing 'effort' required for asymmetries of processing to emerge was not



reached.

The above explanation seems unlikely to be able to account for the asymmetries observed in  $P_3$  amplitude in Experiment 9 as in the case of this parameter asymmetries were observed in the  $P_3$ s elicited by both sets of stimuli. The nature of these asymmetries suggested that they were the result of the left hemisphere reacting in a more discriminating fashion to the letter targets and non-targets and the right hemisphere doing so to the pattern targets and non-targets. As noted in section 9c(iv), a possible reason for this result is that of differential latency jitter. The lack of such effects in Experiment 8, in which different tasks were associated with the stimuli, may reflect the fact that in that experiment the stimuli were subjected to processing the mediation of which was more bilateral than that in Experiment 9. It is of interest to note in this context that in Experiments 1-6 VER asymmetries suggestive of left hemisphere mediated verbal processing were observed in the experiments (3 and 6) in which the eliciting letter stimuli were associated with a non-verbal task. It is possible that, within the general experimental paradigm of these experiments it is only in circumstances in which visuospatial task requirements are associated with verbal stimuli that the hemispheres engage in differential processing of the stimuli, although this explanation does not account for the finding that in Experiment 9 the right hemisphere demonstrated the greater degree of  $P_3$  amplitude change to the target and non-target patterns, a finding highly suggestive that these stimuli engaged the right hemisphere to a greater degree than the left in this

experiment.

Whatever their cause, the stimulus-specific nature of the  $P_3$  amplitude changes observed in Experiment 9 are highly suggestive of stimulus-specific processing asymmetries, as is the asymmetry observed in  $P_3$  latency in the same experiment. These results would appear to demonstrate that asymmetries in cerebral processing may manifest themselves in the  $P_{300}$  component of the VER and, when compared with those of Experiment 8, lend further support to the conclusion reached in section 8d that such asymmetries, at least as indexed by VERs, may depend critically on the interaction between task and stimuli.

Finally, it should be noted that the results of these experiments add further complications to the question of the nature of the precise determinants of  $P_{300}$ . The hypothesis that this component is a reflection of subjects' levels of subjective probability of the occurrence of the eliciting stimuli (i.e.,  $P_{300}$  amplitude is inversely related to how 'expected' the stimuli are) accounts for many of the findings relating to  $P_{300}$  (Donchin, 1976; for an explicit formulation of the 'expectancy model', see Duncan-Johnson & Donchin, 1977). There are, however, findings which cannot be accounted for in such terms and it may be that 'expectancy' explanations owe their apparent validity more to the narrowness of the paradigm in which  $P_{300}$  has been investigated than anything else. The finding of Ritter and Vaughan (1969) that when, in a vigilance task, stimulus discrimination was made difficult both target and non-target stimuli elicited large  $P_{300}$ s, an effect not seen when easy discriminations

were employed, cannot be accounted for in expectancy terms. Similarly, in Experiment 8  $P_{300}$  was observed to be the same size whether elicited by targets ( $p = 0.33$ ) or non-targets and in Experiment 9 actually to be smaller overall to targets. Furthermore, in Experiment 8  $P_{300}$ s elicited by one set of stimuli were found to have a longer latency and larger amplitude than those elicited by another set (in the same subjects) although the relative probabilities of targets and non-targets were identical in each set. The above findings suggest that an important determinant of  $P_{300}$  is the qualitative nature of the information-processing associated with the eliciting stimuli, this being reflected in both the size and latency of this component and its topographical distribution. How these factors are related to and combine with those relating to the dimension of expectancy is a major problem.

## CHAPTER 10

### Experiment 10

#### 10a Introduction

As noted previously (sections 9b(ii) and 9d) the origins and precise significance of the  $P_{300}$  component of ERs are unclear. The wide range of conditions giving rise to this component, its lack of modality-specificity and its long latency (indicative of its being a correlate of post-recognition processes) have led a number of authors to propose that  $P_{300}$  is a 'non-specific' component which reflects a momentary change of state (e.g., arousal) contingent on the recognition of a behaviourally significant stimulus (see, for example, Näätänen, 1975; Karlin & Martz, 1973; and section 8b) and possibly be a component of the orienting response (Ritter, Vaughan & Costa, 1968). Direct evidence that  $P_{300}$  is related to changes in general arousal level has been provided by Friedman, Haberen, Sutton and Fleiss (1973) who reported a significant correlation between  $P_{300}$  amplitude and pupil dilation in an experiment in which subjects' degree of advance knowledge of the eliciting stimuli was varied.

On the whole, investigators have been content to ignore

the comments of reviewers such as Näätänen (1975) and have continued to report psychological manipulations which affect the parameters of P<sub>300</sub> without any discussion of what this component might actually represent in terms of events within the brain. The sensitivity of this component to complex variables such as expectancy and task-relevance would seem to leave no doubt that the processes giving rise to it are heavily influenced by the results of the stimulus processing occurring at the level of the cerebral cortex. This is not to say however that P<sub>300</sub> itself is a specific cortical response; it is possible that this component is generated by, say, a non-specific arousal system the activation of which may give rise to a variety of indices of arousal of which P<sub>300</sub> is only one (cf., Friedman et al., 1973). If this arousal system is sensitive to the results of stimulus processing of a complex nature then the above explanation may be a sufficient explanation of many, if not all, of the findings relating to P<sub>300</sub>.

The hypothesis that P<sub>300</sub> is a result of non-specific changes of state has been challenged by Courchesne, Hillyard and Courchesne (1977) and Courchesne, Courchesne and Hillyard (1978) with particular reference to the suggestion that P<sub>300</sub> may be a component of the orienting reflex. In the former study (Courchesne et al., 1977) it was reported that target stimuli interspersed among a heterogeneous set of more common background stimuli elicited P<sub>300</sub>s which were no different in size or shape from those elicited by the same targets interspersed in a homogeneous background sequence. This, it was argued, indicated that P<sub>300</sub> amplitude was not consequent upon the extent or intensity of the orienting

reflex as this would have been stronger to the more 'deviant' targets, those interspersed in the homogeneous sequence. This interpretation is open to question on the grounds that no attempt was made to determine whether the orienting reflexes elicited by the targets were in fact larger in the 'homogeneous' condition and thus supporting the authors' otherwise unsubstantiated assumption. In the second study (Courchesne et al., 1978) the authors reported that in a situation in which both task-relevant and irrelevant stimuli were interspersed in a sequence of background stimuli the P<sub>300</sub>s to the irrelevant stimuli were found to diminish in amplitude with repeated presentation whilst those elicited by the relevant stimuli did not. This effect was taken to indicate that the P<sub>300</sub>s to these two sets of stimuli were not the result of orientation reflexes as, had this been the case, a similar amplitude decrement would have been observed in the P<sub>300</sub>s both to the relevant and irrelevant stimuli. This interpretation is disputable as it assumes that the determining factor in the elicitation of an orienting response is the deviation of a stimulus from the background, and thus that classes of stimuli which deviate to the same extent should show similar patterns of habituation. Another important determination of the orienting reflex is stimulus significance; those which are highly significant are less likely to result in habituation or will take longer to habituate (Velden, 1978; Kahneman, 1973). This being the case Courchesne et al. (1978) may have demonstrated only that their significant (target) stimuli did not result in habituation whereas their insignificant (non-target) stimuli

did. In any case, whether or not Courchesne et al. (1977, 1978) are correct with respect to their assertions regarding the relationship between the orienting reflex and  $P_{300}$  their results do not preclude the possibility that phasic changes in arousal other than those associated with the orienting reflex were important determinants of the  $P_{300}$ s observed in their experiments.

Evidence against a 'non-specific' explanation of  $P_{300}$  generation is, considering the large number of studies performed with respect to this component, difficult to come by. A powerful means of demonstrating the importance of 'cortical-specific' factors would be through the observation that the topographical distribution of  $P_{300}$  was dependent on the type of stimuli and associated task used to elicit this component. Findings of this type would indicate that, to some extent at least, variations in the locus of the cortical activity mediating a task can influence the  $P_{300}$ s occurring as a result of that processing. This would mitigate against the hypothesis that  $P_{300}$  was 'merely' an index of a general change in organismic state. In this context it is relevant to note that Courchesne (1977) and Courchesne, Hillyard and Galambos (1975) have reported that the normally posteriorly-distributed  $P_{300}$  is frontally-distributed when elicited by stimuli which are both novel and unrecognisable. This was interpreted as reflecting differences in the modes of processing utilised by subjects when confronted with such stimuli compared with stimuli which are easily recognisable. The results of Experiment 9 (see Chapter 9, section 9c), in which stimulus-specific asymmetries were observed both in the latencies and amplitudes

of P<sub>300</sub> provide evidence suggesting that factors associated with cortical asymmetries of processing may influence the generation of P<sub>300</sub>. The results of this experiment further suggest that P<sub>300</sub> might either be generated independently, or subjected to different modifying influences, in each cerebral hemisphere.

Evidence against the notion that P<sub>300</sub> may be independently generated or modified in each cerebral hemisphere comes from a study utilising somatosensory ERs (Desmedt & Robertson, 1977). These investigators used a somatosensory detection task involving the stimulation of the fingers of one or other hand. They reported that whilst the middle-latency negative component (around 150 msec) was highly lateralised (larger over the parietal region contralateral to the stimulated hand) the P<sub>300</sub> component elicited by stimulation of the 'target' finger was symmetrically distributed. This was interpreted as demonstrating that P<sub>300</sub> reflects some non-specific 'channel clearing' operation and not the results of stimulus-specific cortical processing. The authors' conclusion is puzzling in view of the fact that in another study, reported in the same paper, they report that when subjects performed in an 'active touch' paradigm (palpated a perspex edge in order to locate an irregularity) the ERs thus elicited had larger middle-latency components over the hemisphere contralateral to the exploring hand but a larger P<sub>300</sub> over the right hemisphere irrespective of the hand stimulated (Desmedt & Robertson, 1975, figure 5). This result was interpreted as reflecting the dominance of the right hemisphere in this high-level tactual task; no attempt was made to integrate this result with those of their



other experiment which, as noted previously, was interpreted as indicating that  $P_{300}$  did not reflect asymmetrical cognitive processing. Also utilising somatosensory ERs, Barrett, Halliday and Halliday (1978) have reported that stimulation of the right hand (in a somatosensory detection task) of right-handed subjects resulted in larger middle-latency and  $P_{300}$  components from the contralateral (left) hemisphere. This asymmetry was absent from left-handed subjects when they received stimulation to the right hand and reversed in this group when they were stimulated on their left hand. However, as the measurements were made peak to peak, and  $P_{300}$  amplitude was measured from the middle-latency negative component occurring at around 150 msec, it is not possible to discern from this report the extent to which the apparent asymmetry in  $P_{300}$  reflected the asymmetrical amplitude of the negative component.

It is clear that at present a considerable amount of uncertainty exists as to the effects of lateralised sensory input on the  $P_{300}$  component of the resulting ERs. The experiment reported below utilised a paradigm in which rare, task-relevant stimuli were unilaterally exposed to the visual fields so as to lateralise stimulus input to one or other hemisphere under conditions likely to result in the elicitation of large  $P_{300}$  components. An attempt was made to minimise the possibility of large amounts of latency jitter and the effects of the relative specialisations of the two hemispheres by the use of simple and easily recognisable stimuli. The aim was to determine the extent to which the  $P_{300}$  component of the VER was sensitive to the route of stimulus input.

## 10b Method

Ten right-handed subjects, five of each sex, were employed.

The stimuli consisted of 3 horizontally mounted light emitting diodes (LEDs; rise and fall times  $<10$  nsec) arranged such that at the 500 mm viewing distance their diameters subtended a visual angle of  $48'$  and their centre points were separated by visual angles of  $4^\circ$ . The LEDs were mounted on a matt black surface to minimise reflection. The middle LED was constantly dimly illuminated at an intensity of  $0.05 \text{ cd/m}^2$ . When fully illuminated the intensity of this and the two other LEDs was approximately  $9 \text{ cd/m}^2$ ; all three emitted light at the same intensity. The LEDs were controlled using BRD logic modules activated by a sequence of logic pulses generated by a Lab/8e computer and pre-recorded on three channels of a Racal FM tape-recorder. This arrangement allowed the LEDs to be illuminated in a random and irregular fashion as described below.

The stimulus sequence consisted of 250 flashes of the LEDs, each with a duration of 40 msec. The flashes were separated by an inter-stimulus interval which varied randomly between 2 and 5 sec (rectangular distribution). Two hundred of the flashes occurred at the centre LED and 25 at each of the lateral ones. The location of the flashes in the sequence was determined randomly using a Bernouilli sequence. Thus the probability of any flash occurring at either lateral LED was 0.1 and, correspondingly, the probability of a central flash was 0.8.

Subjects were seated in a dimly-lit room facing the

LEDs with their heads resting on a chin rest. They were required to fixate the central dimly-lit LED and rest the index fingers of each hand on two symmetrically placed microswitches (105 mm apart, 192 mm in front of the chin rest, contact distance 4 mm). They were instructed to ignore the flashes of the central LED but to respond when either of the lateral ones flashed, depressing the right switch when the LED in the right visual field flashed, and the left switch to flashes in the left visual field. Subjects were told to respond quickly but accurately. They were requested to minimise their gross body movements and eye blinks. To minimise the effects of fatigue, the stimulus sequence was divided into two halves of 125 presentations and subjects were allowed a short rest in between these; each half of the sequence lasted for approximately 8 min.

EEGs were recorded with silver/silver chloride electrodes placed at  $P_3$  and  $P_4$  according to the 10-20 system and referred to linked mastoids (Beckman miniature electrodes). Inter-electrode impedance was kept below  $5\Omega$ . The EEG signals were amplified with Neurolog NL103 pre-amplifiers and NL105 AC amplifiers and filtered with Kemo active filters. The characteristics of the recording system were: gain, 20 K per channel, low pass 3 dB down at 30 Hz and time-constant 1.56 sec. The EEG was averaged on-line using DEC Advanced Averager system software. VERS from the left and right hemispheres were separately formed to LED flashes occurring in the left and right visual fields.<sup>1</sup>

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<sup>1</sup> Due to a recurring technical fault on the Lab/8e used to run the averaging program it was not possible to form VERS to the central LED flashes, as originally intended.

The VERs were formed from 600 msec epochs of EEG digitised at 1000 Hz and starting 150 msec prior to stimulus onset.

EOG was recorded from electrodes (Beckman miniature) placed above and on the outer canthus of the left eye. They were amplified with a Devices high-gain AC amplifier and a Kemo active filter giving a system with a gain of 4 K, low-pass 3 dB down at 30 Hz and time-constant 10 sec. EOG was monitored continuously on a slow-decay oscilloscope. In the event of a subject failing to maintain fixation or blinking excessively the experimental run was halted and restarted from the beginning after informing the subject of what had happened. This procedure was found to be necessary with two subjects.

#### 10c Results

Three components were consistently recognisable in subjects' VERs, a positive component with a latency around 60 msec ( $P_1$ ), a negative component around 85 msec ( $N_1$ ) and a large positive component peaking around 290 msec ( $P_3$ ). In two subjects' VERs  $P_1$  could not be identified and their data were excluded from the analysis of this component. Four subjects' VERs contained a  $P_2$  component peaking around 200 msec; as this was absent in the majority of subjects it was not subjected to analysis. Latencies were measured from stimulus onset and peak amplitudes were measured with respect to the averaged 150 msec baseline. Mean latencies and amplitudes are shown in Tables 10(i) and 10(ii) and representative waveforms are shown in Figure 10(i).

Separate 2-way ANOVAs (factors: visual field and hemisphere) were performed on the data relating to each

Table 10(i). Mean latencies (msec) of VER components from the left and right hemispheres to stimuli in the left and right visual fields.  
(Experiment 10)

		Left vis. field		Right vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
P <sub>1</sub>	Mean	60.56	60.20	48.50	54.08
	S.D.	4.44	6.70	13.14	12.24
N <sub>1</sub>	Mean	88.88	92.24	81.14	90.08
	S.D.	16.98	15.66	14.85	18.13
P <sub>3</sub>	Mean	291.14	290.96	280.88	282.26
	S.D.	37.87	38.58	44.08	47.40

Table 10(ii). Mean baseline to peak and peak to peak amplitudes ( $\mu V$ ) of VER components from the left and right hemispheres to stimuli in the left and right visual fields. (Experiment 10)

		Left vis. field		Right vis. field	
Component		L.Hem.	R.Hem.	L.Hem.	R.Hem.
$P_1$	Mean	0.06	0.82	0.74	0.53
	S.D.	2.50	2.52	2.84	3.14
$N_1$	Mean	-3.20	-2.87	-5.13	-2.97
	S.D.	2.80	3.17	2.56	2.54
$P_1-N_1$	Mean	4.37	4.51	5.05	4.49
	S.D.	1.08	1.87	1.34	2.84
$P_3$	Mean	8.11	8.56	8.64	7.75
	S.D.	5.22	6.38	4.52	4.79

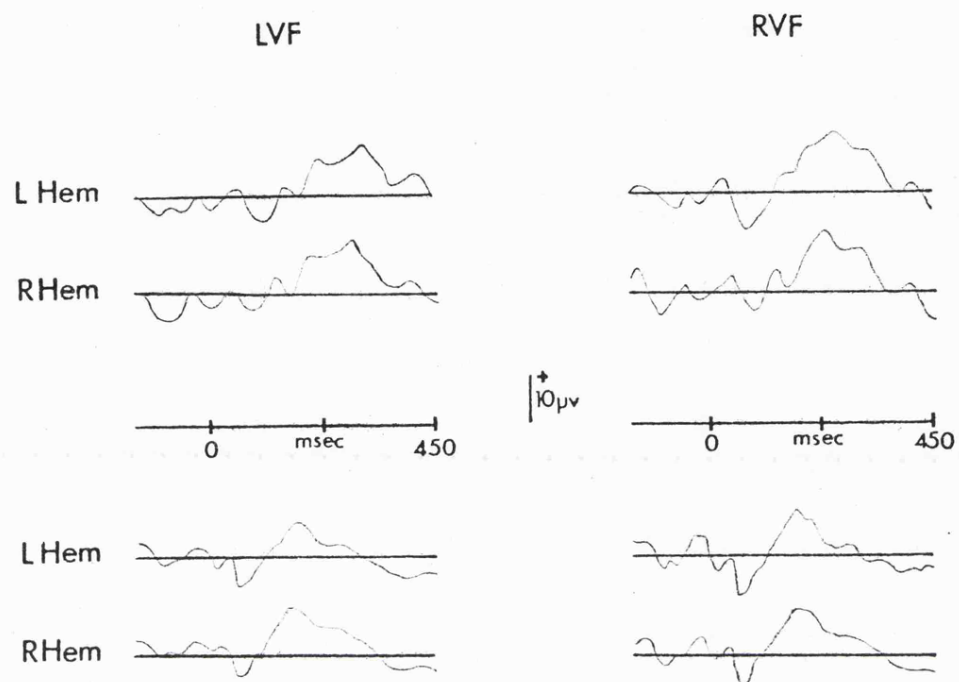


Figure 10(i). Two subjects' VERs from left and right hemispheres elicited by stimulation of the left and right visual fields. (Experiment 10)

component. Analysis of  $P_1$  latencies revealed a significant effect of visual field ( $F_{1,7} = 8.72$ ,  $p < 0.025$ ) in the absence of any other significant effects. This was caused by the latencies of this component being shorter in both hemispheres when elicited by stimulation in the right visual field. Analysis of  $N_1$  latency gave rise to a marginally significant effect of hemispheres ( $F_{1,9} = 5.10$ ,  $p \approx 0.05$ ) and a significant hemisphere x visual field interaction ( $F_{1,9} = 7.55$ ,  $p < 0.025$ ). This was due to  $N_1$  latency being shorter when recorded from the left hemisphere, the difference being greater when the stimuli were presented in the right visual field. No significant effects were observed with respect to the latencies of  $P_3$ .

Analysis of the amplitudes of  $P_1$  and  $P_1-N_1$  revealed no significant effects. That of the amplitude of  $N_1$  gave rise to a significant effect of visual field ( $F_{1,9} = 7.55$ ,  $p < 0.025$ ), due to this component being larger in each hemisphere when stimuli were presented in the right visual field. Analysis of  $P_3$  amplitude revealed a significant hemisphere x visual field interaction ( $F_{1,9} = 5.67$ ,  $p < 0.05$ ) caused by the amplitude of  $P_3$  being greater in the right hemisphere when stimuli were presented in the left visual field and greater in the left hemisphere to right visual field stimulation.

Subjects' performance was monitored by recording the number of responses made with each hand during the stimulus sequence. No subject made less than 23 responses with either hand. Subjects reported finding the task very easy.



## 10d Discussion

All three of the VER components measured in this experiment were found to vary with visual field of stimulus presentation. On the basis of the results of Experiments 1-3 and the study of Andreassi et al. (1975) it might have been expected that the latency of  $P_1$  would have shown a cross-over visual field x hemisphere interaction reflecting the anatomical arrangements of the visual system. However, no hemisphere asymmetries were observed in the latency of this component which was found to have a shorter latency when elicited by stimuli in the RVF. A hemisphere x visual field interaction was observed in the latencies of  $N_1$  such that while the latency of this component was shorter in the left hemisphere this interhemispheric difference was greater in VERs elicited by RVF stimulation. These results suggest that stimuli directed to the left hemisphere were processed more rapidly than those directed to the right. Furthermore, the pattern of latencies of  $N_1$  suggests that it was the left hemisphere which may have been pre-eminent in the processing of the stimuli, particularly when directly stimulated.

The finding that the amplitude of  $N_1$  was larger in the VERs elicited by RVF stimulation, but that no hemisphere asymmetry obtained, suggests that these stimuli (those in the RVF) were not only processed more rapidly than those in the LVF but were subjected to a greater degree of processing (or, perhaps, caused a greater reactive change of state; see section 8b and Näätänen, 1975). It is possible that this amplitude asymmetry to stimuli in the two visual fields mainly reflects differential positivity in this region of the

VER because of the asymmetry in the latencies of  $P_1$  (which were longer in the LVF; cf., section 9b(iv)). This is unlikely, at least with respect to the amplitude asymmetry observed in the left hemisphere, however, as the latency asymmetry between the visual fields in  $P_1$  was paralleled in  $N_1$  in the VERs from this hemisphere. It is also unlikely to be the case that the larger  $N_1$  (and the latency effects) reflect biases in peripheral orientation such that subjects tended to fixate in the RVF and bring stimuli in that field more into central vision. Apart from the fact that such a tendency was not observed in subjects' EOG records were this to be the case then it might have been expected that hemisphere asymmetries would have been observed in the VERs to stimuli in the LVF as these stimuli would have fallen well into that visual field.

With regard to the asymmetry in the amplitude of  $N_1$  it is of interest to note that Eason et al. (1969) and Van Voorhis and Hillyard (1977) have reported that the first negative components of their subjects' VERs were enhanced when elicited by stimuli which were being selectively attended to. In both experiments it was reported that stimuli presented in one or other lateral visual field elicited larger  $N_1$ s when they were the focus of attention than when they were not. It is possible, therefore, that in the present study the  $N_1$  asymmetry between the visual fields (and possibly the other visual field effects) reflects the fact that subjects maintained an attentional bias towards the RVF, although for what reason is unclear.<sup>1</sup> A highly speculative

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<sup>1</sup> It should be noted that no such bias was reflected in the number of responses made to the stimuli in each visual field as determined by the number of left and right hand responses. Had an RT task been used it is possible that an asymmetry of performance reflecting this bias might have been observed.

and post hoc explanation for this effect could be that the relative ease of the task and infrequency of the target stimuli resulted in subjects engaging in covert activity (e.g., verbalisations such as counting the stimuli) which activated the left hemisphere and resulted in a biasing of attention towards the RVF. This would be predicted by the model of Kinsbourne (1970) who (Kinsbourne, 1973) has presented evidence that subvocalisation does lead to such biases in attention across the visual fields (see also section 8b). Other than for the possible reason just noted the asymmetries between the visual fields observed in  $P_1$  and  $N_1$  would appear at present to be inexplicable.

Notwithstanding the nature of the asymmetries observed in the earlier components the amplitude of  $P_3$  was observed to be larger in the hemisphere contralateral to the stimulated visual field, albeit by relatively small amounts (RVF: L. Hem. exceeded R. Hem. by an average of  $0.89\mu V$ ; LVF: R. Hem. exceeded L. Hem. by  $0.45\mu V$ ). No asymmetries were observed in the latencies of this component. Whilst it is tempting to interpret the amplitude asymmetry as evidence in favour of the suggestion that  $P_{300}$  can be modulated by cortical asymmetries of processing it is necessary to examine other possible causes of this effect.

One possible reason for the  $P_3$  asymmetry in amplitude stems from the fact that subjects' responses to the stimuli were asymmetrical in that spatially compatible left or right hand responses were made to stimuli in the corresponding visual fields. The purpose of this response requirement was to minimise the amount of inter-hemispheric interaction which might occur (with the possible result of obscuring potential

asymmetries in  $P_3$ ) by establishing a situation in which there could be little doubt that each hemisphere was capable of detecting the stimuli directed to it and organising and initiating the appropriate response. Thus the possibility exists that the VERS to stimuli in each visual field were contaminated by asymmetrical response-related (motor) potentials (McAdam, 1974; Regan, 1972, p.150; Vaughan, Costa, & Ritter, 1968) preceding subjects' responses to the stimuli. Although the possibility of asymmetrical contamination of ERs has not been investigated the contribution of motor potentials to the size of  $P_{300}$ S recorded from the midline has been studied by Karlin, Martz, Brauth and Mordkoff (1971). Eliciting  $P_{300}$ S with auditory stimuli Karlin et al. (1971) observed that the  $P_{300}$ S elicited by stimuli which required a response were in fact smaller than those to which no response was required. This effect was ascribed not to the effect of motor potentials in the ERs elicited by stimuli requiring a response, however, but to the psychological factors associated with response inhibition. The authors reported that they could find no evidence of any contamination of the ERs, including the  $P_{300}$  component, with pre-movement potentials and argued that as such potentials were time-locked to responses they would be highly variable in the trials which were averaged with reference to the onset of the stimulus and would therefore be 'smeared' by the averaging process. Roth et al. (1978) similarly concluded that response induced potentials were not a likely source of contamination in late ER components. These studies suggest that it is unlikely that asymmetrical response-related potentials contributed significantly to the asymmetries in  $P_3$  observed in the present

experiment although it is not possible totally to eliminate this possibility.

A further possible cause of these asymmetries in  $P_3$  is that they reflect differential CNV resolution to the stimuli, the CNV from the hemisphere to which the stimuli were originally directed giving rise to a more fully resolved CNV and thus contributing a larger amount of positivity to the stimulus-evoked activity. Whilst this explanation is possible it is unlikely that significant CNVs actually were generated in this experiment as the use of relatively long inter-stimulus intervals (in this experiment with a mean of 3.5 sec) and an unpredictable foreperiod is not favourable to the development of the CNV (McAdam, Knott, & Rebert, 1969).

If it is the case that neither motor potential contamination nor differential CNV resolution was responsible for the asymmetries observed in  $P_3$  in the present study then the asymmetry observed in this component adds further weight to the notion that  $P_{300}$  may reflect processes other than changes in the general level of arousal or activation. The findings may indicate that if  $P_3$  is the result of phasic changes in response to the recognition of task-relevant or significant stimuli then these changes can be asymmetrical across the cerebral hemispheres and may further indicate that  $P_3$  is indexing asymmetrical activation of the hemispheres, possibly an alerting or mobilisation process of the type considered by Karlin *et al.* (1971) to underlie the generation of  $P_{300}$ .

These results, along with those of Experiment 9 and of Courchesne (1977) and Courchesne *et al.* (1975) provide evidence which suggests that whatever its genesis  $P_{300}$  may

reflect the locus of the information-processing occurring in the cortex as well as the results of such processing.

Whether this is due to the fact that  $P_{300}$  is a specific cortical response or is part of a wider range of responses but is modulated by the cortical activity precipitating it is not at present clear.

## CHAPTER 11

### General Discussion

#### 11a Introduction

Prior to a general discussion of the findings and interpretations presented in the preceding chapters it is relevant to note and discuss some of the limitations to which these experiments are subject.

##### 11a(i). Eliciting stimuli:

Excluding Experiments 7 and 10, which utilised unstructured stimuli, all the experiments reported used at the most two types of eliciting stimuli. These consisted either of upper-case letters or superimposed letters which produced non-verbal geometrical patterns. Each stimulus of each set was equal in size and intensity, thus eliminating variability in subjects' ERs associated with inequalities in these parameters. The use of this limited set of stimuli also allowed a large measure of comparability between the experiments. However, these advantages are achieved at the expense of the demonstrable generality of the experimental results as it is not possible to know the extent to which the reported findings reflect factors associated with the use of such stimuli, although there is no obvious reason why

this should be the case. It would, however, be of interest to determine the robustness of the present findings to variations in variables such as stimulus intensity, size, shape, fine-structure, etc.

11a(ii). Response requirements:

In all the experiments requiring a discrimination prior to a go/no-go decision (Experiments 1-6 and 8 and 9) an identical response requirement involving a slight raising of the right index finger was utilised. Whilst this eliminates the factor of variability in response requirements in the comparison of the different experiments it is arguable that the use of such an asymmetrical response might preclude the generalisation of the experimental results to situations in which other responses were required and thus to a general consideration of hemisphere function. The reasons for this are two-fold. Firstly, it is possible that the asymmetrical response requirement led to the production of response-related potentials which distorted the VERs. This possibility is of greatest relevance to Experiments 1 and 2, and 8 and 9; in the other experiments only stimuli to which responses were not required were included in the averaging process, thus eliminating possible contamination from all but the relatively few false positive responses. As noted in section 10d the evidence for such ER contamination is slim. Moreover, in the experiments in which the stimuli requiring a response were averaged separately (8 and 9) the resulting VERs did not differ from those to which no response was required in a manner interpretable in terms of asymmetrical response processes. No differences between the VERs to target and



non-target stimuli were observed in Experiment 8 and the difference observed in Experiment 9 was at a latency far greater than any of the components analysed in Experiments 1 and 2. The results of Experiments 8 and 9 suggest that it was unlikely that the asymmetrical response requirement led to a distortion of the VERs obtained in Experiments 1 and 2 even though they were formed by averaging across all the eliciting stimuli.

The second way in which the response requirement may be of importance is in terms of interpretation rather than methodology. It is possible that the requirement to respond with the right hand may have led to the left hemisphere assuming the function of response initiation in all the experimental tasks, and this may in turn have led to the asymmetrical transfer of information from the right to the left hemisphere in every task. The possibility of the occurrence of this process places limitations on the generality of the experimental results. Whether different response requirements (e.g., left hand response) would alter the task- and stimulus-specific effects observed in the VERs of these experiments is an open question, especially in view of the contradictory results of such studies utilising behavioural indices of asymmetries of processing (cf., Rizzolatti et al., 1971, and Moscovitch, 1973).

11a(iii). Possible sex differences:

There is a growing body of evidence which suggests that sex differences exist in the patterning of cerebral laterality (the need to view this evidence with caution has been noted by Fairweather (1976), who has pointed out many of

the inconsistencies and problems of interpretation in earlier studies). The weight of the evidence would seem to suggest that females are less laterally differentiated than males. For example, Levy and Reid (1978) have reported that females show less extreme asymmetries than males both in a task involving the recognition of unilaterally presented nonsense syllables and in a dot location task. McGlone (1977) and McGlone and Kertesz (1973) have presented data from neurological populations which suggest that females are less lateralised for both verbal and visuospatial functions and Lake and Bryden (1976) reported females to be less lateralised than males on a verbal dichotic listening test.

With respect to electrophysiological phenomena studies of on-going EEG have provided further evidence to suggest that males may be more laterally differentiated than females (Beaumont et al., 1978; Tucker, 1976). However, no sex differences have yet been reported in ER studies utilising meaningful stimuli although Culver et al. (1971) have reported such a difference in VERS to unilaterally presented flash stimuli. Although no formal attempt was made to analyse the data from the experiments reported in the previous chapters with respect to the possibility of sex differences it should be noted that informal analysis revealed no hint of any such differences.

## 11b Discussion

The results and interpretation of the experiments described in the preceding chapters are summarised below and discussed in the context of how they may add to present knowledge concerning hemisphere function in the brain.

Whilst the findings are subject to the provisos outlined in section 11a and their interpretation to the problems discussed in sections 8b and 8c there would appear to be some conclusions which are generalisable to situations other than the experimental paradigm in which they were derived.

The results of Experiments 1-3 were interpreted as demonstrating that the VER is sensitive to asymmetrical stimulation across the visual fields in that the inter-hemispheric latency and amplitude differences so obtained appeared to reflect the anatomical arrangements of the visual system. However, it was further concluded that these 'structural' effects on the VER were modifiable to a large extent by 'cognitive' factors, particularly the nature of the eliciting stimulus and experimental task. The experiments which utilised the same verbal eliciting stimuli but dissimilar tasks (verbal vs visuospatial) were found to give rise to VERs which had similar patterns of asymmetry in  $P_1$  and  $N_1$  latency but different patterns of asymmetry in  $N_1-P_2$  amplitude. The VERs in the experiments using dissimilar stimuli (letters and patterns) but similar tasks (visuospatial) were observed to show different patterns of  $P_1$  latency and similar patterns of  $N_1$  latency and  $N_1-P_2$  amplitude. These effects were interpreted as reflecting the different patterns of interhemispheric asymmetries of processing contingent on task and stimulus characteristics.

The finding that asymmetries of processing resulting from structural factors (i.e., unilateral input) may be modified and even eliminated by 'cognitive' factors supports the conclusions of Swanson *et al.* (1978). In the light of a review of studies attempting to index the time taken for

information to cross the corpus callosum (inter-hemispheric transfer-time) based on the use of simple reaction-time measures, and also in the light of their own experiments, these authors concluded that in situations in which stimuli are presented unilaterally it was often the case that structural factors were overshadowed by cognitive ones, e.g., expectancy, stimulus-response compatibility, etc. The three VER experiments discussed above, in which task and stimulus factors were varied independently, would appear to demonstrate that, in circumstances in which subjects know in advance the nature of the stimuli and task, and, presumably, 'set' themselves accordingly, the modifying effects of cognitive variables occur early (ca. 100 msec) in the processing of the eliciting stimuli, in the form of processes such as the differential transfer of stimulus information across the corpus callosum, an effect observed in Experiment 3 (see section 4d).

These 'modifying effects' may underly the well-known asymmetries of processing observed when behavioural responses are made contingent on the selective processing of unilaterally presented stimuli (i.e., stimulus material requiring processing presumed to be mediated primarily by one hemisphere is found to be more effectively processed when it is transmitted directly to the 'appropriate' hemisphere rather than to the 'inappropriate' one (see section 1c)). However, the relationship between these behavioural indices of asymmetries of processing and electrophysiological indices is far from clear. For instance, in Experiments 1 and 2 task-dependent asymmetries in VER components were observed in the absence of any behavioural asymmetries of processing,

a finding similar to that of Neville (1978). It would seem that factors other than asymmetries of stimulus processing between the hemispheres (as reflected by VERs) may operate to produce the behavioural asymmetries observed, and that variables associated with response selection and initiation, not reflected in early- and middle-latency components of VERs, may be of importance.

A further observation in these first three experiments was that the component  $P_2-N_2$  was relatively large and symmetrical in Experiment 1, somewhat smaller and asymmetrical (left hem. > right hem.) in Experiment 2 and smaller still and symmetrical in Experiment 3. These findings led to the speculation that this component, invariant with respect to the direction of stimulus lateralisation, was in some way specific to verbal processing, this being bilaterally mediated in Experiment 1 but asymmetrically mediated in Experiment 2.

The  $P_2-N_2$  component was further investigated in Experiments 4 and 5. In Experiment 4, in which VERs to stimuli presented across the visual midline were elicited in separate blocks either with verbal stimuli requiring verbal processing or non-verbal stimuli requiring visuospatial processing,  $P_2-N_2$  was found to be bilaterally enhanced in the verbal compared with the non-verbal condition. This supported the view that this component was related in some way to verbal processing of the eliciting stimuli. It was hypothesized that in circumstances in which verbal processing of the eliciting stimuli was task-relevant this component indexed a bilateral involvement of the hemispheres in some aspect of the task. In circumstances in which such processing

was not task-relevant the component indexed the fact that only the left hemisphere engaged in the processing of the stimuli in a verbal mode. Experiment 5 tested this hypothesis by eliciting VERS with letter stimuli in central vision to which a response based on visuospatial processing was required. It was predicted that, as in Experiment 2, a hemisphere asymmetry would be observed in this component, which would be larger in the left hemisphere. The predicted effect was observed to occur to an extent which was slightly outside conventional levels of statistical significance. The results of this experiment were interpreted as further evidence in favour of the hypothesis that  $P_2-N_2$  reflected some kind of processing specific to verbal stimuli.

The results obtained with respect to the  $P_2-N_2$  component suggest that the hemispheres vary in the extent to which they mediate processing in an asymmetric fashion, acting in a more concerted fashion in some circumstances than in others. The results present evidence which suggests that 'structural' asymmetries in the brain (in this case the pre-eminence of the left hemisphere for verbal processing) interact with 'cognitive' factors (the task-relevance or irrelevance of verbal processing) to produce varying patterns of processing. The pattern of results obtained with the  $P_2-N_2$  component also supports the contention (Searleman, 1977) that the right hemisphere is capable of the mediation of some aspects of verbal processing. Furthermore, the findings cast doubt upon the model of letter processing which assumes that verbal processing of letters occurs in the left hemisphere and physical processing in the right (e.g., Cohen, 1972; Wilkins & Stuart, 1974). Although evidence exists to suggest that these processes occur in parallel (Posner, 1976) their

loci would appear not to be restricted, but rather to be modifiable in the light of the task demands placed on the subject.

The findings of Experiment 6, in which verbal and non-verbal stimuli associated with different tasks were intermixed, indicated that an enhanced  $P_2$ - $N_2$  was not a necessary concomitant of verbal processing, and suggested that a possible source of the variation observed in this component in previous experiments was the factor of preparatory set. This finding supports the contention of Kinsbourne (1973) that an important factor leading to observations of lateral asymmetries of processing is the operation of pre-stimulus factors, these causing subjects to adopt different attentional sets contingent on the type of processing required. The observation of a task-dependent asymmetry in the latency of  $N_2$  in the VERS observed in this experiment suggests that, in the absence of differential preparatory factors asymmetries of processing resulting from post-stimulus effects are observable in VERS.

The finding in Experiments 4, 5 and 8 that  $P_1$  latency was shorter from the right hemisphere and that, in Experiment 6 (in which more complex visual processing was required) this effect extended to include a right hemisphere latency advantage for  $N_1$  and  $P_1$ - $N_1$  amplitude asymmetry led to the conclusion that in the initial stages of stimulus processing the right hemisphere was pre-eminent irrespective of the task demands associated with the stimuli. The robustness of this asymmetry in the face of variations in task and stimulus may indicate that it reflects a fundamental asymmetry in 'low-level' visual processing. This conclusion is congruent with

the growing evidence from other sources (e.g., Bryden & Allard, 1976; Meyer, 1976; Davidoff, 1975; Kimura & Durnford, 1974) suggesting a right hemisphere advantage for elementary visual processing, this in turn suggesting the possibility that this asymmetry is mediated by functional asymmetries at the level of the visual cortex (Meyer, 1976; Kimura & Durnford, 1974).

Comparison of the results of Experiments 1-3 and 4-6 suggests that there may be important differences in the way that stimuli are processed which are contingent on whether input is unilateral or in central vision. This conclusion stems from the fact that the component  $N_1-P_2$ , observed in Experiments 1-3 to be sensitive not only to the effects of unilateral stimulation but also to task and stimulus factors showed no task- or stimulus-specific variation in Experiments in which midline stimulation was employed. This supports the contention of Beaumont (1978b) that unilateral stimulation (far and away the most common means by which lateral asymmetries in the processing of visually presented stimuli are investigated) may give rise to 'artificial' results which are not relevant to the way individuals usually process visual information. The differences observed in the relative sensitivity of  $N_1-P_2$  to task and stimulus factors in the two sets of experiments may be related to the fact that as the amount of overlap between the temporal and nasal hemiretinae is no more than a few minutes of arc (Noback & Demarest, 1977) when a stimulus is presented transiently across the midline only one half of it is projected to each hemisphere (this has been dramatically demonstrated by Levy, Trevarthen, and Sperry (1972) with the presentation of



'chimeric' stimuli to callossectomised subjects). Prior to the full processing of the stimulus the hemispheres must therefore interact to the extent necessary to 'recombine' the stimulus. This type of processing is obviously unnecessary when unilateral stimulation is used, in which case the directly stimulated hemisphere is the recipient of the 'whole' stimulus. It follows from this discussion that a 'true' measure of the asymmetries of processing associated with a particular stimulus necessitates bilateral presentation, thus ensuring that each hemisphere is the recipient of the stimulus information independently of the other.

The possibility that hemisphere asymmetries of processing might be reflected in post-recognition components of the VER ( $P_{300}$ ) was investigated in Experiments 8 and 9. Using essentially the same procedure as in Experiment 4 Experiment 8 investigated the  $P_{300}$  components associated with these stimuli and tasks. No evidence was obtained to suggest that, in these circumstances,  $P_{300}$  indexed any asymmetrical processing of the stimuli. The results suggested, however, that task-irrelevant factors were important determinants of the latency and amplitude of  $P_{300}$  and, furthermore, that the 'expectancy model' of  $P_{300}$  generation was inadequate in this experimental paradigm. In Experiment 9 the same types of stimuli as were utilised in the previous experiment were employed, each type being subjected to visuospatial processing. In these circumstances, stimulus-dependent asymmetries both in the latency and amplitude of  $P_{300}$  were observed. That associated with  $P_{300}$  latency was considered to reflect the contrasting levels of difficulty of the tasks when associated with the letter or pattern stimuli; only in

the case of the harder task (discrimination of the pattern stimuli) was an asymmetry observed, suggesting that an important factor in the elicitation of asymmetries of processing might be the information-processing load placed on the subject. The amplitude asymmetry was not amenable to an explanation in such terms. The complex nature of this asymmetry (involving the differential decrement of  $P_{300}$  in each hemisphere to the two types of target stimuli compared with the non-targets) precludes a simple explanation. However, it provides further evidence for the importance of the influence of task x stimulus interactions on patterns of processing between the hemispheres. The notion that  $P_{300}$  was sensitive to the hemispheric locus of the processing precipitating it received further support from Experiment 10, in which the amplitude of  $P_{300}$  was found to vary slightly but significantly with the visual field in which the (unstructured) eliciting stimuli were exposed. The results of this experiment along with those of Experiment 9 indicate that, whatever its origin,  $P_{300}$  is influenced by the nature of the processing which precedes its occurrence as well as the results of such processing. Whilst amplitude asymmetries only allow the inference that, on its emission,  $P_{300}$  is modulated by asymmetrical cortical activity the asymmetry in latency observed in Experiment 9 offers support for the contention that the component may be independently generated in each hemisphere.

### 11c Conclusions

In drawing final conclusions from the experiments presented in this thesis it is as well to remember the limited nature of the stimuli and tasks utilised as independent variables as well as the problems of interpretation of ER parameters noted in section 8d. The data base provided by these studies hardly constitutes sufficient grounds for proposing a model of hemisphere function. The data do, however, suggest constraints to which, at least with respect to the processing of relatively simple, visually presented stimuli, any such model must conform.

One conclusion to be drawn from the results of these experiments is that a 'switch-board' analogy of the flow of stimulus information in the brain does not appear to be appropriate. It does not seem to be the case that the hemispheres operate according to a model whereby information flows along invariant pathways to appropriate specialised regions, as implied by a model such as that of Moscovitch (1973). The interactions between the hemispheres are complex, for example, 'callosal transmission time' may be undetectable in some circumstances and of the order of 10 msec in others, as measured by VER latency differences (cf., the interhemispheric latency difference in  $P_1$  of the VERs elicited by right and left visual field stimulation in Experiment 3).

The finding that the extent to which verbal processing is mediated unilaterally may be dependent upon the task-demands placed upon the subject militates against the view that the hemispheres can be regarded simply as parallel computers, each containing a different program; these

programs appear to be flexible and the 'computers' linked in a way which allows co-operation as well as independent action.

The observation that the patterns of information flow between the hemispheres are variable and dependent on factors such as the task demands of the situation and the nature of the stimuli to be processed implies that these processes are subject to some form of control. The relatively simple model of the control of information flow between the hemispheres based on the concepts of asymmetrical activation and lateral biases in selective attention (see, for example, Kinsbourne, 1973, 1978) is not supported by the present data (e.g., the data suggest that the right hemisphere maintains its pre-eminence for some aspects of visual processing irrespective of the informational content of the stimuli, the related task and the presence or absence of foreknowledge of the nature of the stimuli on the part of the subjects). It is clear, however, that some such mechanism or mechanisms must be proposed to account for the stimulus- and task-dependent differences in asymmetries of processing which may be observed from relatively early on in the course of stimulus processing. The nature and localisation of these 'control mechanisms' in the processing of sensory input is a question to which, at present, only the work of Kinsbourne has been addressed and for the answer to which much more empirical work is required.

On a more speculative note it is arguable that one reason that the asymmetries of processing of the stimuli utilised in these experiments seemed to be so flexible was that the relatively simple nature of the tasks meant that they did not fully engage strongly lateralised functions.

Whether such a high degree of flexibility would be observed with stimuli the processing of which was of a more complex nature is an empirical question well worth asking. It could be predicted that as tasks became more complex the degree of flexibility of processing (in response to 'extra-structural' factors such as differential preparation) would decrease as it became necessary to engage more highly lateralised functions to maintain an optimum level of performance; the 'options' available to the previously-mentioned 'control mechanism' in the way in which it allocates the processing capacity of the hemispheres would become more limited.

The preceding discussion is framed in terms which might perhaps be labelled 'teleological'; they assume that even 'low-level' sensory processing has a goal-oriented, 'purposeful' nature. This is because the results of the present set of experiments would appear to be interpreted most profitably in a context in which the behavioural goal of the information-processing associated with the stimulus is taken into account.

Finally it should be noted that the results of the experiments presented in this thesis indicate that cerebral processes associated with the lateralisation of information-processing can profitably be studied using evoked response techniques. The design of future studies of this kind in such a manner that any observed ER effects may be interpreted relatively unambiguously (see Chapter 8) would be of great value, contributing to the elucidation not only of cerebral correlates of information-processing but also of the processes giving rise to variations in evoked responses.

## APPENDIX 1

## Programs utilised in Experiments 1-10

## i) General:

All the following programs were written in UWCIG and run on a DEC Lab/8e computer. The majority of them were used to present characters on a VR14 display oscilloscope (these being the eliciting stimuli) while monitoring subjects' performance and placing event markers (10 msec positive 1 V square-waves) on to one or more channels of a RACAL FM tape-recorder. The tape-recorder was used to record subjects' EEGs during the time that the programs were running. EEG averaging was performed using the DEC System Software Advanced Averager program. The event-markers recorded on the tape-recorder were used to fire a Schmitt trigger in the Lab/8e and thus facilitate the averaging of EEG samples appropriate for the formation of VERs from each hemisphere in each experimental condition.

## ii) Experiments 1 and 2:

These utilised the program LET. This program presented, on the VR14 oscilloscope, two pre-determined series of upper-case letters to either the left or right of a constantly displayed fixation point. An event marker was placed on one of two channels of the tape-recorder, the channel being contingent on the side of stimulus presentation. At the end

of each series the number of stimuli presented in each visual field and subjects' mean RTs to those to which they responded were printed out.

iii) Experiment 3:

This experiment was run with program LETTS2. This presented two predetermined series of superimposed pairs of letters to the right and left of a constantly displayed central fixation dot. The visual field of presentation of each stimulus was also pre-determined. Event markers were placed on the tape-recorder channels only to 'non-target' (i.e., asymmetrical) stimuli. The print-out consisted of subjects' mean RTs to the target stimuli to which they responded in each visual field, the number of target stimuli to which they responded and the number of 'false positive' responses.

iv ) Experiment 4:

This was run with programs MID and MIDV. MID allowed the presentation of two series of superimposed letter pairs and MIDV the presentation of two series of letters. In each case the stimuli were presented to the point of fixation (the fixation dot was constantly on except during stimulus presentation). Event markers were generated only for the 'non-targets' in each stimulus series. After each series mean RT, number of hits and number of false positives were printed out.

v) Experiment 5:

Programs MIX1 and MIX2. Each program presented a pre-determined series of letters and superimposed letter pairs interspersed in a pre-determined random order. Event markers preceding the presentation of non-targets of each type of stimulus were placed on one of two channels of the FM recorder. After each series had been presented mean RTs to targets, number of hits and number of false positives were printed out for each stimulus type.

vi) Experiment 6:

Program RANG. This program presented two series of letters to the centre of the VR14, generated event markers for each non-target and, after the completion of each series printed out mean RT's to targets, number of hits and number of false positive responses.

vii) Experiment 7:

This experiment utilised VFCAL. This program allowed small dots of light to be repetitively presented either at fixation (superimposed on a smaller, fainter, fixation dot) or at 2°, 4°, 6°, 8°, or 10° left or right of fixation. An event marker preceded each stimulus presentation.

viii) Experiment 8:

Programs LEP300 and NVP300. These programs' display functions were identical to MIDV and MID respectively (Experiment 4). They differed in that event markers were generated both to target and non-target stimuli. As three channels of the tape-recorder were dedicated to recording



electrophysiological parameters (EEG and EOG) the remaining channel was used to indicate both types of target by generating negative pulses for non-targets and positive pulses for targets. By use of the Advanced Averager 'Sort' option and appropriate BRD logic circuitry this arrangement allowed VEPs to targets and non-targets to be formed with only one pass of the recorded EEG and EOG into the computer, instead of the multiple passes previously required.

ix) Experiment 9:

Programs LEN300 and NVP300. LEN300 was identical to LEP300 except that the sequences of letters were arranged such that targets were those letters containing right angles.

x) Experiment 10:

Program SEQP30. This experiment was run on-line, subjects' EEGs being fed directly into the Lab/8e running an Advanced Averager routine. SEQP30 was used to place event markers (10 msec 1 V positive square waves) on to three channels of an FM recorder. Each channel controlled one of the stimulus lights used in the experiment through the use of BRD logic circuitry. The program placed pulses randomly on the tape-recorder channels with the constraints that the interval between them varied randomly between 2 and 5 secs, that 200 of these should be on the channel controlling the central stimulus, and that 25 should be placed on each of the other channels.

```

C U/W-FOCAL: MIDV NO/DA/TE

13.05 A +-1
13.10 S N=13;D 21;S N=13;D 21;S N=7;D 20;S N=26;D 21;S N=16;D 20
13.20 S N=9;D 21;D N=15;D 21;S N=5;D 20;S N=8;D 21;S N=23;D 21
13.30 S N=17;D 21;S N=19;D 21;S N=13;D 21;S N=11;D 21;S N=20;D 20
13.40 S N=12;D 21;S N=23;D 21;S N=24;D 21;S N=19;D 21;S N=18;D 21
13.50 S N=6;D 21;S N=11;D 21;S N=14;D 21;S N=22;D 20;S N=9;D 21
13.60 S N=17;D 21;S N=13;D 21;S N=4;D 20;S N=12;D 21;S N=8;D 21
13.70 S N=10;D 21;S N=3;D 20;S N=15;D 21;S N=12;D 21;S N=11;D 21
13.80 S N=18;D 21;S N=15;D 21;S N=7;D 20;S N=21;D 21;S N=10;D 21
13.90 S N=25;D 21;S N=5;D 20;S N=15;D 21;S N=9;D 21;S N=10;D 21
13.95 S N=12;D 21;S N=26;D 21;S N=2;D 20;S N=1;D 21;S N=11;D 21
13.97 D 28

20.10 D 22;X FDO(2,-3,-60);D 25
20.22 S RR=RR+FD(-1);X FDO(2,1)
20.30 I (FD(-4))20.4,20.5,20.4
20.40 Y DD
20.50 R

21.10 D 22;X FDO(2,3,528) FDO(2,-3,-10) FDO(2,4,528) FDO(2,-3,-50);D 25
21.20 S R=R+FD(-4);X FDO(2,1)

22.10 S T=FRAN();I (T-.5)22.15,22.15,22.16
22.15 X FDO(2,-3,-1000)
22.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)
22.20 S Z=FD(N,-FD(N))
22.30 S Z=FD(27,-FD(27))

25.10 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))
25.20 X FDO(2,-3,-1000)

28.10 T %4.0,"RT TO TARGETS =",RR/DD,!
28.20 T "RESPONSES TO TARGETS =",DD,!
28.30 T "ERRORS", "=",R,!
28.40 Z RR,DD,R
28.50 L G MID

```



C U/W-FOCAL: MID NO/DA/TE

01.01 X FDO(4,0);Z;X FDO(2,-2,-2,2759),FDO(2,1)

01.10 D 3,5;T "START WITH GO THEND 6 FOR NON VERBS D 19 VERBS",!!

01.20 Q

02.05 S X=-20

02.10 D 11;S Z=1;D 8;S Z=X;D 8;S Z=-19;D 8;S Z=2;D 8;S Z=10;D 8;S Z=5;D 8

03.05 F G=,25;D 2;S Z=(193+G)-1024;D 8

03.10 F T=1,26;D 4

04.10 S Z=FD(T,-FD(T))

05.10 D 11;S Z=1;D 8;S Z=0;D 8;S Z=7;D 8

05.20 S Z=-1024;D 8;S Z=-1024;D 8

06.10 D 13,28

08.10 X FD(FD(),Z);S Z=FD(,FD()+1)

11.10 S Z=FD(63,FD(63)+1)

11.20 S Z=FD(Z,FD())

11.30 S Z=0;D 8

13.10 S N=8,M=26;D 21;S N=8,M=9;D 23;S N=12,M=24;D 20

13.11 S N=16,M=15;D 20;S N=16,M=15;D 20;S N=8,M=9;D 24

13.12 S N=11,M=10;D 20;S N=7,M=9;D 20;S N=16,M=15;D 21

13.13 S N=5,M=15;D 20;S N=6,M=17;D 20;S N=21,M=22;D 24

13.14 S N=16,M=14;D 20;S N=14,M=5;D 20;S N=19,M=20;D 20

13.15 S N=24,M=25;D 23;S N=11,M=10;D 20;S N=23,M=26;D 21

13.16 S N=24,M=25;D 24;S N=23,M=26;D 20;S N=19,M=20;D 21

13.17 S N=7,M=12;D 21;S N=8,M=26;D 20;S N=14,M=5;D 21

13.18 S N=3,M=12;D 21;S N=9,M=10;D 21;S N=6,M=17;D 20

13.19 S N=8,M=9;D 23;S N=19,M=20;D 20;S N=23,M=26;D 21

13.20 S N=9,M=10;D 21;S N=8,M=26;D 21;S N=12,M=24;D 20

13.21 S N=21,M=22;D 23;S N=7,M=9;D 21;S N=24,M=23;D 24

13.22 S N=23,M=26;D 21;S N=15,M=20;D 24;S N=16,M=15;D 21

13.23 S N=5,M=15;D 20;S N=12,M=24;D 21;S N=23,M=26;D 21

13.24 S N=16,M=14;D 21;S N=7,M=9;D 20;S N=16,M=15;D 21

13.25 S N=23,M=26;D 21;S N=8,M=26;D 20;S N=7,M=9;D 21

13.26 S N=8,M=9;D 23;S N=8,M=2;D 20

19.10 L G MIDV 13

20.10 D 21

21.10 D 22;X FDO(2,3,528) FDO(2,-3,-10) FDO(2,4,528) FDO(2,-3,-50);D 25

21.20 S R=R+FD(-4);X FDO(2,1)

22.10 S T=FRAN();I (T-.5)22.15,22.15,22.16

22.15 X FDO(2,-3,-1000)

22.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)

22.20 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M))

22.30 S Z=FD(27,-FD(27))

23.10 D 24

24.10 D 22;X FDO(2,-3,-60);D 25

24.20 S RR=RR+FD(-1);X FDO(2,1)

24.30 I (FD(-4))24.4,24.5,24.4

24.40 Y DD

24.50 R

25.05 S Z=FD(27,-FD(27))

25.10 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M))

25.20 X FDO(2,-3,-1000)

28.10 T %4.0,"RT TO TARGETS =",RR/DD,!

28.20 T "RESPONSES TO TARGETS =",DD,!

28.30 T "ERRORS","=",R,!

28.40 Z RR,DD,R



C U/W-FOCAL: LETTS2 NO/DA/TE

01.01 X FDO(6,0)Z: X FDO(2,-2,-2,2759),FDO(2,1)  
 01.10 D 3,5:T "START WITH GO THEN D 6 OR D 7",!!  
 01.20 Q

02.10 D 11:S Z=1:D 8:S Z=X:D 8:S Z=-19:D 8:S Z=2:D 8:S Z=10:D 8:S Z=5:D 8

03.05 F G=r,25:D 2:S Z=(193+G)-1024:D 8  
 03.10 F T=1,26:D 4

04.10 S Z=FB(T,-FB(T))

05.10 D 11:S Z=1:D 8:S Z=0:D 8:S Z=0:D 8:S Z=7:D 8  
 05.20 S Z=-1024:D 8:S Z=-1024:D 8

06.10 F G=1,2:D 12  
 06.20 D 28

07.10 F G=1,2:D 13  
 07.20 D 28

08.10 X FD(FD(),Z):S Z=FD(,FD()+1)

11.10 S Z=FD(63,FD(63)+1)  
 11.20 S Z=FD(Z,FD())  
 11.30 S Z=0:D 8

12.10 S N=8,M=26:D 20:S N=8,M=9:D 23:S N=7,M=9:D 21  
 12.11 S N=8,M=26:D 20:S N=23,M=26:D 21:S N=6,M=15:D 21  
 12.12 S N=7,M=9:D 20:S N=16,M=14:D 21:S N=23,M=26:D 21  
 12.13 S N=12,M=24:D 21:S N=5,M=15:D 20:S N=16,M=15:D 21  
 12.14 S N=15,M=20:D 24:S N=23,M=26:D 20:S N=24,M=23:D 24  
 12.15 S N=7,M=9:D 21:S N=21,M=22:D 23:S N=12,M=24:D 20  
 12.16 S N=8,M=26:D 21:S N=9,M=10:D 21:S N=23,M=26:D 21  
 12.17 S N=19,M=20:D 20:S N=8,M=9:D 23:S N=6,M=17:D 20  
 12.18 S N=9,M=10:D 21:S N=3,M=12:D 21:S N=14,M=5:D 21  
 12.19 S N=8,M=26:D 20:S N=7,M=9:D 21:S N=19,M=20:D 21  
 12.20 S N=23,M=26:D 20:S N=24,M=25:D 24:S N=23,M=26:D 21  
 12.21 S N=11,M=10:D 20:S N=24,M=25:D 23:S N=19,M=20:D 21  
 12.22 S N=14,M=5:D 20:S N=16,M=14:D 20:S N=21,M=22:D 24  
 12.23 S N=6,M=17:D 20:S N=5,M=15:D 20:S N=16,M=15:D 21  
 12.24 S N=7,M=9:D 20:S N=11,M=10:D 20:S N=8,M=9:D 24  
 12.25 S N=16,M=15:D 20:S N=16,M=15:D 20:S N=12,M=24:D 20  
 12.26 S N=8,M=9:D 23:S N=8,M=26:D 21

13.10 S N=16,M=15:D 20:S N=16,M=15:D 20:S N=12,M=24:D 20  
 13.11 S N=7,M=9:D 20:S N=11,M=10:D 20:S N=8,M=9:D 24  
 13.12 S N=6,M=17:D 20:S N=5,M=15:D 20:S N=16,M=15:D 21  
 13.13 S N=8,M=26:D 20:S N=8,M=9:D 23:S N=7,M=9:D 21  
 13.14 S N=14,M=5:D 20:S N=16,M=14:D 20:S N=21,M=22:D 24  
 13.15 S N=11,M=10:D 20:S N=24,M=25:D 23:S N=19,M=20:D 21  
 13.16 S N=23,M=26:D 20:S N=24,M=25:D 24:S N=23,M=26:D 21  
 13.17 S N=8,M=26:D 20:S N=7,M=9:D 21:S N=19,M=20:D 21  
 13.18 S N=9,M=10:D 21:S N=3,M=12:D 21:S N=14,M=5:D 21  
 13.19 S N=19,M=20:D 20:S N=8,M=9:D 23:S N=6,M=17:D 20  
 13.20 S N=8,M=26:D 21:S N=9,M=10:D 21:S N=23,M=26:D 21  
 13.21 S N=7,M=9:D 21:S N=21,M=22:D 23:S N=12,M=24:D 20  
 13.22 S N=15,M=20:D 24:S N=23,M=26:D 20:S N=24,M=23:D 24  
 13.23 S N=12,M=24:D 21:S N=5,M=15:D 20:S N=16,M=15:D 21  
 13.24 S N=7,M=9:D 20:S N=16,M=14:D 21:S N=23,M=26:D 21  
 13.25 S N=8,M=26:D 20:S N=23,M=26:D 21:S N=6,M=15:D 21  
 13.26 S N=8,M=26:D 21:S N=8,M=9:D 23

20.10 F J=66,8,266:X FD(J,-171)  
 20.15 D 22:X FDO(2,3,272) FDO(2,-3,-10) FDO(2,4,272) FDO(2,-3,-90):D 25  
 20.20 S ER=ER+FD(-4):X FDO(2,1)

21.10 F J=66,8,266:X FD(J,143)  
 21.15 D 22:X FDO(2,3,528) FDO(2,-3,-10) FDO(2,4,528) FDO(2,-3,-100):D 25  
 21.20 S EL=EL+FD(-4):X FDO(2,1)

22.10 S T=FRAN():I (T-0,5)22.15,22.15,22.16  
 22.15 X FDO(2,-3,-1000)  
 22.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)  
 22.20 S Z=FB(N,-FB(N)),Z=FB(M,-FB(M))

23.10 Y AA:F J=66,8,266:X FD(J,-171)  
 23.11 D 22:X FDO(2,-3,-100):D 25  
 23.12 S RL=RL+FD(-1):X FDO(2,1)  
 23.15 I (FD(-1))23,3,23,35,23,3  
 23.30 Y CC  
 23.35 R

24.10 Y BB:F J=66,8,266:X FD(J,143)  
 24.11 D 22:X FDO(2,-3,-100):D 25  
 24.12 S RR=RR+FD(-1):X FDO(2,1)  
 24.15 I (FD(-1))24,3,24,35,24,3  
 24.30 Y DD  
 24.35 R

25.10 S Z=FB(N,-FB(N)),Z=FB(M,-FB(M))  
 25.20 X FDO(2,-3,-1000)

28.10 T %2,0,"NO LEFT=","AA," NO RIGHT=","BB,!  
 28.20 T %4,0,"RT LEFT=","RL/CC," RT RIGHT=","RR/DD,!!  
 28.30 T "RESPONSES TO TARGET STIMULI:- LEFT=","CC," RIGHT=","DD,!  
 28.40 T "ERRORS IN EACH FIELD:- LEFT=","EL," RIGHT=","ER,!  
 28.50 Z



C U/W-FOCAL: LET NO/DA/TE

01.01 X FDO(6,0);Z;X FDO(2,-2,-2,2759),FDO(2,1)

01.10 D 3,5;T "START WITH GO THEN D 6 OR D 7",!!

01.20 Q

02.10 D 11;S Z=1;D 8;S Z=X;D 8;S Z=-19;D 8;S Z=2;D 8;S Z=10;D 8;S Z=5;D 8

03.05 F G=,25;D 2;S Z=(193+G)-1024;D 8

03.10 F T=1,26;D 4

04.10 S Z=FD(T,-FD(T))

05.10 D 11;S Z=1;D 8;S Z=0;D 8;S Z=0;D 8;S Z=7;D 8

05.20 S Z=-1024;D 8;S Z=-1024;D 8

06.10 D 13,28

07.10 D 12,28

08.10 X FD(FD(),Z);S Z=FD(,FD()+1)

11.10 S Z=FD(63,FD(63)+1)

11.20 S Z=FD(Z,FD())

11.30 S Z=0;D 8

12.11 S N=2;D 20;S N=25;D 20;S N=21;D 20;S N=14;D 20;S N=1;D 20

12.12 S N=5;D 20;S N=11;D 20;S N=12;D 20;S N=16;D 20;S N=18;D 20

12.13 S N=17;D 20;S N=19;D 20;S N=3;D 20;S N=15;D 20;S N=6;D 20

12.14 S N=14;D 20;S N=13;D 20;S N=26;D 20;S N=24;D 20;S N=9;D 20

12.15 S N=6;D 20;S N=16;D 20;S N=23;D 20;S N=14;D 20;S N=1;D 20

12.16 S N=23;D 20;S N=8;D 20;S N=11;D 20;S N=12;D 20;S N=12;D 20

12.17 S N=22;D 20;S N=20;D 20;S N=17;D 20;S N=14;D 20;S N=6;D 20

12.18 S N=5;D 20;S N=1;D 20;S N=25;D 20;S N=25;D 20;S N=21;D 20

12.19 S N=23;D 20;S N=6;D 20;S N=8;D 20;S N=14;D 20;S N=23;D 20

12.20 S N=1;D 20;S N=18;D 20;S N=4;D 20;S N=8;D 20;S N=21;D 20

13.11 S N=1;D 20;S N=18;D 20;S N=4;D 20;S N=8;D 20;S N=21;D 20

13.12 S N=23;D 20;S N=6;D 20;S N=8;D 20;S N=14;D 20;S N=23;D 20

13.13 S N=5;D 20;S N=1;D 20;S N=25;D 20;S N=25;D 20;S N=21;D 20

13.14 S N=22;D 20;S N=20;D 20;S N=17;D 20;S N=14;D 20;S N=6;D 20

13.15 S N=23;D 20;S N=8;D 20;S N=11;D 20;S N=12;D 20;S N=12;D 20

13.16 S N=6;D 20;S N=16;D 20;S N=23;D 20;S N=14;D 20;S N=1;D 20

13.17 S N=14;D 20;S N=13;D 20;S N=26;D 20;S N=24;D 20;S N=9;D 20

13.18 S N=17;D 20;S N=19;D 20;S N=3;D 20;S N=15;D 20;S N=6;D 20

13.19 S N=5;D 20;S N=11;D 20;S N=12;D 20;S N=16;D 20;S N=18;D 20

13.20 S N=2;D 20;S N=25;D 20;S N=21;D 20;S N=14;D 20;S N=1;D 20

20.10 S G=FRAN();I (G-.5)21.1,21.1,22.1

21.10 F J=66,8,266;X FD(J,-171);Y AA

21.20 D 23;X FDO(2,3,272) FDO(2,-3,-10) FDO(2,4,272) FDO(2,-3,-60);D 24

21.30 S RR=RR+FD(-1);I (FD(-1))21.4 22

21.40 Y CC

21.45 R

22.10 F J=66,8,266;X FD(J,143);Y BB

22.20 D 23;X FDO(2,3,272) FDO(2,-3,-10) FDO(2,4,272) FDO(2,-3,-60);D 24

22.30 S RR=RR+FD(-1);I (FD(-1))22.4,22.45;22.4

22.40 Y DD

22.45 R

23.10 S T=FRAN();I (T-.5)23.15,23.25,23.16

23.15 X FDO(2,-3,-100)

23.16 X FDO(2,-3,-2000)

23.20 S Z=FD(N,-FD(N))

24.10 S Z=FD(N,-FD(N));X FDO(2,-3,1000)

28.10 T %2.0,NO LEFT=",AA,"NO RIGHT=",BB

28.20 T %4.0,"RT LEFT=",RL/CC,"RT RIGHT =",RR/DD

28.30 Z

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C U/W-FDCAL:  VFCAL  NO/DA/TE

01.10 Z: X FDO(2,-2,-2,2759),FDO(6,0)
01.20 T "2 DEG L=-80,R=80",!,"4 DEG L=-160,R=160",!
01.30 T "6 DEG L=-240, R=240",!,"8 DEG L=-320,R=320",!
01.40 T "10 DEG L=-400,R=400",!
01.45 A X
01.48 D 4,7,15,17
01.50 D 7,T "D 3 TO CONTINUE",!!
01.60 Q

03.10 F B=1,80,D 12
03.20 T "DONE",!

04.10 D 11:S Z=1:D 8:S Z=X:D 8:S Z=0:D 8:S Z=7:D 8:F G=,4:D 5

05.10 F J=,4:D 6

06.10 S Z=(-2+J)--1024:D 8:S Z=(2-G)--1024:D 8

07.10 D 11:S Z=1:D 8:S Z=0:D 8:S Z=0:D 8:S Z=7:D 8:S Z=-1024:D 8:S Z=-1024:D 8

08.10 X FD(FD(),Z):S Z=FD(FD(),+1)

11.10 S Z=FD(63,FD(63)+1)
11.20 S Z=FD(Z,FD())
11.30 S Z=0:D 8

12.10 D 15:X FDO(2,3,528) FDO(2,-3,-50) FDO(2,4,528)
12.20 D 15:X FDO(2,-3,-1000) FDO(2,-3,-500)

15.10 F K=1,3:D 16

16.10 S Z=FD(K,--FD(K))

17.10 D 11:S Z=1:D 8:S Z=0:D 8:S Z=-500:D 8:S Z=7:D 8:S

```



C U/W-FOCAL: RANG NO/DA/TE

01.01 X FDO(6,0) FDO(2,-2,-2,2759) FDO(2,1)  
01.10 D 3,5;T "D 12 OR 13 FOR STIMULI",!!  
01.20 Q

02.05 S X=-20  
02.10 D 11;S Z=1;D 8;S Z=X;D 8;S Z=-19;D 8;S Z=2;D 8;S Z=10;D 8;S Z=5;D 8

03.05 F G=,25;D 2;S Z=(193+G)-1024;D 8  
03.10 F T=1,26;D 4

04.10 S Z=FD(T,-FD(T))

05.10 D 11;S Z=1;D 8;S Z=0;D 8;S Z=0;D 8;S Z=7;D 8  
05.20 S Z=-1024;D 8;S Z=-1024;D 8

08.10 X FD(FD(),Z);S Z=FD(,FD()+1)

11.10 S Z=FD(63,FD(63)+1)  
11.20 S Z=FD(Z,FD())  
11.30 Z Z;D 8

12.01 S N=14;D 21;S N=3;D 21;S N=26;D 21;S N=20;D 20;S N=11;D 21  
12.02 S N=22;D 21;S N=19;D 21;S N=12;D 20;S N=22;D 21;S N=13;D 21  
12.03 S N=26;D 21;S N=8;D 20;S N=13;D 21;S N=14;D 21;S N=26;D 21  
12.04 S N=19;D 21;S N=6;D 20;S N=11;D 21;S N=11;D 21;S N=22;D 21  
12.05 S N=26;D 21;S N=19;D 21;S N=6;D 20;S N=13;D 21;S N=13;D 21  
12.06 S N=12;D 20;S N=3;D 21;S N=11;D 21;S N=15;D 21;S N=19;D 21  
12.07 S N=25;D 21;S N=1;D 20;S N=14;D 21;S N=8;D 20;S N=23;D 21  
12.08 S N=19;D 21;S N=14;D 21;S N=3;D 21;S N=3;D 21;S N=15;D 21  
12.09 S N=1;D 20;S N=26;D 21;S N=13;D 21;S N=21;D 21;S N=15;D 21  
12.10 S N=5;D 20;S N=22;D 21;S N=25;D 21;S N=21;D 21;S N=14;D 21  
12.20 D 28

13.01 S N=5;D 20;S N=22;D 21;S N=25;D 21;S N=21;D 21;S N=14;D 21  
13.02 S N=1;D 20;S N=26;D 21;S N=13;D 21;S N=21;D 21;S N=15;D 21  
13.03 S N=19;D 21;S N=14;D 21;S N=3;D 21;S N=3;D 21;S N=15;D 21  
13.04 S N=25;D 21;S N=1;D 20;S N=14;D 21;S N=8;D 20;S N=23;D 21  
13.05 S N=12;D 20;S N=3;D 21;S N=11;D 21;S N=15;D 21;S N=19;D 21  
13.06 S N=26;D 21;S N=19;D 21;S N=6;D 20;S N=13;D 21;S N=13;D 21  
13.07 S N=19;D 21;S N=6;D 20;S N=11;D 21;S N=11;D 21;S N=22;D 21  
13.08 S N=26;D 21;S N=8;D 20;S N=13;D 21;S N=14;D 21;S N=26;D 21  
13.09 S N=22;D 21;S N=19;D 21;S N=12;D 20;S N=22;D 21;S N=13;D 21  
13.10 S N=14;D 21;S N=3;D 21;S N=26;D 21;S N=20;D 20;S N=11;D 21  
13.20 D 28

20.10 D 22;X FDO(2,-3,-60);D 25  
20.22 S RR=RR+FD(-1);X FDO(2,1)  
20.30 I (FD(-4))20.4,20.5,20.4  
20.40 Y DD  
20.50 R

21.10 D 22;X FDO(2,3,528) FDO(2,-3,-60) FDO(2,4,528);D 25  
21.20 S R=R+FD(-4);X FDO(2,1)

22.10 S T=FRAN();I (T-.5)22.15,22.15,22.16  
22.15 X FDO(2,-3,-1000)  
22.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)  
22.20 S Z=FD(N,-FD(N))  
22.30 S Z=FD(27,-FD(27))

25.10 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))  
25.20 X FDO(2,-3,-1000)

28.10 T %4.0,"RT TO TARGETS =",RR/DD+60,!  
28.20 T "RESPONSES TO TARGETS =",DD,!  
28.30 T "ERRORS", "=",R,!  
28.40 Z RR,DD,R



12.10 A 1-1;D 13,28

13.01 S N=13;D 20;S N=9;D 20

13.02 S N=8,M=26;D 23;S N=10;D 20;S N=18;D 20

13.03 S N=14;D 20;S N=15;D 20;S N=8,M=9;D 24;S N=3;D 21

13.04 S N=16,M=15;D 23;S N=12,M=24;D 23;S N=11;D 20

13.05 S N=8,M=9;D 24;S N=16,M=15;D 23;S N=7;D 21;S N=26;D 20

13.06 S N=16;D 21;S N=11,M=10;D 23;S N=16;D 21;S N=26;D 20

13.07 S N=5;D 21;S N=15;D 20;S N=16,M=15;D 23;S N=7,M=9;D 23

13.08 S N=24,M=23;D 24;S N=6,M=17;D 23;S N=5,M=15;D 23;S N=8;D 20

13.09 S N=14,M=5;D 23;S N=17;D 20;S N=23;D 20;S N=16,M=14;D 23

13.10 S N=24,M=25;D 24;S N=13;D 20;S N=19;D 20;S N=19,M=20;D 23

13.11 S N=20;D 21;S N=23,M=26;D 23;S N=11,M=10;D 23

13.12 S N=23;D 20;S N=23,M=26;D 23;S N=12;D 20;S N=24,M=25;D 24

13.13 S N=7,M=9;D 23;S N=19,M=20;D 23;S N=19;D 20;S N=24;D 20

13.14 S N=23;D 20;S N=8,M=26;D 23;S N=18;D 20;S N=19;D 20

13.15 S N=9,M=10;D 23;S N=3,M=12;D 23;S N=18;D 20;S N=14,M=5;D 23

13.16 S N=6;D 20;S N=19,M=20;D 23;S N=8,M=9;D 24;S N=6,M=17;D 23

13.17 S N=22;D 21;S N=14;D 20;S N=11;D 20;S N=23,M=26;D 23

13.18 S N=17;D 20;S N=8,M=26;D 23;S N=9;D 20;S N=9,M=10;D 23

13.19 S N=4;D 21;S N=8,M=9;D 24;S N=12,M=24;D 23;S N=13;D 20

13.20 S N=24,M=23;D 24;S N=17;D 20;S N=7,M=9;D 23;S N=5;D 21

13.21 S N=7;D 21;S N=15;D 20;S N=18;D 20;S N=23,M=26;D 23

13.22 S N=12,M=24;D 23;S N=5,M=15;D 23;S N=16,M=15;D 23;S N=15,M=20;D 24

13.23 S N=16,M=14;D 23;S N=23,M=26;D 23;S N=10;D 20;S N=21;D 20

13.24 S N=6,M=15;D 23;S N=7,M=9;D 23;S N=25;D 20

13.25 S N=10;D 20;S N=9;D 20;S N=23,M=26;D 23

13.26 S N=7,M=9;D 23;S N=8,M=26;D 23;S N=12;D 20

13.27 S N=8,M=26;D 23;S N=11;D 20;S N=8,M=9;D 24;S N=1;D 20

20.10 D 22;X FDO(2,3,256) FDO(2,-3,-10) FDO(2,4,256) FDO(2,-3,-50);D 25

20.20 S WL=WL+FD(-4);X FDO(2,1)

21.05 D 22;X FDO(2,-3,-60);D 25

21.10 S RL=RL+FD(-1);X FDO(2,1)

21.30 I (FD(-4))21.4,21.5,21.4

21.40 Y L

21.50 R

22.10 S T=FRAN();I (T-.5)22.15,22.15,22.16

22.15 X FDO(2,-3,-1000)

22.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)

22.20 S Z=FD(N,-FD(N))

22.30 S Z=FD(27,-FD(27))

23.10 D 26;X FDO(2,3,512) FDO(2,-3,-10) FDO(2,4,512) FDO(2,-3,-50);D 27

23.20 S WV=WV+FD(-4);X FDO(2,1)

24.10 D 26;X FDO(2,-3,-60);D 27

24.20 S RV=RV+FD(-1);X FDO(2,1)

24.30 I (FD(-4))24.4,24.5,24.4

24.40 Y V

24.50 R

25.10 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))

25.20 X FDO(2,-3,-1000)

26.10 S T=FRAN();I (T-.5)26.15,26.15,26.16

26.15 X FDO(2,-3,-1000)

26.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)

26.20 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M))

26.30 S Z=FD(27,-FD(27))

27.05 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M)),Z=FD(27,-FD(27))

27.10 X FDO(2,-3,-1000)

28.10 T X4.1,"RT TO LETTER TARGETS=", (RL/L)+60,!

28.20 T "HITS TO LETTERS =",L," FALSE POSITIVES =",WL,!!

28.30 T "RT TO NONVERBAL TARGETS =", (RV/V)+60,!

28.40 T "HITS TO NONVERBALS =",V," FALSE POSITIVES =",WV,!

28.50 Z RL,L,WL,RV,V,WV



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C U/W--FOCAL: MIX1 NO/DA/TE
01.01 X FDO(6,0)ZIX FDO(2,-2,-2,2759) FDO(2,1)
01.10 D 3,5IT "D 9 FOR EG'S , D 6 AND 7 FOR EXP BLOCKS ",11
01.20 Q
02.05 S X=-20
02.10 D 11IS Z=1ID 8IS Z=XID 8IS Z=-19ID 8IS Z=2ID 8IS Z=10ID 8IS Z=5ID 8
03.05 F G=25ID 2IS Z=(193+G)-1024ID 8
03.10 F T=1,26ID 4
04.10 S Z=FD(T,-FD(T))
05.10 D 11IS Z=1ID 8IS Z=0ID 8IS Z=0ID 8IS Z=7ID 8
05.20 S Z=-1024ID 8IS Z=-1024ID 8
06.10 D 12,28
07.10 L G MIX2
08.10 X FD(FD(),Z)IS Z=FD(FD(),1)
09.10 L G EGSTIM
11.10 S Z=FD(63,FD(63)+1)
11.20 S Z=FD(Z,FD())
11.30 S Z=0ID 8
12.01 S N=8,M=26ID 23IS N=11ID 20IS N=8,M=9ID 24IS N=1ID 20
12.02 S N=7,M=9ID 23IS N=8,M=26ID 23IS N=12ID 20
12.03 S N=10ID 20IS N=9ID 20IS N=23,M=26ID 23
12.04 S N=6,M=15ID 23IS N=7,M=9ID 23IS N=25ID 20
12.05 S N=16,M=14ID 23IS N=23,M=26ID 23IS N=10ID 20IS N=21ID 20
12.06 S N=12,M=24ID 23IS N=23,M=15ID 23IS N=16,M=15ID 23IS N=15,M=20ID 24
12.07 S N=7ID 21IS N=15ID 20IS N=18ID 20IS N=23,M=26ID 23
12.08 S N=24,M=23ID 24IS N=17ID 20IS N=12,M=24ID 23IS N=5ID 21
12.09 S N=4ID 21IS N=8,M=9ID 24IS N=12,M=24ID 23IS N=9,M=10ID 23
12.10 S N=17ID 20IS N=8,M=26ID 23IS N=9ID 20IS N=9,M=10ID 23
12.11 S N=22ID 21IS N=14ID 20IS N=11ID 20IS N=23,M=26ID 23
12.12 S N=6ID 20IS N=19,M=20ID 23IS N=8,M=9ID 24IS N=6,M=17ID 23
12.13 S N=9,M=10ID 23IS N=3,M=12ID 23IS N=18ID 20IS N=14,M=5ID 23
12.14 S N=23ID 20IS N=8,M=26ID 23IS N=18ID 20IS N=19ID 20
12.15 S N=7,M=9ID 23IS N=19,M=20ID 23IS N=19ID 20IS N=24ID 20
12.16 S N=23ID 20IS N=23,M=26ID 23IS N=12ID 20IS N=24,M=25ID 24
12.17 S N=20ID 21IS N=23,M=26ID 23IS N=11,M=10ID 23
12.18 S N=24,M=25ID 24IS N=13ID 20IS N=19ID 20IS N=19,M=20ID 23
12.19 S N=14,M=5ID 23IS N=17ID 20IS N=23ID 20IS N=16,M=14ID 23
12.20 S N=24,M=23ID 24IS N=6,M=17ID 23IS N=5,M=15ID 23IS N=8ID 20
12.21 S N=5ID 21IS N=15ID 20IS N=16,M=15ID 23IS N=7,M=9ID 23
12.22 S N=16ID 21IS N=11,M=10ID 23IS N=16ID 21IS N=26ID 20
12.23 S N=8,M=9ID 24IS N=16,M=15ID 23IS N=7ID 21IS N=13ID 20
12.24 S N=16,M=15ID 23IS N=12,M=24ID 23IS N=11ID 20
12.25 S N=14ID 20IS N=15ID 20IS N=8,M=9ID 24IS N=3ID 21
12.26 S N=8,M=26ID 23IS N=10ID 20IS N=18ID 20
12.27 S N=13ID 20IS N=9ID 20
20.10 D 22IX FDO(2,3,256) FDO(2,-3,-10) FDO(2,4,256) FDO(2,-3,-50)ID 25
20.20 S WL=WL+FD((-4)IX FDO(2,1)

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01.01 X FDO(6,0);X FDO(2,-2,-2,2759) FDO(2,1)
01.10 D 3,5;T "D 9 FOR EG'S , D 6 AND 7 FOR EXP BLOCKS ",!!
01.20 Q

02.05 S X=-20
02.10 D 11;S Z=1;D 8;S Z=X;D 8;S Z=-19;D 8;S Z=2;D 8;S Z=10;D 8;S Z=5;D 8

03.05 F G=,25;D 2;S Z=(193+G)-1024;D 8
03.10 F T=1,26;D 4

04.10 S Z=FD(T,-FD(T))

05.10 D 11;S Z=1;D 8;S Z=0;D 8;S Z=0;D 8;S Z=7;D 8
05.20 S Z=-1024;D 8;S Z=-1024;D 8

06.10 D 12,28

07.10 L G MIX2

08.10 X FD(FD(),Z);S Z=FD(,FD()+1)

09.10 L G EGSTIM

11.10 S Z=FD(63,FD(63)+1)
11.20 S Z=FD(Z,FD())
11.30 S Z=0;D 8

12.01 S N=8,M=26;D 23;S N=11;D 20;S N=8,M=9;D 24;S N=1;D 20
12.02 S N=7,M=9;D 23;S N=8,M=26;D 23;S N=12;D 20
12.03 S N=10;D 20;S N=9;D 20;S N=23,M=26;D 23
12.04 S N=6,M=15;D 23;S N=7,M=9;D 23;S N=25;D 20
12.05 S N=16,M=14;D 23;S N=23,M=26;D 23;S N=10;D 20;S N=21;D 20
12.06 S N=12,M=24;D 23;S N=5,M=15;D 23;S N=16,M=15;D 23;S N=15,M=20;D 24
12.07 S N=7;D 21;S N=15;D 20;S N=18;D 20;S N=23,M=26;D 23
12.08 S N=24,M=23;D 24;S N=17;D 20;S N=7,M=9;D 23;S N=5;D 21
12.09 S N=4;D 21;S N=8,M=9;D 24;S N=12,M=24;D 23;S N=13;D 20
12.10 S N=17;D 20;S N=8,M=26;D 23;S N=9;D 20;S N=9,M=10;D 23
12.11 S N=22;D 21;S N=14;D 20;S N=11;D 20;S N=23,M=26;D 23
12.12 S N=6;D 20;S N=19,M=20;D 23;S N=8,M=9;D 24;S N=6,M=17;D 23
12.13 S N=9,M=10;D 23;S N=3,M=12;D 23;S N=18;D 20;S N=14,M=5;D 23
12.14 S N=23;D 20;S N=8,M=26;D 23;S N=18;D 20;S N=19;D 20
12.15 S N=7,M=9;D 23;S N=19,M=20;D 23;S N=19;D 20;S N=24;D 20
12.16 S N=23;D 20;S N=23,M=26;D 23;S N=12;D 20;S N=24,M=25;D 24
12.17 S N=20;D 21;S N=23,M=26;D 23;S N=11,M=10;D 23
12.18 S N=24,M=25;D 24;S N=13;D 20;S N=19;D 20;S N=19,M=20;D 23
12.19 S N=14,M=5;D 23;S N=17;D 20;S N=23;D 20;S N=16,M=14;D 23
12.20 S N=24,M=23;D 24;S N=6,M=17;D 23;S N=5,M=15;D 23;S N=8;D 20
12.21 S N=5;D 21;S N=15;D 20;S N=16,M=15;D 23;S N=7,M=9;D 23
12.22 S N=16;D 21;S N=11,M=10;D 23;S N=16;D 21;S N=26;D 20
12.23 S N=8,M=9;D 24;S N=16,M=15;D 23;S N=7;D 21;S N=13;D 20
12.24 S N=16,M=15;D 23;S N=12,M=24;D 23;S N=11;D 20
12.25 S N=14;D 20;S N=15;D 20;S N=8,M=9;D 24;S N=3;D 21
12.26 S N=8,M=26;D 23;S N=10;D 20;S N=18;D 20
12.27 S N=13;D 20;S N=9;D 20

20.10 D 22;X FDO(2,3,256) FDO(2,-3,-10) FDO(2,4,256) FDO(2,-3,-50);D 25
20.20 S WL=WL+FD(-4);X FDO(2,1)

21.05 D 22;X FDO(2,-3,-60);D 25
21.10 S RL=RL+FD(-1);X FDO(2,1)
21.30 I (FD(-4))21.4,21.5,21.4
21.40 Y L
21.50 R

22.10 S T=FRAN();I (T-.5)22.15,22.15,22.16
22.15 X FDO(2,-3,-1000)
22.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)
22.20 S Z=FD(N,-FD(N))
22.30 S Z=FD(27,-FD(27))

23.10 D 26;X FDO(2,3,512) FDO(2,-3,-10) FDO(2,4,512) FDO(2,-3,-50);D 27
23.20 S WV=WV+FD(-4);X FDO(2,1)

24.10 D 26;X FDO(2,-3,-60);D 27
24.20 S RV=RV+FD(-1);X FDO(2,1)
24.30 I (FD(-4))24.4,24.5,24.4
24.40 Y V
24.50 R

25.10 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))
25.20 X FDO(2,-3,-1000)

26.10 S T=FRAN();I (T-.5)26.15,26.15,26.16
26.15 X FDO(2,-3,-1000)
26.16 X FDO(2,-3,-1000) FDO(2,-3,-1000)
26.20 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M))
26.30 S Z=FD(27,-FD(27))

27.05 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M)),Z=FD(27,-FD(27))
27.10 X FDO(2,-3,-1000)

28.10 T %4.1,"RT TO LETTER TARGETS=", (RL/L)+60,!
28.20 T "HITS TO LETTERS =" ,L, " FALSE POSITIVES =" ,WL,!
28.30 T "RT TO NONVERBAL TARGETS =" , (RV/V)+60,!
28.40 T "HITS TO NONVERBALS =" ,V, " FALSE POSITIVES =" ,WV,!
28.50 Z RL,L,WL,RV,V,WV

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C U/W-FOCAL: SEQF30 NO/DA/TE

01.10 X FDO(2,-2,-2,2759) FDO(2,1)
01.15 Z
01.20 D 2
02.01 S P=FRAN(*)X1000;X FDO(2,-3,-P)FDO(2,-3,-P)FDO(2,-3,-2000)
02.02 I (L+M+N)-125)2.1,2.03,2.05
02.03 T "HALF WAY" ;A ;1;G 2.05
02.05 I (L+M+N)-250)2.1,2.07
02.07 T "DONE" ;Q
02.10 S J=FRAN();I (.8-J)2.2,2.3,2.3
02.20 I (.9-J)2.4,2.5,2.5
02.30 D 3;G 2.6
02.40 D 4;G 2.6
02.50 D 5
02.60 G 2.01
03.10 I (200-L)3.2,3.3
03.20 X FDO(2,3,256) FDO(2,-3,-50)FDO(2,4,256);Y L
03.30 R
04.10 I (25-M)4.2,4.3
04.20 X FDO(2,3,512) FDO(2,-3,-50) FDO(2,4,512);Y M
04.30 R
05.10 I (25-N)5.2,5.3
05.20 X FDO(2,3,1024) FDO(2,-3,-50) FDO(2,4,1024);Y N
05.30 R
28.40 Z RR,DD,R

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C U/W-FOCAL: LEN300 NO/DA/TE

01.01 X FDO(6,0) FDO(2,-2,-2,2759) FDO(2,1)

01.10 D 3,5;T "D 12 OR 13 FOR STIMULI",!!

01.20 Q

02.05 S X=-20

02.10 D 11;S Z=1;D 8;S Z=X;D 8;S Z=-19;D 8;S Z=2;D 8;S Z=10;D 8;S Z=5;D 8

03.05 F G=,25;D 2;S Z=(193+G)-1024;D 8

03.10 F T=1,26;D 4

04.10 S Z=FD(T,-FD(T))

05.10 D 11;S Z=1;D 8;S Z=0;D 8;S Z=0;D 8;S Z=7;D 8

05.20 S Z=-1024;D 8;S Z=-1024;D 8

08.10 X FD(FD(),Z);S Z=FD(,FD()+1)

11.10 S Z=FD(63,FD(63)+1)

11.20 S Z=FD(Z,FD())

11.30 Z Z;D 8

12.01 S N=4;D 21;S N=7;D 21;S N=13;D 20;S N=25;D 20;S N=16;D 21

12.02 S N=2;D 21;S N=6;D 21;S N=26;D 21;S N=14;D 21;S N=20;D 20

12.03 S N=10;D 21;S N=1;D 20;S N=18;D 21;S N=19;D 21;S N=20;D 20

12.04 S N=4;D 21;S N=13;D 20;S N=14;D 21;S N=1;D 20;S N=7;D 20

12.05 S N=16;D 21;S N=22;D 20;S N=6;D 21;S N=10;D 21;S N=1;D 20

12.06 S N=18;D 21;S N=26;D 21;S N=25;D 20;S N=2;D 21;S N=4;D 21

12.07 S N=10;D 21;S N=20;D 20;S N=18;D 21;S N=25;D 20;S N=4;D 21

12.08 S N=26;D 21;S N=13;D 20;S N=2;D 21;S N=7;D 21;S N=6;D 21

12.09 S N=19;D 21;S N=22;D 20;S N=14;D 21;S N=16;D 21;S N=25;D 21

12.10 S N=4;D 21;S N=26;D 21;S N=16;D 21;S N=10;D 21;S N=13;D 20

12.11 S N=18;D 21;S N=2;D 21;S N=22;D 20;S N=19;D 21;S N=14;D 21

12.12 S N=20;D 20;S N=6;D 21;S N=7;D 20;S N=22;D 20;S N=7;D 21

12.13 D 28

13.01 S N=20;D 20;S N=6;D 21;S N=7;D 20;S N=22;D 20;S N=7;D 21

13.02 S N=18;D 21;S N=2;D 21;S N=22;D 20;S N=19;D 21;S N=14;D 21

13.03 S N=4;D 21;S N=26;D 21;S N=16;D 21;S N=10;D 21;S N=13;D 20

13.04 S N=19;D 21;S N=22;D 20;S N=14;D 21;S N=16;D 21;S N=25;D 21

13.05 S N=26;D 21;S N=13;D 20;S N=2;D 21;S N=7;D 21;S N=6;D 21

13.06 S N=10;D 21;S N=20;D 20;S N=18;D 21;S N=25;D 20;S N=4;D 21

13.07 S N=18;D 21;S N=26;D 21;S N=25;D 20;S N=2;D 21;S N=4;D 21

13.08 S N=16;D 21;S N=22;D 20;S N=6;D 21;S N=10;D 21;S N=1;D 20

13.09 S N=4;D 21;S N=13;D 20;S N=14;D 21;S N=1;D 20;S N=7;D 20

13.10 S N=10;D 21;S N=1;D 20;S N=18;D 21;S N=19;D 21;S N=20;D 20

13.11 S N=2;D 21;S N=6;D 21;S N=26;D 21;S N=14;D 21;S N=20;D 20

13.12 S N=4;D 21;S N=7;D 21;S N=13;D 20;S N=25;D 20;S N=16;D 21

13.13 D 28

20.05 D 22;X FDO(2,3,32) FDO(2,-3,-10) FDO(2,4,32)

20.06 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))

20.10 X FDO(2,-3,-100);D 25;X FDO(2,-3,-1000)

20.20 S RR=RR+FD(-1);X FDO(2,1);I (FD(-4))20,4,20,5,20,4

20.40 Y DD

20.50 R

21.05 D 22;X FDO(2,3,16) FDO(2,-3,-10) FDO(2,4,16)

21.06 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))

21.20 X FDO(2,-3,-100);D 25;X FDO(2,-3,-1000)

21.30 S R=R+FD(-4);X FDO(2,1)

22.10 S D=FRAN()\*1000;F A=,3;D 26

25.10 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))

26.10 X FDO(2,-3,-D)

28.10 T %4.0,"RT TO TARGETS =",RR/DD+60,!

28.20 T "RESPONSES TO TARGETS =",DD,!

28.30 T "ERRORS", "=",R,!

28.40 Z RR,DD,R



C U/W-FOCAL: NVP300 NO/DA/TE

01.01 X FDO(6,0) FDO(2,-2,-2,2759) FDO(2,1)

01.10 D 3,5;T "D 12 OR 13 FOR STIMULI",!!

01.20 Q

02.05 S X=-20

02.10 D 11;S Z=1;D 8;S Z=X;D 8;S Z=-19;D 8;S Z=2;D 8;S Z=10;D 8;S Z=5;D 8

03.05 F G=,25;D 2;S Z=(193+G)-1024;D 8

03.10 F T=1,26;D 4

04.10 S Z=FD(T,-FD(T))

05.10 D 11;S Z=1;D 8;S Z=0;D 8;S Z=0;D 8;S Z=7;D 8

05.20 S Z=-1024;D 8;S Z=-1024;D 8

08.10 X FD(FD(),Z);S Z=FD(FD()+1)

11.10 S Z=FD(63,FD(63))+1)

11.20 S Z=FD(Z,FD())

11.30 Z Z;D 8

12.01 S N=12,M=24;D 21;S N=15,M=20;D 20;S N=21,M=22;D 20

12.02 S N=14,M=5;D 21;S N=24,M=25;D 20;S N=11,M=8;D 21

12.03 S N=12,M=24;D 21;S N=24,M=23;D 20;S N=23,M=26;D 21

12.04 S N=5,M=15;D 21;S N=24,M=23;D 20;S N=4,M=8;D 21

12.05 S N=5,M=15;D 21;S N=8,M=26;D 21;S N=6,M=17;D 21

12.06 S N=15,M=20;D 20;S N=4,M=8;D 21;S N=8,M=26;D 21

12.07 S N=21,M=22;D 20;S N=8,M=26;D 21;S N=12,M=24;D 21

12.08 S N=16,M=14;D 21;S N=6,M=17;D 21;S N=24,M=23;D 20

12.09 S N=8,M=26;D 21;S N=23,M=26;D 21;S N=21,M=22;D 20

12.10 S N=14,M=5;D 21;S N=8,M=9;D 20;S N=6,M=17;D 21

12.11 S N=5,M=15;D 21;S N=4,M=8;D 21;S N=15,M=20;D 20

12.12 S N=23,M=26;D 21;S N=11,M=8;D 21;S N=24,M=25;D 20

12.13 S N=4,M=8;D 21;S N=5,M=15;D 21;S N=8,M=9;D 20

12.14 S N=23,M=26;D 21;S N=6,M=17;D 21;S N=24,M=23;D 20

12.15 S N=11,M=8;D 21;S N=24,M=25;D 20;S N=11,M=10;D 21

12.16 S N=15,M=20;D 20;S N=16,M=14;D 21;S N=12,M=24;D 21

12.17 S N=21,M=22;D 20;S N=11,M=10;D 21;S N=8,M=9;D 20

12.18 S N=14,M=5;D 21;S N=11,M=10;D 21;S N=14,M=5;D 21

12.19 S N=11,M=8;D 21;S N=11,M=10;D 21;S N=8,M=9;D 20

12.20 S N=24,M=25;D 20;S N=16,M=14;D 21;S N=16,M=14;D 21

12.21 D 28

13.01 S N=24,M=25;D 20;S N=16,M=14;D 21;S N=16,M=14;D 21

13.02 S N=11,M=8;D 21;S N=11,M=10;D 21;S N=8,M=9;D 20

13.03 S N=14,M=5;D 21;S N=11,M=10;D 21;S N=14,M=5;D 21

13.04 S N=21,M=22;D 20;S N=11,M=10;D 21;S N=8,M=9;D 20

13.05 S N=15,M=20;D 20;S N=16,M=14;D 21;S N=12,M=24;D 21

13.06 S N=11,M=8;D 21;S N=24,M=25;D 20;S N=11,M=10;D 21

13.07 S N=23,M=26;D 21;S N=6,M=17;D 21;S N=24,M=23;D 20

13.08 S N=4,M=8;D 21;S N=5,M=15;D 21;S N=8,M=9;D 20

13.09 S N=23,M=26;D 21;S N=11,M=8;D 21;S N=24,M=25;D 20

13.10 S N=5,M=15;D 21;S N=4,M=8;D 21;S N=15,M=20;D 20

13.11 S N=14,M=5;D 21;S N=8,M=9;D 20;S N=6,M=17;D 21

13.12 S N=8,M=26;D 21;S N=23,M=26;D 21;S N=21,M=22;D 20

13.13 S N=16,M=14;D 21;S N=6,M=17;D 21;S N=24,M=23;D 20

13.14 S N=21,M=22;D 20;S N=8,M=26;D 21;S N=12,M=24;D 21

13.15 S N=15,M=20;D 20;S N=4,M=8;D 21;S N=8,M=26;D 21

13.16 S N=5,M=15;D 21;S N=8,M=26;D 21;S N=6,M=17;D 21

13.17 S N=5,M=15;D 21;S N=24,M=23;D 20;S N=4,M=8;D 21

13.18 S N=12,M=24;D 21;S N=24,M=23;D 20;S N=23,M=26;D 21

13.19 S N=14,M=5;D 21;S N=24,M=25;D 20;S N=11,M=8;D 21

13.20 S N=12,M=24;D 21;S N=15,M=20;D 20;S N=21,M=22;D 20

13.30 D 28

20.05 D 22;X FDO(2,3,32) FDO(2,-3,-10) FDO(2,4,32)

20.06 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M)),Z=FD(27,-FD(27))

20.10 X FDO(2,-3,-100);D 25;X FDO(2,-3,-1000)

20.20 S RR=RR+FD(-1);X FDO(2,1);I (FD(-4))20.4,20.5,20.4

20.40 Y DD

20.50 R

21.05 D 22;X FDO(2,3,16) FDO(2,-3,-10) FDO(2,4,16)

21.06 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M)),Z=FD(27,-FD(27))

21.10 X FDO(2,-3,-100);D 25;X FDO(2,-3,-1000)

21.20 X FDO(2,3,256) FDO(2,-3,-10) FDO(2,4,256) FDO(2,-3,-790)

21.30 S R=R+FD(-4);X FDO(2,1)

22.10 S D=FRAN()\*1000;F A=,3;D 26

25.10 S Z=FD(N,-FD(N)),Z=FD(M,-FD(M)),Z=FD(27,-FD(27))

26.10 X FDO(2,-3,-D)

28.10 T %4.0,"RT TO TARGETS =",RR/DD+60,!

28.20 T "RESPONSES TO TARGETS =",DD,!

28.30 T "ERRORS", "=",R,!

28.40 Z RR,DD,R



U/W-FOCAL: LEP300 NO/DA/TE

01.01 X FDO(6,0) FDO(2,-2,-2,2759) FDO(2,1)

01.10 D 3,5;T "D 12 OR 13 FOR STIMULI",!!

01.20 Q

02.05 S X=-20

02.10 D 11;S Z=1;D 8;S Z=X;D 8;S Z=-19;D 8;S Z=2;D 8;S Z=10;D 8;S Z=5;D 8

03.05 F G=,25;D 2;S Z=(193+G)-1024;D 8

03.10 F T=1,26;D 4

04.10 S Z=FD(T,-FD(T))

05.10 D 11;S Z=1;D 8;S Z=0;D 8;S Z=0;D 8;S Z=7;D 8

05.20 S Z=-1024;D 8;S Z=-1024;D 8

08.10 X FD(FD(),Z);S Z=FD(,FD()+1)

11.10 S Z=FD(63,FD(63)+1)

11.20 S Z=FD(Z,FD())

11.30 Z Z;D 8

12.01 S N=15;D 21;S N=15;D 21;S N=20;D 20;S N=4;D 20;S N=12;D 21

12.02 S N=23;D 21;S N=1;D 21;S N=12;D 21;S N=1;D 21;S N=4;D 20

12.03 S N=12;D 21;S N=7;D 20;S N=18;D 21;S N=15;D 21;S N=16;D 20

12.04 S N=12;D 21;S N=20;D 20;S N=23;D 21;S N=2;D 20;S N=14;D 21

12.05 S N=10;D 21;S N=4;D 20;S N=8;D 21;S N=25;D 21;S N=20;D 20

12.06 S N=23;D 21;S N=10;D 21;S N=16;D 20;S N=25;D 21;S N=8;D 21

12.07 S N=14;D 21;S N=4;D 20;S N=1;D 21;S N=7;D 20;S N=10;D 21

12.08 S N=6;D 21;S N=2;D 20;S N=14;D 21;S N=15;D 21;S N=18;D 21

12.09 S N=6;D 21;S N=7;D 20;S N=6;D 21;S N=25;D 21;S N=16;D 20

12.10 S N=14;D 21;S N=6;D 21;S N=8;D 21;S N=25;D 21;S N=2;D 20

12.11 S N=8;D 21;S N=10;D 21;S N=2;D 20;S N=18;D 21;S N=23;D 21

12.12 S N=20;D 20;S N=1;D 21;S N=7;D 20;S N=16;D 20;S N=18;D 21;D 28

13.01 S N=20;D 20;S N=1;D 21;S N=7;D 20;S N=16;D 20;S N=18;D 21

13.02 S N=8;D 21;S N=10;D 21;S N=2;D 20;S N=18;D 21;S N=23;D 21

13.03 S N=14;D 21;S N=6;D 21;S N=8;D 21;S N=25;D 21;S N=2;D 20

13.04 S N=6;D 21;S N=7;D 20;S N=6;D 21;S N=25;D 21;S N=16;D 20

13.05 S N=6;D 21;S N=2;D 20;S N=14;D 21;S N=15;D 21;S N=18;D 21

13.06 S N=14;D 21;S N=4;D 20;S N=1;D 21;S N=7;D 20;S N=10;D 21

13.07 S N=23;D 21;S N=10;D 21;S N=16;D 20;S N=25;D 21;S N=8;D 21

13.08 S N=10;D 21;S N=4;D 20;S N=8;D 21;S N=25;D 21;S N=20;D 20

13.09 S N=12;D 21;S N=20;D 20;S N=23;D 21;S N=2;D 20;S N=14;D 21

13.10 S N=12;D 21;S N=7;D 20;S N=18;D 21;S N=15;D 21;S N=16;D 20

13.11 S N=23;D 21;S N=1;D 21;S N=12;D 21;S N=1;D 21;S N=4;D 20

13.12 S N=20;D 20;S N=1;D 21;S N=7;D 20;S N=16;D 20;S N=18;D 21;D 28

13.13 D 28

20.05 D 22;X FDO(2,3,32) FDO(2,-3,-10) FDO(2,4,32)

20.06 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))

20.10 X FDO(2,-3,-100);D 25;X FDO(2,-3,-1000)

20.20 S RR=RR+FD(-1);X FDO(2,1);I (FD(-4))20.4,20.5,20.4

20.40 Y DD

20.50 R

21.05 D 22;X FDO(2,3,16) FDO(2,-3,-10) FDO(2,4,16)

21.06 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))

21.20 X FDO(2,-3,-100);D 25;X FDO(2,-3,-1000)

21.30 S R=R+FD(-4);X FDO(2,1)

22.10 S D=FRAN()\*1000;F A=,3;D 24

25.10 S Z=FD(N,-FD(N)),Z=FD(27,-FD(27))

26.10 X FDO(2,-3,-D)

28.10 T %4.0,"RT TO TARGETS =",RR/DD+60,!

28.20 T "RESPONSES TO TARGETS =",DD,!

28.30 T "ERRORS", "=",R,!

28.40 Z RR,DD,R

EXPERIMENT 1 COMPONENT P1 LATENCY

SOURCE	SS	DF	MS	F	P
A	113.78	1	113.78	<1	NS
B	21.78	1	21.78	<1	NS
S	7774.39	8	971.80		
A B	3481.00	1	3481.00	58.01	.001
A S	3105.72	8	388.22		
B S	925.72	8	115.72		
A B S	479.50	8	59.94		
TOTAL	15901.89	35			

EXPERIMENT 1 COMPONENT N1 LATENCY

SOURCE	SS	DF	MS	F	P
A	940.44	1	940.44	2.89	NS
B	0.44	1	0.44	<1	NS
S	14117.50	8	1764.69		
A B	860.44	1	860.44	20.32	.001
A S	2604.06	8	325.51		
B S	1822.06	8	227.76		
A B S	301.06	8	37.63		
TOTAL	20646.00	35			

EXPERIMENT 1 COMPONENT P2 LATENCY

SOURCE	SS	DF	MS	F	P
A	491.36	1	491.36	1.30	NS
B	3.36	1	3.36	<1	NS
S	14654.50	8	1831.81		
A B	8.03	1	8.03	<1	NS
A S	3028.39	8	378.55		
B S	84.39	8	10.55		
A B S	110.72	8	13.84		
TOTAL	18380.75	35			

EXPERIMENT 1 COMPONENT N2 LATENCY

SOURCE	SS	DF	MS	F	P
A	1418.78	1	1418.78	1.79	NS
B	256.00	1	256.00	1.03	NS
S	3249.39	8	406.17		
A B	13.44	1	13.44	<1	NS
A S	6332.72	8	791.59		
B S	1991.50	8	248.94		
A B S	1285.06	8	160.63		
TOTAL	14546.89	35			

EXPERIMENT 1 COMPONENT P1-N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	1521.00	1	1521.00	2.56	NS
B	169.00	1	169.00	<1	NS
S	28160.06	8	3520.01		
A B	513.78	1	513.78	1.55	NS
A S	4758.50	8	594.81		
B S	5606.50	8	700.81		
A B S	2636.72	8	329.59		
TOTAL	43365.56	35			

EXPERIMENT 1 COMPONENT N1-P2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	20.25	1	20.25	<1	NS
B	910.03	1	910.03	1.64	NS
S	73000.72	8	9125.09		
A B	2384.69	1	2384.69	10.87	.025
A S	7897.50	8	987.19		
B S	4420.72	8	552.59		
A B S	1755.06	8	219.38		
TOTAL	90388.97	35			

EXPERIMENT 1 COMPONENT P2-N2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	42.25	1	42.25	<1	NS
B	124.69	1	124.69	<1	NS
S	28581.89	8	3572.74		
A B	2.25	1	2.25	<1	NS
A S	2988.00	8	373.50		
B S	3144.56	8	393.07		
A B S	1266.00	8	158.25		
TOTAL	36149.64	35			

A= VISUAL FIELDS  
B= HEMISPHERES  
C= SUBJECTS



## EXPERIMENT 2 COMPONENT P1 LATENCY

SOURCE	SS	DF	MS	F	P
A	277.78	1	277.78	3.76	NS
B	53.78	1	53.78	<1	NS
S	2418.72	8	302.34		
A B	1067.11	1	1067.11	45.56	.001
A S	590.72	8	73.84		
B S	600.72	8	75.09		
A B S	187.39	8	23.42		
TOTAL	5196.22	35			

## EXPERIMENT 2 COMPONENT N1 LATENCY

SOURCE	SS	DF	MS	F	P
A	841.00	1	841.00	3.93	NS
B	177.78	1	177.78	1.27	NS
S	4071.50	8	508.94		
A B	1626.78	1	1626.78	14.21	.01
A S	1711.50	8	213.94		
B S	1117.72	8	139.72		
A B S	915.72	8	114.47		
TOTAL	10462.00	35			

## EXPERIMENT 2 COMPONENT P2 LATENCY

SOURCE	SS	DF	MS	F	P
A	46.69	1	46.69	<1	NS
B	0.03	1	0.03	<1	NS
S	8916.72	8	1114.59		
A B	66.69	1	66.69	2.74	NS
A S	1341.06	8	167.63		
B S	400.72	8	50.09		
A B S	489.06	8	61.13		
TOTAL	11260.97	35			

## EXPERIMENT 2 COMPONENT N2 LATENCY

SOURCE	SS	DF	MS	F	P
A	200.69	1	200.69	<1	NS
B	72.25	1	72.25	1.97	NS
S	5244.50	8	655.56		
A B	140.03	1	140.03	1.39	NS
A S	2361.06	8	295.13		
B S	292.50	8	36.56		
A B S	851.72	8	106.47		
TOTAL	9170.75	35			

## EXPERIMENT 2 COMPONENT P1-N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	5017.36	1	5017.36	4.07	NS
B	380.25	1	380.25	<1	NS
S	28664.89	8	3583.11		
A B	684.69	1	684.69	<1	NS
A S	9858.09	8	1232.36		
B S	3830.00	8	478.75		
A B S	8109.56	8	1013.69		
TOTAL	56545.64	35			

## EXPERIMENT 2 COMPONENT N1-P2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	6032.11	1	6032.11	31.82	.001
B	1.00	1	1.00	<1	NS
S	83202.50	8	10400.31		
A B	6136.11	1	6136.11	15.58	.01
A S	1516.39	8	189.55		
B S	3000.50	8	375.06		
A B S	3150.39	8	393.80		
TOTAL	103039.00	35			

## EXPERIMENT 2 COMPONENT P2-N2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	0.69	1	0.69	<1	NS
B	756.25	1	756.25	10.31	.025
S	17534.06	8	2191.76		
A B	0.69	1	0.69	<1	NS
A S	668.06	8	83.51		
B S	586.50	8	73.31		
A B S	2508.06	8	313.51		
TOTAL	22054.31	35			

A= VISUAL FIELDS  
B= HEMISPHERES  
C= SUBJECTS



## EXPERIMENT 3 COMPONENT P1 LATENCY

SOURCE	SS	DF	MS	F	P
A	632.02	1	632.02	14.42	.01
B	330.63	1	330.63	22.96	.01
S	2935.63	9	326.18		
A B	330.63	1	330.63	4.08	NS
A S	394.23	9	43.80		
B S	129.63	9	14.40		
A B S	727.63	9	80.85		
TOTAL	5480.38	39			

## EXPERIMENT 3 COMPONENT N1 LATENCY

SOURCE	SS	DF	MS	F	P
A	211.60	1	211.60	4.77	NS
B	3.60	1	3.60	<1	NS
S	8160.50	9	906.72		
A B	592.90	1	592.90	7.66	.025
A S	398.40	9	44.27		
B S	300.40	9	33.38		
A B S	696.10	9	77.34		
TOTAL	10363.50	39			

## EXPERIMENT 3 COMPONENT P2 LATENCY

SOURCE	SS	DF	MS	F	P
A	8.10	1	8.10	<1	NS
B	12.10	1	12.10	<1	NS
S	44316.10	9	4924.10		
A B	122.50	1	122.50	3.5	NS
A S	3179.90	9	353.32		
B S	232.90	9	25.88		
A B S	313.50	9	34.83		
TOTAL	48185.10	39			

## EXPERIMENT 3 COMPONENT N2 LATENCY

SOURCE	SS	DF	MS	F	P
A	275.63	1	275.63	1.99	NS
B	93.03	1	93.03	2.98	NS
S	44605.73	9	4956.19		
A B	0.02	1	0.02	<1	NS
A S	1245.13	9	138.35		
B S	280.72	9	31.19		
A B S	323.73	9	35.97		
TOTAL	46823.98	39			

## EXPERIMENT 3 COMPONENT P1-N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	78.40	1	78.40	<1	NS
B	28.90	1	28.90	<1	NS
S	74803.90	9	8311.54		
A B	1123.60	1	1123.60	3.20	NS
A S	5163.60	9	573.73		
B S	3317.10	9	368.17		
A B S	3150.40	9			
TOTAL	87665.90	39			

## EXPERIMENT 3 COMPONENT N1-P2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	874.22	1	874.22	1.42	NS
B	65.03	1	65.03	<1	NS
S	221454.52	9	24606.06		
A B	2975.62	1	2975.62	12.54	.01
A S	5506.62	9	611.84		
B S	1340.72	9	148.997		
A B S	2135.13	9	237.24		
TOTAL	234351.77	39			

## EXPERIMENT 3 COMPONENT P2-N2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	188.90	1	188.90	1.44	NS
B	67.60	1	67.60	2.29	NS
S	16260.40	9	1806.71		
A B	12.10	9	12.10	<1	NS
A S	678.10	9	75.34		
B S	265.40	9	29.49		
A B S	471.90	9	52.43		
TOTAL	17864.40	39			

A= VISUAL FIELDS  
B= HEMISPHERES  
C= SUBJECTS

## EXPERIMENT 4 COMPONENT P1 LATENCY

SOURCE	SS	DF	MS	F	P
A	1.36	1	1.36	<1	NS
B	210.25	1	210.25	5.32	.05
S	1420.22	8	177.53		
A B	66.69	1	66.69	1.47	NS
A S	232.89	8	29.11		
B S	316.00	8	39.50		
A B S	361.56	8	45.19		
TOTAL	2608.97	35			

## EXPERIMENT 4 COMPONENT N1 LATENCY

SOURCE	SS	DF	MS	F	P
A	28.44	1	28.44	<1	NS
B	18.77	1	18.77	<1	NS
S	5164.22	8	645.22		
A B	5.45	1	5.45	<1	NS
A S	1688.56	8	211.07		
B S	1226.23	8	153.28		
A B S	1066.55	8	133.32		
TOTAL	9198.22	36			

## EXPERIMENT 4 COMPONENT P2 LATENCY

SOURCE	SS	DF	MS	F	P
A	1078.03	1	1078.03	2.52	NS
B	46.67	1	46.67	<1	NS
S	16559.50	8	2069.94		
A B	4.70	1	4.70	<1	NS
A S	3426.72	8	428.34		
B S	1376.06	8	172.01		
A B S	301.05	8	37.63		
TOTAL	22792.75	36			

## EXPERIMENT 4 COMPONENT N2 LATENCY

SOURCE	SS	DF	MS	F	P
A	0.04	1	0.04	<1	NS
B	1.21	1	1.21	<1	NS
S	7944.38	8	993.05		
A B	0.06	1	0.06	<1	NS
A S	3938.75	8	492.34		
B S	244.75	8	30.59		
A B S	159.69	8	19.96		
TOTAL	12295.63	36			

## EXPERIMENT 4 COMPONENT P1-N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	1190.25	1	1190.25	2.8	NS
B	61.36	1	61.36	<1	NS
S	92928.06	8	11616.01		
A B	34.03	1	34.03	<1	NS
A S	3324.50	8	415.56		
B S	24673.39	8	3084.17		
A B S	618.72	8	77.34		
TOTAL	122830.21	35			

## EXPERIMENT 4 COMPONENT N1-P2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	191.36	1	191.36	<1	NS
B	250.69	1	250.69	<1	NS
S	84751.56	8	10593.94		
A B	117.36	1	117.36	<1	NS
A S	2302.89	8	287.86		
B S	12597.56	8	1574.69		
A B S	1052.89	8	131.61		
TOTAL	101264.31	35			

## EXPERIMENT 4 COMPONENT P2-N2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	6507.11	1	6507.11	21.46	.01
B	225.00	1	225.00	<1	NS
S	9638.72	8	1204.84		
A B	81.00	1	81.00	<1	NS
A S	2425.39	8	303.17		
B S	2541.50	8	317.69		
A B S	1117.50	8	139.69		
TOTAL	22536.22	35			

A= STIMULI  
B= HEMISPHERES  
C= SUBJECTS



## EXPERIMENT 6 COMPONENT P1 LATENCY

SOURCE	SS	DF	MS	F	P
A	3.03	1	3.03	<1	NS
B	680.23	1	680.23	18.41	.01
S	6456.23	9	717.36		
A B	9.03	1	9.03	<1	NS
A S	1185.22	9	131.69		
B S	332.63	9	36.96		
A B S	89.23	9	9.91		
TOTAL	8755.98	35			

## EXPERIMENT 6 COMPONENT N1 LATENCY

SOURCE	SS	DF	MS	F	P
A	1.23	1	1.23	<1	NS
B	235.23	1	235.23	8.69	.025
S	19840.73	9	2204.53		
A B	7.22	1	7.22	<1	NS
A S	2108.52	9	234.28		
B S	243.52	9	27.06		
A B S	394.53	9	43.84		
TOTAL	22830.98	39			

## EXPERIMENT 6 COMPONENT P2 LATENCY

SOURCE	SS	DF	MS	F	P
A	36.10	1	36.10	<1	NS
B	211.60	1	211.60	3.90	NS
S	7345.90	9	816.21		
A B	193.60	1	193.60	11.36	.025
A S	2574.90	9	286.10		
B S	486.40	9	54.04		
A B S	153.40	9	17.04		
TOTAL	11001.90	39			

## EXPERIMENT 6 COMPONENT N2 LATENCY

SOURCE	SS	DF	MS	F	P
A	289.00	1	289.00	<1	NS
B	53.78	1	53.78	<1	NS
S	18797.72	8	2349.72		
A B	7.09	1	7.09	<1	NS
A S	2528.5	8	316.06		
B S	263.72	8	32.97		
A B S	225.41	8	28.18		
TOTAL	22165.21	36			

## EXPERIMENT 6 COMPONENT P1-N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	2.02	1	2.02	<1	NS
B	18879.02	1	18879.02	7.73	.025
S	168547.73	9	18727.53		
A B	265.23	1	265.23	<1	NS
A S	6824.73	9	758.30		
B S	21974.73	9	2441.64		
A B S	4403.52	9	489.28		
TOTAL	220896.98	39			

## EXPERIMENT 6 COMPONENT N1-P2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	372.01	1	372.01	<1	NS
B	5808.10	1	5808.10	5.02	.05
S	257154.00	9	28572.67		
A B	67.60	1	67.60	<1	NS
A S	6438.90	9	715.43		
B S	10398.90	9	1155.43		
A B S	1938.40	9	215.38		
TOTAL	282170.00	39			

## EXPERIMENT 6 COMPONENT P2-N2 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	198.03	1	198.03	<1	NS
B	1357.23	1	1357.23	3.35	NS
S	79854.52	9	8872.72		
A B	0.02	1	0.02	<1	NS
A S	5109.72	9	567.75		
B S	3636.52	9	404.06		
A B S	637.73	9	70.86		
TOTAL	90793.77	39			

A= STIMULI  
B= HEMISPHERES  
C= SUBJECTS

EXPERIMENT 8 COMPONENT P1 LATENCY

SOURCE	SS	DF	MS	F	P
A	272.25	1	272.25	<1	NS
B	976.56	1	976.56	1.42	NS
C	7353.06	1	7353.06	42.44	.001
S	38710.50	7	5530.07		
A B	0.06	1	0.06	<1	NS
A C	1387.56	1	1387.56	3.38	NS
A S	19014.00	7	2716.29		
B C	400.00	1	400.00	2.08	NS
B S	4787.69	7	683.96		
C S	1212.69	7	173.24		
A B C	49.00	1	49.00	<1	NS
A B S	501.69	7	71.67		
A C S	2866.69	7	409.53		
B C S	1340.25	7	191.46		
A B C S	895.75	7	127.96		
TOTAL	79767.75	63			

EXPERIMENT 8 COMPONENT N1 LATENCY

SOURCE	SS	DF	MS	F	P
A	862.89	1	862.89	<1	NS
B	1991.39	1	1991.39	<1	NS
C	1164.52	1	1164.52	1.46	NS
S	70773.36	7	10110.48		
A B	669.52	1	669.52	2.12	NS
A C	31.64	1	31.64	<1	NS
A S	15846.98	7	2263.85		
B C	50.77	1	50.77	<1	NS
B S	8951.48	7	1278.78		
C S	5581.86	7	797.41		
A B C	70.14	1	70.14	3.24	NS
A B S	2201.86	7	314.55		
A C S	4493.23	7	641.89		
B C S	1303.11	7	186.16		
A B C S	151.23	7	21.60		
TOTAL	114143.98	63			

EXPERIMENT 8 COMPONENT P3 LATENCY

SOURCE	SS	DF	MS	F	P
A	28401.39	1	28401.39	10.30	.025
B	6309.39	1	6309.39	2.16	NS
C	8712.00	1	8712.00	2.43	NS
S	236152.69	8	29519.09		
A B	800.00	1	800.00	1.33	NS
A C	982.72	1	982.72	<1	NS
A S	22047.86	8	2755.98		
B C	1233.39	1	1233.39	1.45	NS
B S	23294.86	8	2911.86		
C S	228653.75	8	3581.72		
A B C	50.00	1	50.00	<1	NS
A B S	4810.25	8	601.28		
A C S	5581.03	8	697.63		
B C S	6793.36	8	849.17		
A B C S	6211.75	8	776.47		
TOTAL	380034.44	71			

EXPERIMENT 8 COMPONENT P1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
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## EXPERIMENT 8 COMPONENT P1 LATENCY

A	370.56	1	370.56	<1	NS
B	68.06	1	68.06	<1	NS
C	441.00	1	441.00	3.22	NS
S	19154.19	7	2736.31		
A B	430.56	1	430.56	4.77	NS
A C	6.25	1	6.25	<1	NS
A S	8042.19	7	1148.88		
B C	90.25	1	90.25	<1	NS
B S	958.19	7	136.88		
C S	1855.25	7	265.04		
A B C	90.25	1	90.25	2.63	NS
A B S	631.69	7	90.24		
A C S	1559.00	7	222.71		
B C S	846.50	7	120.93		
A B C S	239.50	7	34.21		
TOTAL	34783.44	63			

## EXPERIMENT 8 COMPONENT N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	118.24	1	118.24	<1	NS
B	337.59	1	337.59	<1	NS
C	11744.87	1	11744.87	13.91	.01
S	19385.07	7	2769.30		
A B	185.67	1	185.67	1.48	NS
A C	37.53	1	37.53	<1	NS
A S	7572.85	7	1081.84		
B C	153.11	1	153.11	1.29	NS
B S	2430.97	7	347.28		
C S	5908.79	7	844.11		
A B C	192.48	1	192.48	2.82	NS
A B S	874.58	7	124.94		
A C S	1032.96	7	147.57		
B C S	828.05	7	118.29		
A B C S	477.77	7	68.25		
TOTAL	51280.53	63			

## EXPERIMENT 8 COMPONENT P1-N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	49.00	1	49.00	<1	NS
B	650.25	1	650.25	<1	NS
C	7876.56	1	7876.56	5.19	NS
S	44300.00	7	6328.57		
A B	36.00	1	36.00	<1	NS
A C	52.56	1	52.56	2.42	NS
A S	1500.00	7	214.29		
B C	3.06	1	3.06	<1	NS
B S	3979.75	7	568.54		
C S	10605.44	7	1515.06		
A B C	10.56	1	10.56	<1	NS
A B S	1458.00	7	208.29		
A C S	131.44	7	18.78		
B C S	123.94	7	17.71		
A B C S	155.44	7	22.21		
TOTAL	70932.00	63			

## EXPERIMENT 8 COMPONENT P3 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	2556.13	1	2556.13	6.15	.05
B	48.35	1	48.35	<1	NS
C	28.13	1	28.13	<1	NS
S	111030.61	8	13978.83		
A B	931.68	1	931.68	1.65	NS
A C	25.68	1	25.68	<1	NS
A S	3322.50	8	415.31		
B C	767.01	1	767.01	1.32	NS
B S	4552.28	8	569.03		
C S	14347.00	8	1793.38		
A B C	21.13	1	21.13	<1	NS
A B S	4490.94	8	561.37		
A C S	641.44	8	80.18		
B C S	4639.11	8	579.89		
A B C S	423.00	8	52.88		
TOTAL	148624.99	71			

A= STIMULI  
 B= TARGETS/NON-TARGETS  
 C= HEMISPHERES  
 S= SUBJECTS

## EXPERIMENT 9 COMPONENT P3 LATENCY

SOURCE	SS	DF	MS	F	P
A	4339.52	1	4339.52	5.03	NS
B	8258.27	1	8258.27	3.70	NS
C	446.27	1	446.27	9.58	.025
S	236403.11	7	33771.87		
A B	3066.39	1	3066.39	2.39	NS
A C	319.52	1	319.52	6.16	.05
A S	6038.11	7	862.59		
B C	268.14	1	268.14	1.43	NS
B S	15603.86	7	2229.12		
C S	325.86	7	46.55		
A B C	123.77	1	123.77	1.70	NS
A B S	9214.73	7	1316.39		
A C S	362.61	7	51.80		
B C S	1303.48	7	186.21		
A B C S	507.86	7	72.55		
TOTAL	286581.48	63			

## EXPERIMENT 9 COMPONENT P3 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	594.14	1	594.14	<1	NS
B	3407.64	1	3407.64	2.98	NS
C	1991.39	1	1991.39	<1	NS
S	49218.73	7	7031.25		
A B	147.02	1	147.02	<1	NS
A C	34.52	1	34.52	<1	NS
A S	3612.98	7	516.14		
B C	28.89	1	28.89	<1	NS
B S	7998.48	7	1142.64		
C S	6175.23	7	882.18		
A B C	695.64	1	695.64	7.08	.05
A B S	3285.11	7	469.30		
A C S	817.11	7	116.73		
B C S	770.73	7	110.10		
A B C S	686.98	7	98.14		
TOTAL	79464.61				

A= STIMULI  
 B= TARGETS/NON-TARGETS  
 C= HEMISPHERES  
 S= SUBJECTS



## EXPERIMENT 10 COMPONENT P1 LATENCY

SOURCE	SS	DF	MS	F	P
A	1830.12	1	1830.12	8.72	.025
B	153.13	1	153.13	<1	NS
S	4125.50	7	589.36		
A B	200.00	1	200.00	1.93	NS
A S	1468.38	7	209.77		
B S	1239.37	7	177.05		
A B S	727.50	7	103.93		
TOTAL	9744.00	31			

## EXPERIMENT 10 COMPONENT N1 LATENCY

SOURCE	SS	DF	MS	F	P
A	680.63	1	680.63	<1	NS
B	1050.63	1	1050.63	5.10	NS
S	14728.73	9	1636.53		
A B	216.23	1	216.23	7.55	.025
A S	10267.12	9	1140.79		
B S	1851.12	9	205.68		
A B S	257.52	9	28.61		
TOTAL	29051.98	39			

## EXPERIMENT 10 COMPONENT P3 LATENCY

SOURCE	SS	DF	MS	F	P
A	2496.40	1	2496.40	<1	NS
B	10.00	1	10.00	<1	NS
S	160560.60	9	17840.07		
A B	16.90	1	16.90	<1	NS
A S	15254.10	9	1694.90		
B S	1037.50	9	115.28		
A B S	1047.60	9	116.40		
TOTAL	180423.10	39			

## EXPERIMENT 10 COMPONENT P1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	465.13	1	465.13	1.65	NS
B	2016.12	1	2016.12	2.35	NS
S	38293.00	7	5470.43		
A B	84.50	1	84.50	<1	NS
A S	1972.88	7	281.84		
B S	5984.87	7	854.98		
A B S	1103.50	7	157.64		
TOTAL	49920.00	31			

## EXPERIMENT 10 COMPONENT N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	5664.40	1	5664.40	7.55	<1
B	1276.90	1	1276.90	1.02	NS
S	26251.50	9	2916.83		
A B	230.40	1	230.40	<1	NS
A S	6748.60	9	749.84		
B S	11211.10	9	1245.68		
A B S	3774.60	9	419.40		
TOTAL	55157.50	31			

## EXPERIMENT 10 COMPONENT P1-N1 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	195.03	1	195.03	<1	NS
B	81.28	1	81.28	<1	NS
S	7332.47	7	1047.50		
A B	225.78	1	225.78	1.45	NS
A S	4703.22	7	671.89		
B S	9823.97	7	1403.42		
A B S	1084.47	7	154.92		
TOTAL	23446.22	31			

## EXPERIMENT 10 COMPONENT P3 AMPLITUDE

SOURCE	SS	DF	MS	F	P
A	44.10	1	44.10	<1	NS
B	115.60	1	115.60	<1	NS
S	212467.50	9	23607.50		
A B	1020.10	1	1020.10	5.67	.05
A S	6543.40	9	727.04		
B S	5327.90	9	591.99		
A B S	1617.40	9	179.91		
TOTAL	227136.00	39			

A= VISUAL FIELDS  
B= HEMISPHERES  
C= SUBJECTS

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Visual Evoked Response Correlates of Inter-Hemispheric  
Differences in Verbal and Non-Verbal Processing

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Abstract - Ten experiments are reported which are concerned with visual evoked response (VER) correlates of the processing of visual stimuli. In experiments 1 and 2 VERs were elicited by letters requiring verbal and non-verbal processing respectively. The results suggest that hemispheric differences in VERs to lateralised stimuli reflecting the anatomical arrangements of the visual system are modified by the way the stimuli are processed. These conclusions were supported by a third experiment in which non-verbal processing of non-verbal stimuli was required.

A further three experiments investigated VERs elicited by midline presentation of the letter and pattern stimuli. It was concluded that the right hemisphere is pre-eminent for the initial processing of visually presented stimuli and that when subjects had foreknowledge of the stimuli the P<sub>2</sub>-N<sub>2</sub> component reflected whether or not the stimuli were subjected to verbal processing, and whether such processing was asymmetrically distributed across the hemispheres.

Experiment 7 attempted to find a VER index of the limits of trans-callosal connections between the striate cortices, with inconclusive results.

Two further experiments, utilising the stimuli employed in experiments 1-6, were designed to investigate whether the P<sub>300</sub> component of the VER reflected hemispheric asymmetries of processing. No such effects were found in experiment 8 which provided new evidence pertaining to the relationship between P<sub>300</sub> and behavioural measures of information-processing. The results of experiment 9 suggested that P<sub>300</sub> could reflect asymmetrical processing, a conclusion supported by the results of the final experiment in which P<sub>300</sub>s were elicited by simple lateralised stimuli.

The general conclusion drawn from these experiments is that the VERs reflected both structural and dynamic aspects of information-processing and indicated that important determinants of the flow of stimulus information in the brain are the nature of the stimulus, the task-set of the subject and the interaction of these two factors.