DETERMINING CEREBRAL LATERALISATION:
THE USE OF THE P300

By

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ABSTRACT

The P300 component of the average evoked potential was recorded at Pz during two divided visual field tasks. During a lexical decision task, reaction time and P300 latency were faster to stimuli in the right visual field, indicating that the latency of the P300 may be a useful measure in laterality research. A right visual field advantage was obtained for reaction time in a face perception task and the P300 latency difference showed a similar but non-significant advantage. Use of the P300 latency to assess the validity of the assumptions underlying the application of an additive factors model to divided visual field studies of cerebral assymetry was discussed. The present evidence suggests that the assumptions are valid.

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I. INTRODUCTION

A. MODELS OF LATERALIZATION

Two neurological groups have made major contributions to our understanding of asymmetries of cerebral function. The first, chronologically, involves unilaterally brain-damaged individuals. Beginning with Paul Broca's discovery that lesions of the left hemisphere cause aphasia, this technique has been profitably used to study the localization of different aspects of language within the left hemisphere (Benson, 1979; Geschwind, 1970), of praxic functions (Heilman, 1979a), of attentional mechanisms (Geschwind, 1982; Heilman, 1979b; Heilman & Van Den Abell, 1980) and of facial recognition (Damasio, Damasio & Van Hoesen, 1982). This approach, however, has led to an emphasis on a structural or strict localizationist (Moscovitch, 1973) model of cerebral function in which many functions are assumed to be localized to specific areas of neural tissue (these may be fairly circumscribed, e.g. the third frontal convolution of the left hemsiphere, or more distributed, e.g. the right hemisphere). Areas of the brain other than those identified are presumed to be incompetent to perform the task in question. In this tradition, studies of aphasia suggest that only the left hemisphere is competent to process many aspects of language.

Study of another neurological population, however, has led to strategic or split-brain (Moscovitch, 1973) models of cerebral function. In patients who have had their cerebral commissures surgically separated to control the spread of intractable seizures, careful studies of the right hemisphere have revealed limited, but not insubstantial, language abilities (see Searleman, 1977; 1983; Moscovitch, 1983; Hecaen, 1978; Zaidel, 1978a,b for reviews). Similarly, visual and spatial tasks for which the right hemisphere is specialized can also be performed by the left hemisphere at above chance level (Levy, Trevarthen & Sperry, 1972; Sperry, 1974). The split-brain model is characterized therefore by bilateral competence for most tasks, although one hemisphere may be more efficient for a particular task.

The application of these two models to normal populations has been extensively discussed by Moscovitch (1973; 1976; 1979) and Zaidel (1984). Many of the ideas outlined below derive from Zaidel (1984) to whom the reader is referred for more details. He refers to the two models as the Direct Access model, according to which the task can be carried out in either hemisphere, and the Callosal Relay model, according to which the task can be performed only in one hemisphere, the other being functionally incompetent in the intact individual. There are two tests by which one can determine which model fits a particular task, tests of processing dissociation and of contralateral advantage.

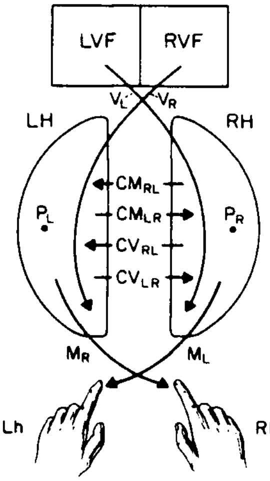
Processing dissociation, which is not the central concern of this proposal, involves showing differential effects on a task presented in the right visual field (RVF) and left visual field (LVF). Increasing a concurrent verbal memory load, for instance might interfere with performance of a task only when presented in the RVF. Such a manipulation would imply independent processing by the two hemispheres and therefore a direct access model would be appropriate for this task.

The contralateral advantage test can be applied whenever motor output, whether manual or verbal, as well as task input is lateralized. In this situation one can apply an additive information processing model, in which sensory relay, central processing and motor responses are identifiable, independent and temporally sequential stages of an information processing sequence (cf. Sternberg, 1969). In particular, a set of equations, illustrated in Figure 1 (from Zaidel, 1984), can be derived, where V represents transmission time from the visual field to the occipital cortex, P represents central processing time in one of the hemispheres and M represents the latency from the initiation of a motor response to the button press measured as reaction time (RT). Additionally, CV represents the delay due to the cross-callosal transfer of (unprocessed) visual information and CM represents the delay due to the cross-callosal transfer of a motor command (post-stimulus processing). The full model is shown schematically in Figure 1 with subscripts indicating which of the two sides the parameters represent. If a task is presented to each visual field and responses are required from each hand in a fully crossed design, some simplifying assumptions allow one to derive different predictions from the direct access and callosal relay models. The assumptions usually made, resulting in the simplified equations in Figure 1, are that $V_L=V_R$, $CM_{LR}=CM_{RL}$, $CV_{LR}=CV_{RL}$ and $M_L=M_R$. With these assumptions the callosal relay model predicts that regardless of which VF the stimulus is presented in, only one hemisphere will be able to process it and therefore the RT difference between the two VFs will be the same whichever hand is responding. This difference will be equal to the time taken to transfer the visual information across the corpus callosum to the competent hemisphere (CV). Similarly, once processed, the delay to respond with the hand ipsilateral to the competent hemisphere will be a constant amount, equal to CM, the time taken to transfer a motor command to the contralateral hemisphere (the model assumes purely contralateral motor innervation). The graph in Figure 1 presents these predictions schematically. In analysis of variance, one would predict main effects for VF and responding hand but no interaction.

A similar analysis can be performed for the direct access model. As well as the assumptions listed above, it is often assumed that P_L does not equal P_R; in the case of most verbal tasks $P_L<P_R$. In other words even if both hemispheres are

competent, the left is usually more efficient than the right for verbal processing. This leads to the prediction of an overall VF advantage and a VF x Hand interaction (see Figure 1).

Strict application of these criteria to DVF experiments is rare, although "when the data of a laterality reading experiment do not fit either the direct access or the callosal relay models, there is no rationale for interpreting the experiment, and in the absence of further information, it should remain undecided. This would apply to many, perhaps most, experiments in the literature..." (Zaidel, 1984, p. 121). After reviewing a large number of DVF studies published between 1970 and 1980, Zaidel (1984) found only 14 which provided adequate data (lateralized stimulus presentation and responses) for such model fitting. Of these, only Day (1977, Expt. 1) provided a consistent model fit, indicating that the left hemisphere was uniquely able to perform a lexical decision task on abstract words. There are some major methodological problems with applying the model as it stands, however, which may have contributed to the lack of clearly interpretable results; these will be considered in the next section.

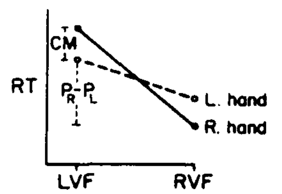


DIRECT ACCESS

Input VF	Output hand	Response time
L	L	$V_L + P_R + M_L$
L	R	$V_L + P_R + CM_{RL} + M_R$
R	L	$V_R + P_L + CM_{LR} + M_L$
R	R	$V_R + P_L + M_R$
Simplified,		
L	L	$V + P_R + M$
L	R	$V + P_R + CM + M$
R	L	$V + P_L + CM + M$
R	R	$V + P_L + M$

CALLOSAL RELAY

Input VF	Output hand	Response time
L	L	$V_L + CV_{RL} + P_L + CM_{LR} + M_L$
L	R	$V_L + CV_{RL} + P_L + M_R$
R	L	$V_R + P_L + CM_{LR} + M_L$
R	R	$V_R + P_L + M_R$
Simplified,		
L	L	$V + CV + P + CM + M$
L	R	$V + CV + P + M$
R	L	$V + P + CM + M$
R	R	$V + P + M$



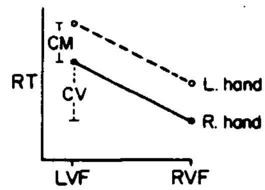


Figure 1. Direct access and callosal relay analyses of a tachistoscopic laterality experiment in which hemifield presentations are paired with unimanual responses. V_L=transmission time of sensory stimuli from the LVF to the occipital cortex of the right hemisphere (RH); P_R=central processing time for the stimulus in the RH; M_L=latency from the initiation of a motor response in the RH to its conclusion by the left hand; CV_{RL}=delay in response due to cross callosal transfer of the visual information from the RH to the LH; CM_{LR}=cross-callosal transmission of the motor command from the processing LH to the motor cortex of the RH controlling the responding left hand; and so forth.

From Zaidel (1983).

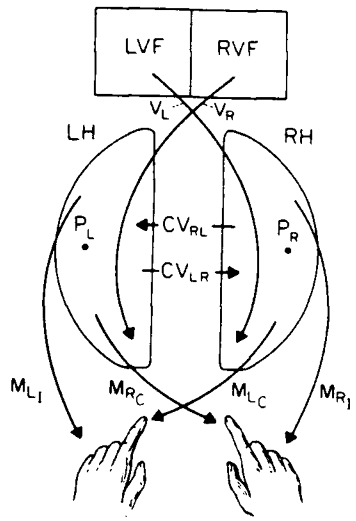
B. PROBLEMS IN APPLYING THE CRITERION OF CONTRALATERAL DOMINANCE

The Callosal Relay and Direct Access models, when simplified by certain assumptions, reduce to two sets of equations as shown in Figure 1. In each case there are four equations in five unknowns, meaning that further constraints must be introduced to obtain solutions. There are two serious problems with the assumptions which must be made when these models are strictly applied.

In the first place, the equality assumptions $CM_{LR}=CM_{RL}$, $M_L=M_R$ etc. are probably incorrect to varying degrees. Cross-callosal transmission times in particular differ greatly depending on the task, with values normally ranging from 4 to 60 msec (Bashore, 1981; Day, 1977; Swanson, Ledlow & Kinsbourne, 1978). It seems likely, then, that CM and CV may depend on the type of information being transferred (Bashore, 1981) and may vary systematically depending on the hemisphere from which it is being projected, because the hemispheres seem to differ in the type of information they process (Bradshaw & Nettleton, 1981). Similarly the assumption that $M_L=M_R$ may be incorrect in strongly handed individuals.

Potentially more damaging is the evidence that there may be significant motor control of the hand by the ipsilateral hemisphere (Zaidel, 1984). Although demonstrated in split-brain patients, it is not certain whether these results can be generalized to intact subjects, but if they can then we can derive a different set of equations for the two models as shown in Figure 2 (from Zaidel, 1984), which assume both ipsilateral and contralateral motor control and no callosal transfer of motor commands. If this were strictly the case then deciding between the two models would not be a problem, since both contralateral and ipsilateral assumptions predict the same pattern of VF x Hand effects (see Figures 1 & 2), but in practice it is impossible to know what tasks, if any, allow exclusive ipsilateral or contralateral motor control and in many cases both are probably operating. Trying to model so many alternative systems using only RT data is impossible, and this may account for the many findings inconsistent with either model.

We would have a potential solution to this problem if we could measure some sub-components of the processing equations in Figures 1 and 2 independently of RT. This may be possible using the P300 component of the evoked potential.



DIRECT ACCESS

Input VF	Output hand	Response time
L	L	$V_L + P_R + M_{L_C}$
L	R	$V_L + P_R + M_{R_I}$
R	L	$V_R + P_L + M_{L_I}$
R	R	$V_R + P_L + M_{R_C}$

CALLOSAL RELAY

Input VF	Output hand	Response time
L	L	$V_L + CV_{RL} + P_L + M_{L_I}$
L	R	$V_L + CV_{RL} + P_L + M_{R_C}$
R	L	$V_R + P_L + M_{L_I}$
R	R	$V_R + P_L + M_{R_C}$

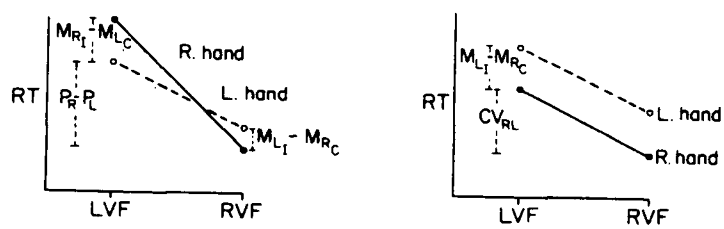


Figure 2. Analyses of a laterality experiment, pairing hemifield presentations with manual responses but assuming ipsilateral motor control. M_{LI}=latency of executing a motor response of the left hand in the LH using ipsilateral control; M_{RC}=latency of executing a motor response of the right hand in the LH using the usual contralateral control; and so forth. From Zaidel (1983).

II. THE P300

A. P300 LATENCY AND STIMULUS EVALUATION

The P300 component of the event-related potential (ERP) is a positive potential recorded maximally over the parietal scalp of subjects discriminating between or responding to infrequent or 'surprising' events (Donchin, 1981; Donchin, Ritter & McCallum, 1978; McCarthy & Donchin, 1983; Sutton, Braren, Zubin & John, 1965; 1967). It is recorded with a latency of 300-600 msec after a stimulus has been presented and might more properly be termed the P3b (Squires, Squires & Hillyard, 1975), only one of a number of late positive components of the ERP (Ruchkin & Sutton, 1983). Recently it has become increasingly prominent in chronometric analyses of information processing as an adjunct to RT (Chase, McCarhty, Squires & Schvanveldt, 1984; Donchin, 1981; Duncan-Johnson, 1981; McCarthy & Donchin, 1981; 1983) and in this capacity it may prove useful in determining models of cerebral asymmetry.

In this context the interest of the P300 lies in its variable latency and the dissociations which this can show with reaction time (Donchin, 1984). Ritter, Simson & Vaughan (1972) were the first to examine individual P300 latencies in relation to reaction time on a trial by trial basis, using hand-scored raw records, but most studies since then have relied on an adaptive filter similar to that proposed by Woody (1967). Kutas, McCarthy & Donchin (1977) used three categorization tasks of different difficulty in conditions which emphasized either speed or accuracy of responding. As expected, RT varied with instructions and between tasks. The latency of the P300 was similarly variable for the different tasks but varied very little as a result of the speed-accuracy instructions (a range of 90 vs 19 msec for the task vs instruction conditions) suggesting that the P300 is sensitive to the processes of perception, evaluation and categorization but is unaffected by changes in response criteria. This interpretation is supported by two further studies carried out specifically to test the applicability of an additive factors model to P300 data (McCarthy & Donchin, 1983). In these experiments, stimulus discriminability and response compatibility were independently varied in a manner that resulted in completely additive RT effects. P300 latency varied with stimulus discriminability but was unaffected by S-R compatibility. The P300 appears to be triggered only on completion of stimulus evaluation independent of response requirements.

B. THE USE OF THE P300 IN DETERMINING CEREBRAL ASYMMETRY

This summary indicates how the P300 may used to apply the Callosal Relay or Direct Access models. The methodological problems in fitting a model to RT data relate mainly to motor response times, and it is precisely these processes which are independent of P300 latency. We can assume, therefore, that in a lexical decision task the P300 will be initiated as soon as either hemisphere categorizes a stimulus as a word or non-word and that dissociations between the P300 and RT can therefore be attributed to some combination of M and CM (Figure 1). Because response initiation may vary considerably independently of central processing (McCarthy & Donchin, 1983), an adequate model fit may be possible in tasks not determined by RT alone. The detailed predictions for patterns of P300 latency for the two models are shown in Table I.

As they exist, these equations are still not fully determined, but with one plausible assumption, that $V_L = V_R$, we can obtain estimates of $V_L + P_R$, $V_R + P_L$ and CV_{RL}. With these data alone it is impossible to decide between the competing models because a RVF advantage for the P300 could be due either to a difference in processing efficiency or to the delay due to callosal transfer. These data may be useful in two ways however. Firstly, in tasks for which there is good reason to attempt to fit one model or the other, either because of previous research or because the RTs fit the model, the P300 latencies may provide the extra equations necessary to fit the complete model (as far as is feasible; one still cannot separate the duration of V from P). More interestingly, comparison of the P300 and RT data may allow determination of a suitable model in situations which are undetermined using RT alone.

This latter point is worth expanding. Data incompatible with either model may occur for a number of reasons. Inherent variability and error will occur for all stimuli and this is sometimes compounded by the experimental design. It is common, for instance, to present all words once to each visual field, to ensure that the lists presented to the two hemispheres are fully balanced (e.g. Day, 1977). Although stimulus biases are probably avoided in this design, there may be priming on the second presentation of the word, even after a considerable delay (Scarborough, Cortese & Scarborough, 1977). This will increase the RT variability since half the words in each VF are novel and half have been seen before.

It is possible, of course, that the model itself, and the assumptions inherent in it, are inappropriate. The hypothesized processing stages may be neither independent nor sequential. Furthermore,many tasks may require complex interactions between the hemispheres for successful performance and until alternative models and techniques are developed we have no way of modelling them. Temple (1981) (cited in Zaidel, 1984), for instance, has reported data in which response hand affected the balance of hemispheric asymmetry in a complex way. Lastly the role of ipsilateral motor innervation remains indeterminable.

The P300 may help to alleviate these difficulties. By separating stimulus evaluation from response requirements one may remove some extraneous sources of variation, between-subjects differences in speed-accuracy criteria for instance (Kutas, McCarthy & Donchin, 1977). It may in the end prove a more accurate way of determining overall VF advantages than RT. This must be determined empirically however, because little research has been done testing the temporal resolution or accuracy for identifying P300 latencies in the EEG and they may prove to be less accurate than RT (cf. Chase et al, 1984).

Assuming that the latency of the P300 can be identified with sufficient accuracy, the question of the appropriateness of the additive factors model may also be addressed. A strong prediction is that the hand of responding should not affect the P300 latency in either the Direct Access or Callosal Relay model, so any Hand effect would immediately invalidate the use of these models. A simple comparison of LVF-Left Hand(LH) with LVF-Right Hand(RH) and RVF-RH with RVF-LH P300s and evidence of a Hand main effect or interaction would probably indicate a variable degree of hemispheric interaction for the task.

It remains impossible to choose between the contralateral and ipsilateral motor control alternatives because for both RT and P300 data they make identical predictions; however this very fact means that the conflict presents no real difficulty for interpreting laterality results. Further use may be made of the P300, therefore, by subtracting this latency from the overall RT. This interval should be defined exclusively by post-processing stages and the equations which define this interval are shown in Table II under the assumptions of either contralateral or ipsilateral innervation. From these it is apparent that the two models should display different patterns of RT-P300 data in much the same way that the overall RTs do. For the Direct Access model the LVF-LH and RVF-RH conditions should show approximately the same RT-P300 , both of which should be shorter than the LVF-RH and RVF-LH conditions. This should result in an ANOVA interaction with no main effects. In contrast, the Callosal Relay data should show only a main effect for hand (Table II).

These predictions may be useful for more than determining the appropriateness of applying an additive factors model. Firstly the predictions made are slightly simpler than those for the RT with no expectation of a VF main effect which is required for the Callosal Relay model. Secondly, the number of stages presumed to intervene between the P300 and the button press is far fewer than for the RT model, decreasing the likelihood that extraneous task related factors will intrude. A third source of error that is rarely acknowledged is that although processing time may be different between the two hemispheres, it is generally assumed to be the same for all stimuli processed within a single hemisphere. This is unlikely to be true. I have already discussed one possible reason for this in priming, where a word seen for a second time is likely to be categorized more quickly than it was initially (assuming that the locus of priming is pre-stimulus categorization) and the variability due to this or to other extraneous sources (eg. word frequency or specific personal connotations of a word) might be reduced by using RT-P300 predictions to determine which model fits the data. This may also help to bypass another problem referred to by Zaidel (1984) who points out that the tasks most likely to yield interpretable RT data are likely to be relatively simple. The longer a task takes to do, the more likely it is to involve hemispheric interaction and the less likely it is that small differences in the response times for the two hands will be significantly different, since the variability of central processing time is likely to increase with complex tasks, although callosal transfer time, CM, presumably remains relatively fixed. By measuring RT from the latency of the P300, and therefore only after the central processing is completed, these effects should be reduced.

A fourth advantage is that the stages of stimulus processing should not interact with motor command stages, so the estimates obtained for CM and M ought to be relatively constant across tasks. Just as an effect of response hand on P300 would be diagnostic of an interaction between stages, so an effect of varying the task demands on RT-P300 would suggest that an additive factors model is inappropriate.

A number of difficulties with the procedures outlined have been omitted from the discussion so far, the most pressing of which is the resolution of measuring single trial P300 latencies. The Woody filter has proved useful in a number of studies (Duncan-Johnson, 1981; Kutas, McCarthy & Donchin, 1977; McCarthy & Donchin, 1981) but often in situations where differences of 100s of msecs have been reported. There is no certain way of validating the technique using real EEG other than to see if it proves useful, and little is known about the properties of the filter on simulated data.

Woody filtering also requires extensive and time-consuming data processing. An alternative approach to investigating the duration of the post-P300 processing stage may be possible and it is proposed to follow this simpler procedure initially in the present study. Although the latency of the P300 is variable with respect to stimulus onset it should be relatively invariant with respect to reaction time. In other words, according to the additive factors model, once a decision has been reached, a constant time should elapse between the elicitation of the P300 and the behavioural measure of reaction time. If this is so, then averaging trials together time-locked to the button press on each trial should effectively correct for the trial by trial latency variation seen with forward averaging. If such a method works, it should provide both a truer estimate of the amplitude of the P300 and an accurate estimate of the duration of the RT-P300 processing stage.

A third problem relates to the interpretation of the P300 itself. The waveform is triggered upon the identification of a surprising or significant stimulus, which is assumed to take place only after the stimulus has been categorized (Donchin, 1981; 1984; Duncan-Johnson, 1981). Therefore it provides an upper limit on the latency of these processes. The P300 should not be identified with the categorization process itself. The precise psychological significance and the site of origin of the wave are controversial (Okada, Kaufman & Williamson, 1983; Squires, Halgren, Wilson & Crandall, 1983). It follows that the latency of the peak of the P300 is not a valid measure of anything in itself, but with the assumption that the P300 is of a constant duration whenever it is elicited, one may use this as a relative measure of the onset of the wave. Whether this assumption is valid is unknown, but the use of Principal Component Analysis (PCA) (Glaser & Ruchkin, 1976) will allow an estimation of the onset and duration of each component uncontaminated by overlapping waves (cf. Ruchkin & Sutton, 1983 for an example of this application of PCA). If there is variability of the P300 onset to peak latency under different experimental conditions, a better estimate of P300 onset (and therefore a better estimate of the completion of stimulus evaluation processes) could be obtained by subtracting the onset-to-peak latency determined for each condition and using the resulting P300 onset estimates as a measure of the P300 latency.

That the P300 peak is only a relative measure is well illustrated by the data of McCarthy & Donchin (1983). In a condition emphasizing speed of response, they obtained P300 peak latencies which occurred on average 7 msec after the RT. Of added interest in their paper was the analysis of trials on which errors were made: on average RT preceded P300 peak by 286 msec. Although not discussed by the authors, the implication of these data is that a certain number of correct responses are also likely to be made simply because of response bias and these trials should also be rejected prior to data analysis. Developing a distribution of RT-P300 times may allow one to identify these trials both for correct and incorrect responses which will also contribute to less variable data.

This proposal intends to begin testing the predictions outlined above using tasks presumed to be preferentially performed in either the right or the left hemisphere.

TABLE I

Predictions for the latency of the P300 derived from the Direct Access and Callosal Relay models.

Direct Access Model

VF	HAND	P300
L	R	V_L+P_R
L	L	V_L+P_R
R	R	V_R+P_L
R	L	V_R+P_L

Callosal Relay Model

VF	HAND	P300
L	R	$V_L+CV_{RL}+P_L$
L	L	$V_L+CV_{RL}+P_L$
R	R	$V_R\quad +P_L$
R	L	$V_R\quad +P_L$

TABLE II.

Post processing stages: Reaction time - P300 latency

Direct Access Model

		Assumption of Motor Control:	
VF	HAND	IPSILATERAL	CONTRALATERAL
L	L	M_{LC}	M_L
L	R	M_{RI}	$CM_{RL}+M_R$
R	L	M_{LI}	$CM_{LR}+M_L$
R	R	M_{RC}	M_R

Callosal Relay Model

		Assumption of Motor Control:	
VF	HAND	IPSILATERAL	CONTRALATERAL
L	L	M_{LI}	$CM_{LR}+M_L$
L	R	M_{RC}	M_R
R	L	M_{LI}	$CM_{LR}+M_L$
R	R	M_{RC}	M_R

III. LATERALIZED COGNITIVE FUNCTIONS

A. LANGUAGE

That the left hemisphere is specialized for language perception and production is one of the oldest observations in neuropsychology (Benson, 1979). It has already been noted that the study of aphasia led to a view of hemispheric specialization as an all-or-none phenomenon. This is hardly surprising in view of the gross deficits seen after left hemisphere damage. It is becoming increasingly clear however that right hemisphere damage can also result in specific types of linguistic deficits (Brownell, Potter & Michelow, 1984; Heilman, Scholes & Watson, 1975; Millar & Whitaker, 1983; Ross, 1981; Weintraub Mesulam & Kramer, 1981; Zurif, Caramazza, Myerson and Galvin, 1974). Nevertheless It is in split-brain patients that the most precise delineation of the linguistic capacities of the two hemispheres has been carried out.

Zaidel in particular has investigated the right hemisphere's competence on a variety of linguistic tasks. Performance on a number of standard tests of auditory comprehension of single words reveals an extensive lexicon, at least for concrete nouns and verbs, which displays word frequency effects parallel to those shown by the left hemisphere (Zaidel, 1976a). Syntactical understanding may also be present to a degree (Zaidel, 1978a; 1978b) although performance on the Token Test is severely limited, being comparable to a 4 year olds (Zaidel, 1977). The pattern of these results points to a selective deficit in the maintenance of complex, sequential auditory material in short term memory. This may not, however, impair the understanding of language in many ordinary situations, where it is highly redundant and context dependent. Additionally, the right hemisphere appears to be able to read without difficulty many of the words it can understand when spoken, although the two hemispheres undoubtedly differ in the strategies they use (Zaidel & Peters, 1981).

These and other studies (Gazzaniga, 1970; Gazzaniga, Smylie & Baynes, 1984; Levy & Trevarthen, 1977) suggest that certain linguistic capacities are bilaterally represented. Studies of these abilities in intact subjects, therefore, might be expected to yield results consistent with the split-brain or Direct Access model of lateralized functions. Other aspects of linguistic processing appear to be uniquely performed in the left hemisphere. Evidence has already been presented that lexical decisions on abstract, non-imageable words cannot be performed in the isolated right hemisphere (Zaidel, 1984) but that either hemisphere can process highly imageable words. The results of Day (1977) suggest that this is true for intact subjects also. Studies of Deep Dyslexia (Coltheart, Patterson & Marshall, 1980) and split-brain subjects (Zaidel, 1977) suggest that the capacity to read pronouncable nonsense syllables or to perform tasks requiring judgements of whether written words rhyme are also abilities unique to that hemisphere, mediated by a system of grapheme-phoneme conversion rules (Zaidel, 1981). Thirdly, the ability to understand non-redundant semantically complex material, although hard to test in conventional laterality studies using normal subjects, appears to be exclusively left lateralized in split-brain subjects (Zaidel, 1977) and patients undergoing Sodium Amytal testing (McGlone, 1984). A last plausible candidate for unique left lateralization is the perception of stop consonants. Meaningless stop consonant CVs yield the most reliable REA for verbal stimuli in dichotic listening (Bryden, 1982; Studdart-Kennedy & Shankweiler, 1970), are amongst the stimuli least affected by manipulations and biases in attention and appear to be virtually indistinguishable in the isolated right hemisphere (Zaidel, 1976b).

These abilities, if tested in the appropriate way, might be expected to give results consistent with the strict localizationist or Callosal Relay model.Although the evidence concerning the linguistic competence of the isolated right hemisphere is compelling, there is still disagreement concerning the role of this hemisphere in intact subjects' understanding of language (see Coltheart, 1985). Moscovitch

(1973) pointed out that relatively circumscribed left hemisphere lesions can lead to crippling aphasia, far worse than the competence seen in the isolated right hemisphere. He proposed the model of functional localization, suggesting that the right hemisphere's linguistic abilities are actively suppressed via the corpus callosum, thereby preventing the takeover of lost language functions by the right hemisphere in most cases (Moscovitch, 1976). If this were indeed so, one would not expect to see any evidence of right hemisphere language competence in normal subjects. A number of studies, however, suggest that the right hemisphere of intact subjects can read common concrete and imageable nouns and adjectives (Day, 1977; 1979; Martin, 1978; Strauss, 1983; Zaidel, 1984). In studies such as these, a strong LVF advantage compatible with exclusive left hemisphere performance is found for abstract words, but little or no VF difference is found for highly imageable (and particularly emotional) words. Furthermore, there have been two studies using lateralized stimulus presentations both of which reported priming apparently mediated by the right hemisphere (Marcel & Patterson, 1978; Zaidel, 1984).

Although a number of studies using error rates for verbal recognition of briefly presented words have claimed to see a reduced or absent RVF advantage for highly imageable words (Ellis & Shepard, 1974; Hines, 1976; 1977), reaction time is probably a more sensitive measure of right hemisphere linguistic capacity. Lambert & Beaumont (1983) failed to find such an effect in a carefully controlled experiment and demonstrated that the effects reported by Ellis & Shepard (1974) and Hines (1976,1977) were probably due to the simultaneous bilateral presentation of words and a failure to control order of report. There was a strong effect of imageability, but only for words presented first, combined with an order of report effect, LVF words being reported first.

Studies with RT as the dependent measure have been more consistent. Day (1977) presented abstract and concrete nouns to the right and left VF and found a RVF advantage and a RH advantage for abstract nouns but no significant effects for concrete nouns. As already mentioned, his data for abstract words are a rare case of results compatible with one of the models outlined above, the Callosal Relay model. Although the results for the concrete nouns are not compatible with the direct access model, the lack of a VF advantage in this case suggests right hemisphere involvement in reading. In two further experiments he presented categories and exemplars sequentially (Expt. 2) or simultaneously (Expt.3) in the two visual fields and obtained very similar results for category judgements. In both cases abstract categories/exemplars yielded data compatible with the Callosal Relay model and the concrete categories/exemplars revealed no main VF effect. In Expt. 2 the data were compatible with the Direct Access model.

Day (1979) extended this study to nouns, verbs and adjectives, but in this instance responding hand was a between subjects-variable rather than within-subjects. He found a RVF advantage and no Hand x VF interaction for all low imagery words and for high imagery verbs, but no significant effects for high imagery nouns or adjectives. A similar result was obtained by Elman, Takahashi & Toshaku (1981) using abstract and concrete Kanji nouns. They found a strong RVF advantage for abstract words but a slight LVF advantage for concrete words.

These studies, together with our knowledge of split-brain patients, suggest that there is access to a usable lexicon from the right hemisphere for concrete words. Although imageability and concreteness are highly correlated (Paivio, Yuille & Madigan, 1968; Toglia & Battig, 1978) and have been used largely interchangeably up to this point, there is evidence that imageability is the dimension of interest in the experiments cited so far (Paivio, 1983; Richardson, 1980). It seems unlikely, however, that imagery ratings per se define what words will be accessible to one or both hemispheres and Marcel & Patterson (1978) have offered a plausible suggestion regarding the distinction of which imagery ratings may be a good measure. They suggest that high ratings define not simply words with an imageable referent, but those which arouse a sensory experience, and consequently they suggest a division of words into those representing the sensori-motor sphere and those based on logical and linguistic concepts. This division, which corresponds to a distinction drawn by developmental psychologists, is being made at the semantic level rather than the level of the lexicon, which is in line with Zaidel's (1984) suggestion that both hemispheres have access to a shared (possibly subcortical) lexicon. Using this distinction there is a rationale for the bilateral acquisition of sensori-motor semantics early in life, prior to the development of full hemispheric specialization, and for the unique specialization of the left hemisphere for logical-linguistic semantics.

This well-documented difference in the reading of abstract and concrete words provides an ideal test of the usefulness of the P300 in determining which model fits a DVF RT experiment, since behavioural measures themselves would be expected to indicate the appropriate model. An initial experiment therefore will use a lexical decision task similar to that of Day (1977) Expt.1.

B. FACE PERCEPTION

There are few, if any, tasks for which there is convergent evidence that the right hemisphere has unique abilities. Until recently it might have been claimed that the perception and recognition of faces was a likely candidate, but more recent studies have cast doubt on this conclusion

(Sergent, 1982a; Sergent & Bindra, 1981).

Early studies of unilaterally brain-damaged subjects (e.g. Milner, 1968) found greater impairments in facial recognition after right than left hemisphere damage, a finding replicated more recently both for the identification of emotional expressions and for the recognition of facial identity (DeKosky, Heilman, Bowers & Valenstein, 1980; Etcoff, 1984). Recent reviews of prosopagnosia, however, have concluded that bilateral lesions are present in many, if not all, patients suffering from this disorder (Benton, 1980; Damasio, Damasio & Van Hoesen, 1982; Meadows, 1974). Furthermore, Hecean (1981) suggests that several distinct syndromes are at present lumped together under the term prosopagnosia, each involving different anatomical substrates both bilateral and unilateral. Since the precise nature of the perceptual or mnestic deficit which may occur for facial stimuli after right hemisphere damage has yet to be delineated, the evidence regarding the competence of the two hemispheres is at present equivocal.

Research with split-brain subjects is meagre and similarly undecisive. Levy, Trevarthen and Sperry (1972) flashed chimeric faces centrally to four patients, thereby projecting different half-faces to the two hemispheres. Pointing responses with either hand were required to pick the face seen from a set of three. This procedure greatly favoured the LVF, indicating not only much better performance by the right than left hemisphere but also the ability of that hemisphere to assume control of gross motor responses on a task for which it, presumably, is dominant. When the faces were given names, however, and verbal report was required, a slight RVF advantage was seen, although performance fell to 85% (chance being 67%). It is interesting to note that the subjects had great difficulty learning to associate the three faces with names, taking 10-15 minutes to learn them satisfactorily and only succeeding by assigning the verbal label to some clearly identifiable feature on each face. It seems likely therefore that left hemisphere performance was mediated in this instance by strategies not normally employed for facial recognition, except perhaps of familiar faces (Marzi & Berlucchi, 1977) and that the left hemisphere displayed little other competence in this task.

If the isolated left hemisphere is very poor at facial perception or recognition, then it should be possible to obtain RT measures in normal subjects consistent with the Callosal Relay model, which would be particularly significant in view of the equivocal nature of the brain-damage literature. Despite numerous studies involving lateralized presentation of faces, few have required lateralized responses of the kind necessary to fit either model and only one, Geffen, Bradshaw and Wallace (1971), obtained both right and left hand responses from the same subjects. They used a set of five drawn faces each differing from the others on seven features. Subjects memorized a target face and responded yes/no with each hand in turn to lateralized test faces. They found a LVF advantage but no hand main effect or hand x VF interaction and therefore were unable to choose between the two models. A second experiment using vocal reaction time yielded data suggesting that both hemispheres were able to perform the task but that the right hemisphere was quicker than the left.

Moscovitch, Scullion and Christie (1976), tested facial discrimination and recognition in five experiments in which the results were reported for each responding hand (varied between subjects). They found no VF differences for the discrimination of identical faces presented simultaneously or for those presented sequentially with an ISI of 5 or 50 msec. With 100 msec ISI or longer a LVF advantage emerged, as it did if subjects were required to match a test face to a previously memorized target. The hand x VF analysis was largely indeterminate according to the criteria laid out above, but suggested that identification at a short ISI was being performed by both hemispheres. At longer ISIs there was no indication of a VF x Hand interaction but neither was there a Hand main effect and those subjects responding with their right hands were generally faster. Moscovitch et al interpreted these results in terms of the Transmitted Lateralization hypothesis (Moscovitch, 1979) which suggests that hemispheric asymmetries emerge only at late stages of processing at which sensory input must access lateralized memory processes.

Two recent studies qualify this hypothesis (Strauss & Moscovitch, 1981; Strauss and Williamson, Note 1). In these studies a LVF advantage emerged for SAME responses with both simultaneous presentation and at a 50 msec ISI. In both cases, however, subjects were required to respond to identity of emotional expression portrayed by different actors or to identify a given actor when displaying different expressions. In both cases therefore subjects had to classify the stimuli according to an emotional category or a personal identity, tasks which have greater face validity than the recognition of identical photographs and which are more likely to require specialized forms of processing. In addition these two studies used photographs of posed actors whereas many studies, including those of Geffen et al (1972) and Moscovitch et al (1976), have used either schematic or cartoon faces either of which may depend less on the specialized abilities of the right hemisphere.

The two studies just described were investigating the lateralization of emotional facial expressions and there is considerable clinical and experimental evidence that the perception and production of emotions are lateralized to some degree in the right hemisphere (Borod, Koff & Caron, 1983; Bryden and Ley, 1983a,b; Moscovitch, 1983; Tucker, 1981). DVF studies in normals (e.g. Ley & Bryden, 1979; Suberi &

McKeever, 1977) have shown more accurate and faster recognition of emotional expressions in the LVF and in some cases statistical independence of the VF advantage for recognition of facial identity and emotional expression (Ley and Bryden, 1979). This finding supports the dissociation sometimes seen after right hemisphere damage between perception of identity and of emotion in faces (Etcoff, 1984; Hecean, 1981).

A study by Suberi and McKeever (1977) is of particular interest since they used validated photographs of actors displaying sad, happy, angry or neutral expressions in a memory paradigm of the type predicted to produce a strong asymmetry. They varied whether subjects memorized and were tested on emotional or neutral faces and found a larger LVF advantage for those who had memorized emotional than neutral faces. Unfortunately they tested subjects only on identical photographs to those memorized, so subjects who memorized emotional faces responded SAME only to emotional faces. It is impossible, therefore to separate the effects of the emotional memory load from those of perceiving an emotional stimulus in their data. Ley and Bryden (1983) have shown that maintaining a concurrent verbal memory load which is either emotional or highly imageable can improve the performance of the right hemisphere on both dichotic listening to CV syllables and perception of lateralized faces, an effect they term hemispheric priming. One explanation of the results of Suberi and McKeever therefore would suggest that selective activation of the right hemisphere improved LVF performance. Studies of lexical decision tasks using emotional words which employed no concurrent memory task however, have found both an increase in the performance of the right hemisphere and an overall facilitation of RT to emotional words (Strauss, 1983). By using judgements of facial identity in a paradigm similar to that of Suberi and McKeever (1977) it should be possible to obtain a robust LVF advantage and to assess the relative contributions of hemispheric priming and the emotionality of the stimuli to an increased LVF advantage.

However, there is still controversy over the direction of lateralization of positive and negative emotions. Tucker (1981) argues on the basis of clinical and electrophysiological evidence that positive emotions are predominantly represented in the left hemisphere and negative emotions in the right, but most DVF studies of RT or recognition incorporating faces displaying emotions of both valences of affect have found similar LVF advantages for all emotions (e.g. Ley & Bryden, 1979; Strauss & Moscovitch, 1981; Suberi & McKeever, 1977). Reuter-Lorenz and Davidson (1981) and Reuter-Lorenz, Givis and Moscovitch (1983) however used bilateral presentations and required subjects to judge which of the two faces was displaying an emotional expression and found the appropriate dissociation of VF advantages. This issue must remain undecided at present, but it is true nevertheless that the strongest LVF RT advantages have been found for studies involving emotional faces.

The work of Sergent (1982a, b, c; 1983; 1984; Sergent & Bindra, 1981) requires consideration in this selective review since she addresses directly the question of left hemisphere competence for the processing of faces. She argues that the conditions of DVF experiments are likely to result in a LVF advantage for reasons not related to face perception per se but to stimulus quality and the difficulty of the discrimination. She argues that brief presentations and the use of faces that differ on several features and are therefore easy to discriminate will favour the right hemisphere since it appears to be more sensitive to features in which the distinctive information is carried at relatively high spatial frequencies (Sergent, 1982b; 1983). In support of this she showed that drawn faces differing by only one or two features were identified equally fast in either VF but that analysis of the responses to different faces indicated that the two hemispheres were performing this task using different strategies (Sergent, 1982a). A second study also analysing DIFFERENT RTs concluded again that the two hemispheres were performing differently, and that both were using strategies which could best be described as holistic (Sergent, 1984).

A precise analysis of the information processing requirements of different paradigms is certainly required to bring order to the many variables which have been shown to affect face perception but there are a number of reasons for doubting the generality of Sergents' conclusions. Although very short stimulus exposures can induce a LVF advantage, several studies using faces have obtained robust LVF advantages with exceptionally long stimulus durations (800 msec: Strauss & Moscovitch, 1981; 400 msec: Strauss & Williamson, Note 1; 300 msec: Moscovitch et al, 1976). Furthermore, Hellige, Corwin and Jonsson (1984) systematically varied stimulus duration, retinal eccentricity and the presence of visual noise and found that duration (10-100 msec) had no differential effect on the two VFs, but that noise and increased eccentricity impaired LVF-right hemisphere performance significantly more than RVF-left hemisphere performance. Like Sergent, however, they found that the effect of noise interacted with the type of processing required to perform the task correctly, emphasizing again the need for a more precise analysis of task requirements in terms of feature differences.

Three other important caveats must be made about Sergent's work. She obtains precise control of the degree of similarity between her stimuli by using line drawings of faces. Although these do often produce a LVF advantage, there has been no adequate comparison of subjects' strategies for processing these and real faces and any specialized processes which may have developed for the analysis of physiognomies is less likely to be engaged by drawings than by photographs.

Secondly, her analyses concentrate on RT differences in DIFFERENT responses, which may or may not be performed in a similar way to SAME responses (eg Strauss & Moscovitch, 1981). Thirdly, she has yet to address the issue of the perceived emotionality of the faces she uses which is an important factor as we have seen. Indeed a precise delineation of the mode of analysis required to classify a face as displaying a particular emotion or a certain strength of emotion might help to clarify the separate roles of face perception and emotion perception.

Conclusions regarding the competence of the two hemispheres to process faces and facial expressions can only be tentative. Specific strategies are clearly available which can be employed by the left hemisphere to perform some facial processing, but the extraction of a facial identity or the interpretation of an emotional expression seem, at the very least, to be strongly right lateralized. For this reason, a facial recognition task will be used in addition to a lexical decision task to assess the usefulness of the P300 in DVF studies.

IV. RATIONALE AND HYPOTHESES

This study consists of two experiments. The first is designed to test the validity and usefulness of recording RT and the P300 jointly in a task engaging lateralized cognitive processes. For this reason a lexical decision task using high and low imagery words was chosen since converging evidence, reviewed above, suggests that this paradigm would produce data compatible with the Direct Access and Callosal Relay Models. This task should determine whether there are measurable differences in the latency of the P300 to words presented in the two visual fields.

The second task assesses the generality of the results obtained for linguistic material. The facial recognition task is designed to engage right hemisphere processing and therefore should provide evidence for a double dissociation for both reaction time and P300 latency.

A. LEXICAL DECISION TASK

The design closely matched that of Day (1977) Expt. 1. High and low imagery words were presented briefly to the right and left visual fields intermixed with pronounceable non-words and subjects responded to real words with a button press. A replication of Days' results was expected allowing different predictions to be made for high and low imagery words. Low imagery words were expected to show a RVF advantage with no effect of hand and high imagery words should show a VF x Hand interaction, in addition to a reduced visual field main effect.

Predictions concerning P300 latency depend on adequate behavioural evidence for lateralized stimulus processing, and they were made on the assumption that the expected VF and Hand effects would occur for reaction time. P300 latency should mimic the visual field main effects seen for reaction time, showing a strong effect for low imagery words and perhaps a weaker effect for high imagery words. Unlike reaction time, however, there should be no effect of responding hand either as a main effect or in interaction with other factors. Such effects would be evidence against the appropriateness of the additive factors model to this data. Finally, the RT-P300 latency determined by back-averaging should produce a main effect in favour of the right hand, at least for low imagery words, and a VF x Hand interaction for high imagery words. For low imagery words any main effect or interaction involving visual field would be evidence that the additive factors model is inappropriate.

B. FACIAL RECOGNITION

This experiment attempted to use joint P300 and RT measures to determine the appropriateness of either the Direct Access or the Callosal relay model for the recognition of facial identity. The design was similar to that of Suberi and McKeever (1977) but followed Strauss and Moscovitch (1981) and Strauss and Williamson (Note 1) in requiring the perception of facial identity across different expressions.

The experiment was designed to elicit a LVF advantage by incorporating factors believed to underlie right hemisphere involvement in the processing of faces. These include the need to access a long-term memory for the faces (Moscovitch et al 1976, Moscovitch 1979), the use of emotional faces both as targets and as an emotional memory load for some subjects (Ley & Bryden, 1979, 1983, Suberi & McKeever 1977) and the identification of facial identity across different expressions (Strauss & Moscovitch 1981, Strauss & Williamson Note 1).

Evidence for the involvement of lateralized memorial processes in cerebral asymmetries has been reviewed by Moscovitch (1979) and led him to propose the Transmitted Lateralization hypothesis. A study by Strauss & Moscovitch (1983) however showed that a LVF advantage could be obtained when subjects were asked to judge facial identity and identity of expression for simultaneously presented pairs of faces. This task appears to have made no demands on long-term memory processes but to have required the abstraction of information concerning facial identity from different visual images. Since recognizing a face in real life will always involve extracting information about identity from highly variable and often rapidly changing images, tasks which involve identifying a face from different photographs are likely to involve specialized right hemisphere processes more often than those requiring simple recognition of identical photographs (see Bertelson, Vanhaelen & Morais, 1979). The mechanisms underlying this recognition of facial identity are still poorly understood, but they might be conceived of as performing some form of transformation or "normalization" on an image prior to its comparison with a "standard" memory trace. Such "normalization" may be a specialized right hemisphere process independent of lateralized memory processes so it is of interest to determine to what extent memory and "normalization" processes contribute independently to LVF advantage seen in facial perception.

This experiment was designed with this question in mind. Although in all cases subjects will be asked to memorize faces, positive responses were required both to identical photographs and to unmemorized photographs of the actor displaying different expressions. In other respects the design resembled that of Suberi and McKeever (1977). Subjects memorized two photographs of different actors and were required to respond whenever they saw either of those faces again. Two types of positive responses were required then, those to identical photographs showing the same face and same expression (SFSE) as the memorized target, and those showing the same face and different expression (SFDE). Subjects refrained from reponding when they saw a different face showing either the same (DFSE) or a different expression (DFDE) to either of those memorized.

Finally the emotional expression of the two memorized faces was be varied across subjects to determine whether this factor would contribute to a LVF advantage over and above that induced by the other factors. Ley and Bryden (1983) have shown that a memory load of emotional words can improve the performance of the right hemisphere relative to the left and it seems likely that memorizing emotional faces will have a similar effect. Happy, surprised and neutral expressions will be used since they are relatively easy to distinguish and are therefore likely to lead to relatively accurate performances. This is desirable for studies using reaction time as the major dependent variable.

A LVF reaction time advantage for all faces was the major prediction for this experiment although this should be increased both by increasing the emotionality of the memory load and by requiring responses to the same face showing a different expression. Previous studies of face perception have rarely allowed a strict application of either the Callosal Relay or the Direct Access models. Often a LVF advantage has been found along with a slight (non-significant) right hand advantage, a result incompatible with either model. If the data from this experiment were to be interpretable in these terms one might expect a VF and Hand main effect compatible with the Callosal Relay model for the SFDE condition. The SFSE condition would be more likely to be performed by either hemisphere, resulting in a VF x Hand interaction.

As in the previous experiment, the predictions made for P300 latency depended on the behavioural evidence regarding subjects' performances. P300 latency should mimic the visual field effects seen for RT but again should show no main effect or interaction involving Hand. The latency of the RT-P300 back average may be useful in determining which of the two models best fit the data in this experiment since other studies suggest that reaction time alone will be inconclusive. Precise predictions for the two models have been outlined in the previous experiment.

V. METHODS

A. SUBJECTS

Subjects were recruited by advertisement in the Psychology department and on the University campus. Volunteers were selected to participate if they were male, 16-40 years of age, strongly right handed according to the criteria of Annet (1970), had no left-handed parents, siblings or children, were free of known neurological or reading impairments, had normal or corrected-to-normal vision and had learned English as their first language. The Annet handedness questionnaire was completed by all volunteers. 1 was scored for each task performed by the right hand, 0 for the left and 1/2 for a response of "either". Subjects were considered right handed with scores of 9.5 or greater. These criteria were used to ensure that the subjects tested were as homogenous as possible with respect to language lateralization. The first 21 volunteers meeting these criteria participated in the study and were paid $4 per hour. A few had previously participated in either divided visual field or EEG research but all were naive to the particular hypotheses being tested. The data from 5 subjects was not analyzed for technical reasons leaving 16 subjects[1].

B. STIMULUS PRESENTATION

All stimuli were photographed against a white background and presented as slides back-projected by a Kodak Carousel projector. A second slide projector was used to provide a fixation cross. Stimulus presentation and inter-stimulus interval was controlled by a Corona microcomputer which also performed data acquisition and storage. An electronic iris controlled the timing of stimulus onset and offset. The projectors were placed outside the sound-proof and electrically shielded chamber in which the subjects sat, so stimulus presentation was completely silent.

Twenty high and twenty low imagery 3 or 4 letter words were selected from the norms of Paivio, Yuille and Madigan (1968) matched for frequency (Kucera & Francis 1967) and pleasantness (Toglia & Battig 1978). Low imagery words were rated less than 5 (Mean=3.46) on Paivio et al's 7-point scale and high imagery words were all rated above 6. Apart from length and imagery value, words were selected which matched

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[1]Data from 3 subjects was lost due to computer-related errors in the data acquisition and storage system. One subject was given incorrect faces to memorize and one subject performed at chance level in one experiment. Other subjects were run as replacements.

for frequency on an individual basis as closely as possible. Finally the two word lists were closely matched for pleasantness ratings (means for high and low imagery words being 4.29 and 4.27 respectively) since a words emotional value is known to affect visual field asymmetries (Ley & Bryden 1983, Strauss 1983). Although there are several rating scales for words emotional meaning (eg Snyder & Osgood 1969) none are as comprehensive as those of Toglia and Battig (1978). Osgood and Suci (1955) have reported factor analytic data showing that ratings of good-bad and pleasant-unpleasant both load heavily on the same factor which they term Evaluation. Pleasantness ratings therefore can be considered equivalent to emotionality ratings. In order to maintain equal frequencies for the two lists one word, UNIT, was included for which no pleasantness rating was available.

Forty pronounceable non-words were created by altering a single letter, other than the first, for each of the selected words. Full details of the words and non-words used can be found in Appendix A.

Each word and non-word was typed vertically and photographed twice, once to the left and right of centre. When projected, the words subtended a visual angle of 1.53° (3-letter) or 2.25° (4-letter) vertically and 0.31° horizontally. The inner edge of each word appeared approximately 2.4° from a central fixation cross[2]. Background illumination was approximately 14cd/m^2 between trials while the fixation cross was on the screen and 27cd/m^2 during the presentation of each word.

Face stimuli were photographs of posed expressions from taken from those of Ekman and Friesen (1976). There were 3 photographs each of 4 male subjects displaying expressions objectively rated as the most clear representation of neutral, happy and surprised expressions (Ekman and Friesen 1976). A full description of the photographs used is given in Appendix B.

Each face was photographed once to the right and once to the left of centre. When projected, the faces subtended an angle of 3.6° vertically and 2.5° horizontally and the inner edge of each face fell approximately 1.3° to the right or left of the central cross. The background illumination for the slides was approximately 13.2 cd/m^2.

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[2]Because of the use of slide presentation the precise location of each word or face depended on how each slide fell into position and varied by up to 1° from trial to trial. The figures given are approximate means. This variation undoubtedly made the tasks more difficult although most stimuli appeared at very similar eccentricities and any variation was randomly distributed between the different conditions. This mode of presentation also required separate slides for words or faces in each visual field. Finally, use of a slide projector is likely to have resulted in slow changes in the background illumination throughout the course of the study due to the aging and occasional replacement of projector bulbs.

C. PHYSIOLOGICAL RECORDING

EEG was recorded from central midline (Cz), parietal midline (Pz), and left and right parieto-temporal (PT3, PT4) cortex referred to linked ears (A1A2). The two lateral sites are midway from Pz to the external auditory meatus and are intended to overlie the tempero-parietal junction, and specifically Wernicke's area in the left hemisphere. Signals were obtained via Beckman silver chloride EEG electrodes and amplified with a Beckman Type R-711 polygraph, with Type 9806A A.C. couplers with bandpass filters set to produce 3dB rolloff at 0.16 and 100 Hz. All sites were cleaned thoroughly with Redux electrode paste and abraded lightly with a blunt needle. Electrodes were glued in place with Collodion and Redux paste acted as an electrolyte. Electrode impedances were measured at all sites at the beginning and end of each session and never exceeded 3 Kohms.

Vertical and horizontal eye movements were also recorded via Beckman miniature electrodes placed at the outer canthus of each eye and above and below the left eye. Vertical EOG was recorded in an identical manner to EEG but horizontal EOG was bandpassed with a 3dB rolloff at 0.013 and 30 Hz.

EEG and EOG were digitized on-line by a Corona microcomputer at 1024 Hz for 100 msec pre-stimulus onset and for 1000 msec post-stimulus onset and were stored on a

Tallgrass hard disk for off-line analysis. A 50 microvolt calibration signal was recorded on each channel at the beginning of each session for subsequent amplitude measurements. Reaction times were calculated to the nearest millisecond for each trial and were stored with the digitized EEG. Each subjects data was transferred to Scotch magnetic tape cartridges for permanent storage.

D. PROCEDURE

All subjects participated in both experiments on different days. With one exception, between 2 and 20 days elapsed between sessions. Half the subjects performed the lexical decision task and half performed the face recognition task first. On both occasions the subjects were requested to avoid coffee, tea, alchohol or cigarettes for at least 4 hours before the study. All testing was carried out in a sound-proof, electrically shielded chamber with the stimuli projected through a glass window. On the first day all subjects received a description of the procedures to be used. Subsequent preparations were identical for the two days. The electrodes were attached and calibration carried out followed by the recording of resting EEG, 20 seconds with eyes open and 20 seconds with eyes closed. In both sessions 40 seconds of resting EEG was recorded similarly on three occasions, once immediately after a series of practice trials, once at the midpoint of the experiment and once at the end of the experiment.

Horizontal eye movements were then recorded for 16 trials to allow subsequent calibration and accurate measurements of eye movements during the experiment. Subjects were requested to fixate a central cross and to look at a dot either to the right or left on hearing a signal tone. Seven seconds of EOG was recorded at 64 Hz for 16 trials during which the experimenter signalled the subjects to move their eyes 0.75°, 1.5°, 3.0° or 6.0° to the left or right. Each movement was recorded twice. The experiments were then carried out with resting EEG recorded as already described.

For both tasks subjects were instructed to rest their chins in a head rest placed 58cm from the screen and to fixate a central cross in the middle of the screen. Trials were presented in blocks during which subjects were asked not to move around, not to look away from the central cross and to blink as little as possible. The beginning and end of each block was signaled by a tone and subjects were given brief rest periods between each block. During a block, stimuli were presented for 200 msecs at intervals varying randomly between 2 and 4 seconds. In order to maintain approximately similar background luminance levels the central fixation slide was switched off at stimulus onset and reappeared at offset. Subjects were instructed to rest the index finger of one hand on a response key placed in front of them at the midline and to respond to a real word or a memorized face "as quickly as possible but accurately". All subjects responded with one hand for the first half of the experiment and with the other for the second half. Hand order was the same in both sessions for each subject and was balanced across subjects.

For the lexical decision task subjects were asked to respond to real words and to refrain from responding to non-words. Each of the 4 sets of 20 high and low imagery words and their corresponding non-words were presented 2 times in each visual field while the subjects responded with one hand. The trials were then repeated in identical order resulting in 320 trials for that hand. The procedure was then repeated for the other hand. Subjects were warned that words would appear more than once, but no one reported recognizing the ordered repetition. Within each set of 40 stimuli, words and non-words appeared in each visual field in a random order. Words and their corresponding non-words from the two word types were divided in half and words from one half were grouped with non-words from the other half. Thus a word and its corresponding non-word never appeared in the same set of 40 stimuli. Each stimulus appeared once in one visual field in the first 80 trials and was then repeated in the opposite visual field in the next 80.

Subjects were given 80 practice trials using a different set of words of intermediate imagery value (rating 5-6). First they were asked to read aloud the words and non-words then were given 80 practice trials in blocks of 20 stimuli.

The experiment began with subjects reading aloud the 40 experimental words followed by the 40 non-words, pronounced however seemed appropriate to the subject. This was intended to reduce the effects of priming which can facilitate reaction time to a word presented more than once (Scarborough et al. 1977). Then the subject performed 320 trials with one hand in blocks of 20, followed by 320 trials with the other hand.

The face recognition task began by showing the subjects all 12 photographs to be used in the experiment for 10 seconds each, projected centrally and considerably larger than the test photographs. They were then shown 10 randomly chosen trials at the speed and size they were to occur in the experiment. Finally they were shown all 12 photographs again for 10 seconds each, followed by 2 photographs of different models presented for 2 minutes each. They were asked to memorize these two people and were told that they would have to respond to photographs of these people regardless of facial expression.

Because of the small number of faces, trials were divided into sets of 64 which were repeated 5 times for each hand. Within this set, each of the 4 actors appeared 16 times, and for the two target faces half the appearances showed the same photograph as was memorized and half showed an equal number of photographs of each of the other two expressions. For the non-target faces, expressions were balanced so that the probability of a face being a target was the same as the probability of being a non-target for each expression.

The first 64 trials were treated as practice and were not included in subsequent analyses. Subjects were again asked to respond as fast as they could but accurately to any photographs of the people they had memorized. They were given 64 practice trials and 320 trials for each hand in blocks of 16. To ensure good performance, the two target faces were shown again for 15 seconds each at 4 points in the experiment, always displaying the same expression as originally memorized.

Subjects were assigned randomly to one of 4 groups according to the type of expression shown by the memorized faces. These groups were Neutral-Neutral (NN), Neutral-Happy (NH), Neutral-Surprised (NS) and Happy-Surprised (HS). Different actors were used as memorized targets across different subjects but the same actor pairs appeared in each of the 4 groups. Table III summarizes the design for the face recognition experiment.

Throughout both experiments subjects were reminded not to blink during testing, to maintain fixation on the central cross and not to look towards a word or face when it appeared. In addition the were reminded that both speed and accuracy were important.

TABLE III

Design summary for face recognition task

SUBJ	MEMORY SET	FACES MEMORIZED
1	NN	N1 N2
2	NN	N2 N3
3	NN	N3 N4
4	NN	N4 N1
5	NH	N1 H2
6	NH	N2 H3
7	NH	N3 H4
8	NH	N4 H1
9	NS	N1 S2
10	NS	N2 S3
11	NS	N3 S4
12	NS	N4 S1
13	SH	S1 H2
14	SH	S2 H3
15	SH	S3 H4
16	SH	S4 H1

N: NEUTRAL
H: HAPPY
S: SUPRISED
1-4: MODEL NUMBER

VI. PRELIMINARY DATA ANALYSIS

Because of the relatively long stimulus presentation, horizontal EOG was recorded to check for trials on which eye movements may have allowed bilateral viewing of the stimulus. For each subject the 16 EOG calibration trials were digitally filtered at 16 Hz, plotted and the onset of each lateral eye movement was identified. This was easily accomplished for movements of 6°, 3° and for most movements of 1.5°, but for approximately half of the 0.75° movements no displacement in the expected direction could be identified. For all identifiable movements the maximum digital displacement value was identified and the mean value for the following 0.5 sec was calculated. This value was subtracted from a premovement baseline to obtain the digital displacement associated with that particular movement. The relationship between angular movement and digital displacement was plotted for a number of subjects and appeared to be linear. Therefore a regression line was fitted to the displacement values for each of the four angles (or as many as were available for a particular session) and this was used to calculate the digital displacement associated with a given angular movement. These calculations were performed separately for movements to the left and right for each experimental session.

Reaction time was analyzed separately for each of the 8 conditions formed by the 2(word/face types) x 2(hands) x 2(visual fields) design. Event-related potentials (ERPs) were analyzed similarly except that an extra factor, Response type, was included. For the purposes of this analysis the abstract/concrete distinction was maintained when analyzing the ERP's to non-words and the distinction between the same expression/different expression as either of those memorized was maintained for analyzing ERPs to non-memorized faces. Each cell of the factorial design contained 40 trials. This is a large number for a DVF study but was considered the minimum acceptable to allow a sufficient number of trials to be averaged together for each condition.

For each trial, horizontal EOG was filtered using the same 16 Hz digital filter used for the calibration files[3]. Baseline was defined as the average EOG prior to stimulus onset and displacement from this baseline was measured for the 200 msec during which the stimulus was presented. Thresholds of 2^{o} for words and 1.5^{o} for faces were selected since these values could be reliably measured and were within the inner edge of the lateralized stimuli. If eye movement above threshold was detected in the direction of the stimulus then

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[3]For all EOG analyses a recursive linear phase filter described by Lynn (1977, Type 1) was employed. The phase delay introduced by the filter was unimportant for the calibration trials, but was calculated to be 31 msec for EOG recorded at 1024 Hz. All calculations concerning latency of eye movements took this phase delay into account.

the average displacement during the subsequent 100 msec was calculated. If this average remained above threshold that trial was omitted from further analysis. Less than 0.8% of trials were found to be contaminated by horizontal eye movement by this procedure.

Uncontaminated trials on which the subject responded correctly were averaged together in two ways. Conventional averages time-locked to the stimulus onset and spanning the full 1.1 second recording epoch were made, as well as averages for the 400 msec prior to the button press on each trial (obviously back-averaging was not possible for no-response trials). These back averages therefore were time-locked to the button press, but incorporated different sections of data with respect to the stimulus onset. For both types of averages, trials were omitted if there was evidence of vertical eye movement above a threshold of 75 microvolts during the epoch of interest. This was done to allow the inclusion of as many trials as possible in the back averages. Trials used in forward averages therefore were a subset of those used for back averages which in turn were a subset of all correct responses.

The total number of trials included in individual averages varied greatly for different subjects and different conditions. As few as 8 or as many as 40 trials were available for forward averaging although in most cases many more trials were included in back averages than in forward averages. Such differences in the number of trials averaged together will have two effects on the resulting individual waveforms. In general, amplitudes of individual peaks will be directly related to the number of trials included in the average, since the larger the number of trials included, the larger the signal-to-noise ratio. It would be unwise therefore to use amplitude measures from such widely discrepant averages without some form of correction. Measures of the latency of peaks, however, should not be related to the number of trials in each average, although the reliability with which the peak can be measured will be greater with a larger number of trials. Since the primary interest of this experiment is the latency of the P300 it was decided therefore to use data from all subjects regardless of the number of trials included in any individual average. Although amplitude measures were also obtained, they will not be discussed further. Similarly, the data concerning resting EEG and the ERPs recorded from sites other than Pz do not address directly the hypotheses under investigation and will not be discussed further in this report.

It was intended that complete data could be analyzed for both experiments from all 16 subjects. Faults in the tape cartridge data storage system, however, prevented recovery of the data for the lexical decision task for two subjects and for the face recognition task for one. Furthermore, one subject withdrew at the midpoint of the lexical decision task and his data were not replaced. For this reason the two experiments were treated separately with 13 subjects in the lexical decision task and 15 in the face recognition task.

VII. RESULTS

A. GRAND AVERAGE ERPS

1) Forward Averages

The grand average ERPs for Pz are shown in Figures 3 and 4 for abstract and concrete words and non-words in each visual field for each responding hand. Two prominent late positive waves are visible in most averages with peaks at approximately 400 and 600 msecs. Inspection of the corresponding Cz averages revealed a similar peak at approximately 400 msec but a much less prominent later peak. This distribution would be consistent with the interpretation of the two peaks as corresponding to the P3a and P3b identified by Squires et al (1975). They will therefore be referred to by these names for convenience.

The corresponding grand average ERPs for faces are shown in figures 5 and 6. For the positive conditions (SFSE, SFDE) a single, much larger late positive peak is visible with a maximum at approximately 600 msec. The negative conditions (DFSE, DFDE) however suggest that this late peak may also consist of two separable components. Examination of individual averages for a number of subjects revealed identifiable peaks at approximately 400 and 600 msec.

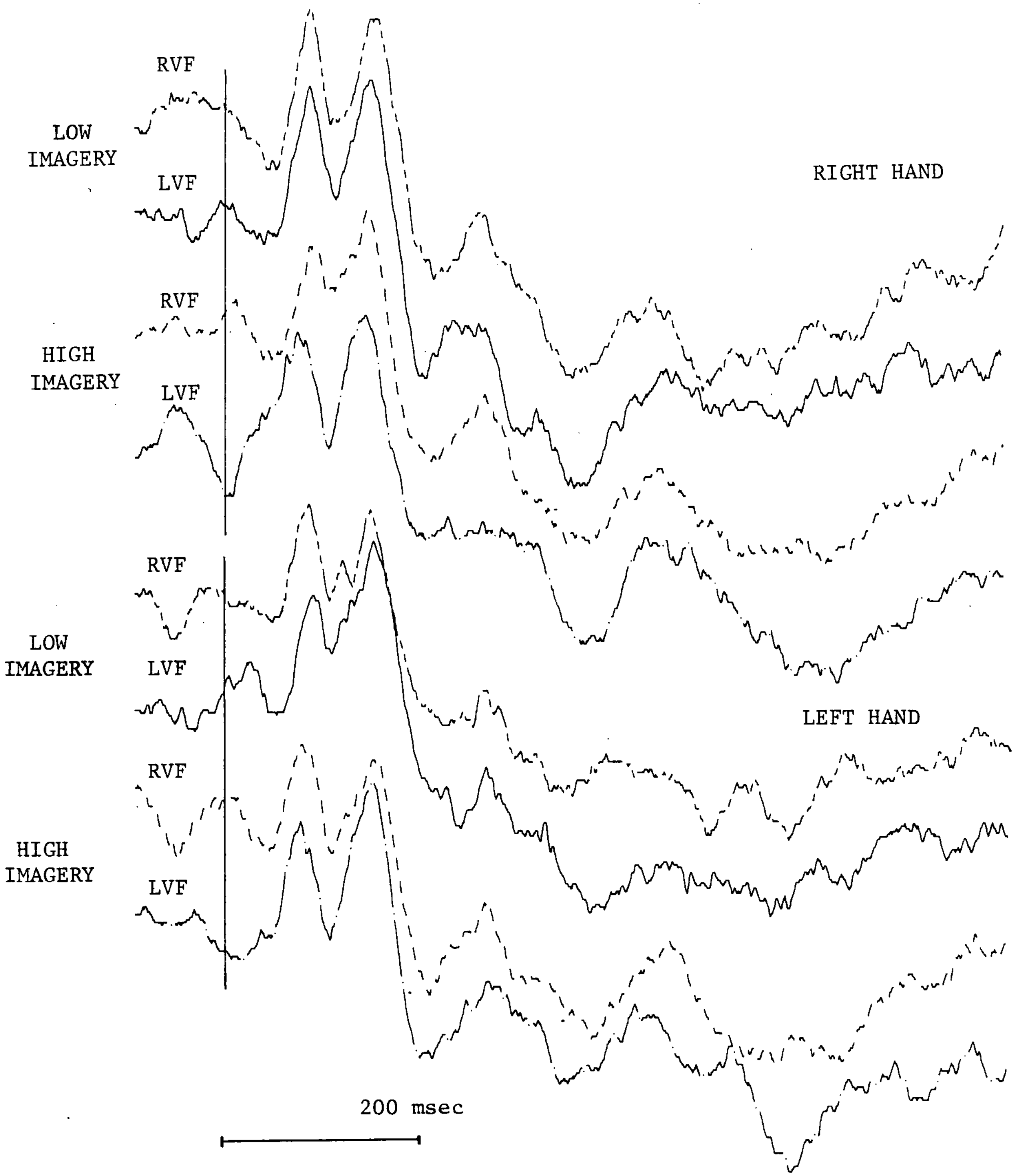

FIGURE 3. Grand average ERPs at Pz for words.

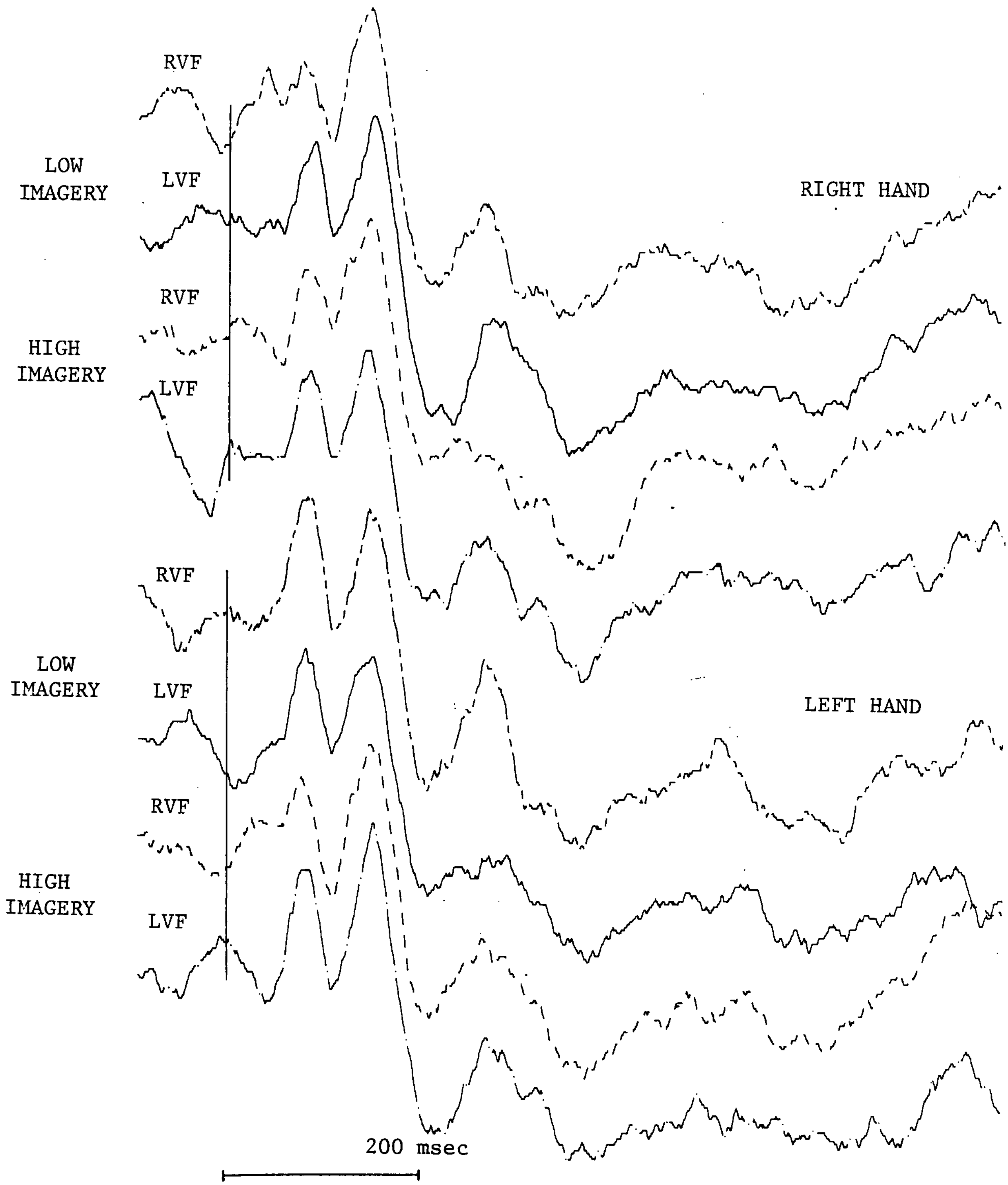

FIGURE 4. Grand average ERPs at Pz for non-words.

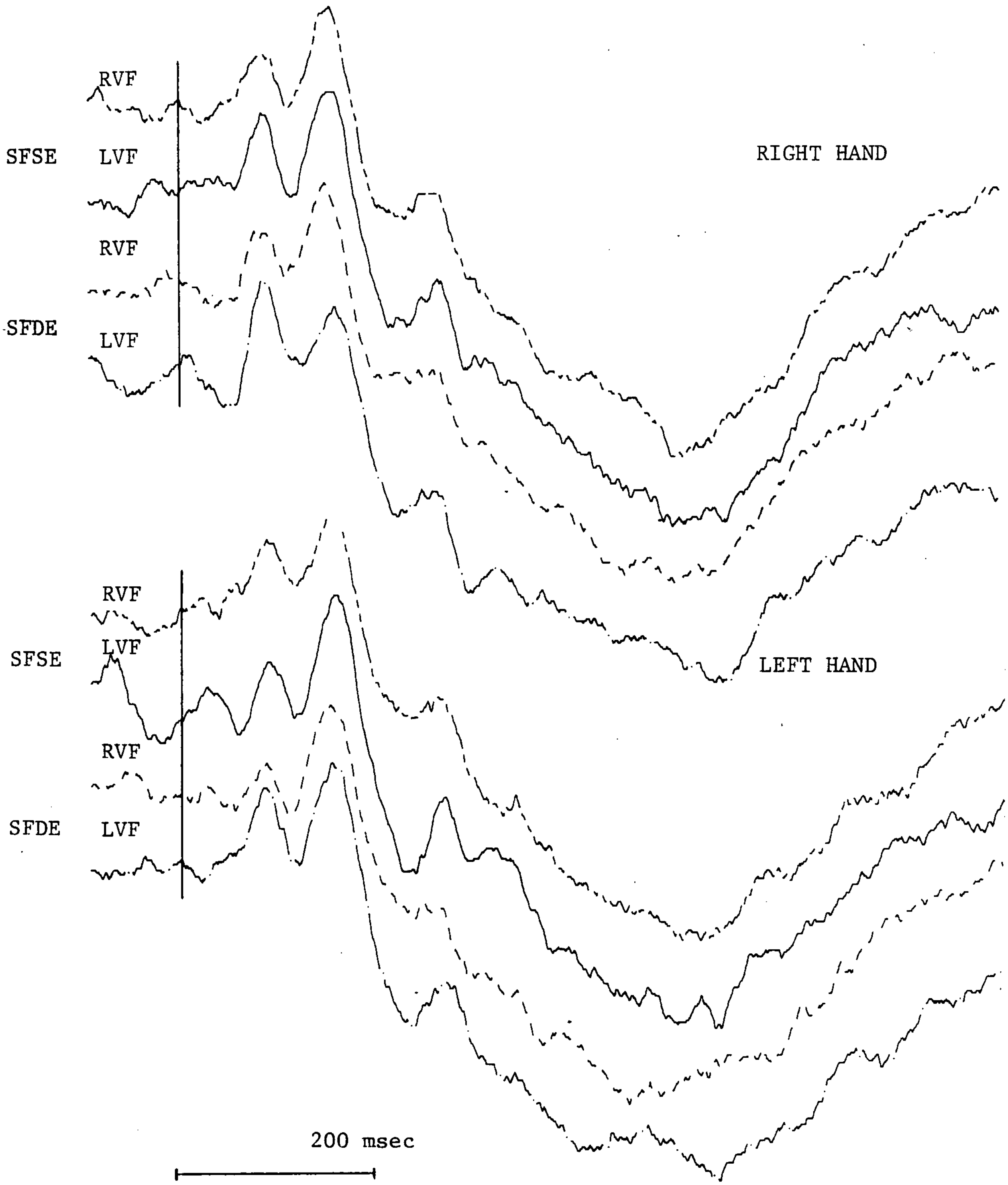

FIGURE 5. Grand average ERPs at Pz for memorized faces.

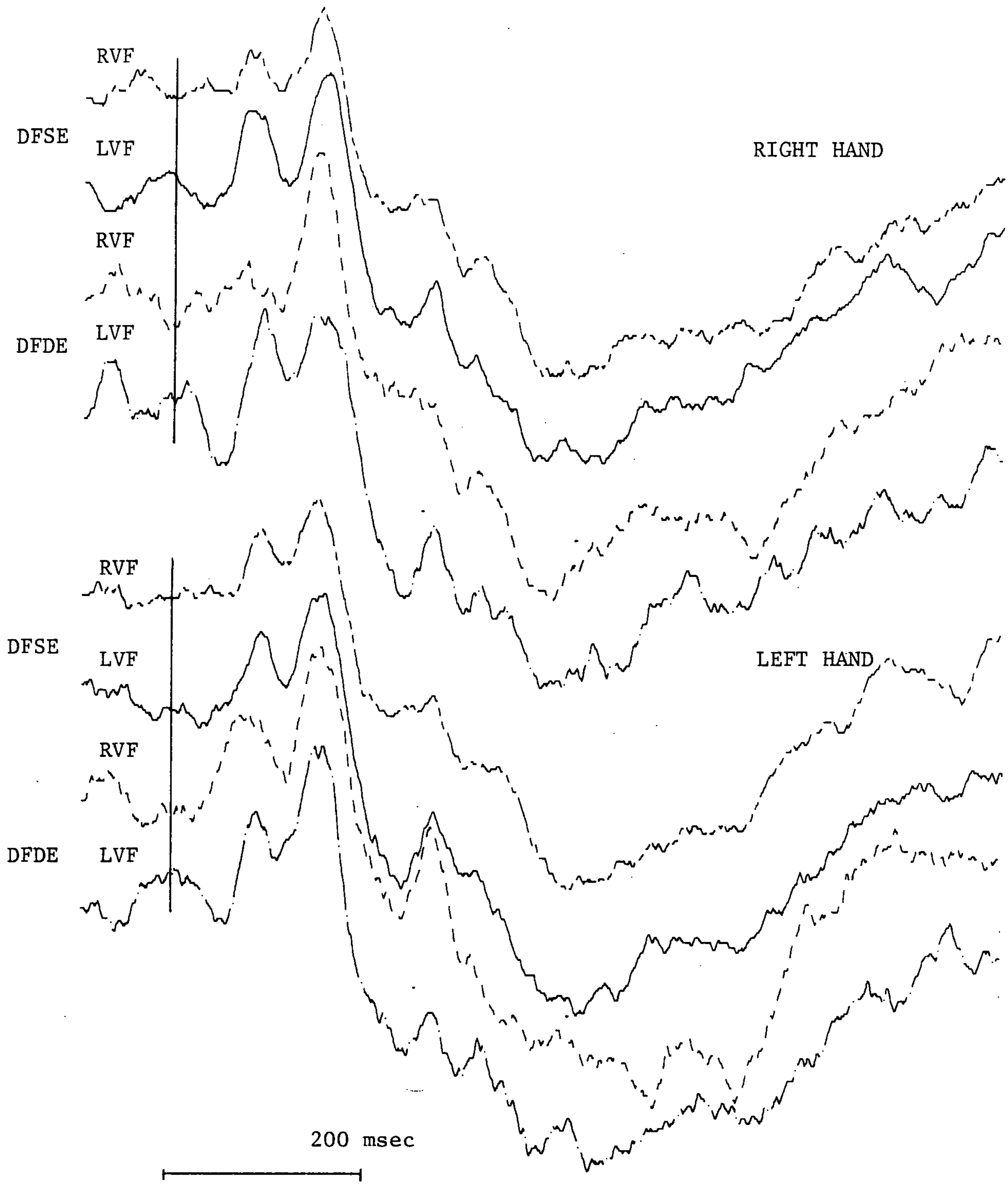

FIGURE 6. Grand average ERPs at Pz for non-target faces.

In the absence of a more objective criterion for deciding the number of components in the waveform (eg principal components analysis) it seemed best to assume that two late positive waves were present in the waveforms for both words and faces but that the size of the P3b to faces had caused the two to merge in the grand average. Therefore data from the two experiments were treated in a similar way. Individual averages for Pz in each condition were smoothed with a 20 Hz filter[4] to facilitate accurate peak identification and maxima and minima were identified between 300 and 700 msec after stimulus onset. The largest maximum in a 300-500 msec window was scored as the P3a and the largest maximum in the 500-700 msec range was scored as the P3b.

2) Back Averages.

Grand back averages at Pz for all conditions are shown for words in Figure 7 and for faces in Figure 8. Although the waveforms for the words appear variable, a positive peak is apparent at about -200 msec. The grand back averages for faces are very different and appear to show no evidence of a P300 peak. Inspection of the individual waveforms however did reveal maxima at approximately -200 msec so again it was decided to treat both sets of data alike.Individual averages

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[4]For this stage of the experiment a phases free digital filter was available so no correction was necessary for subsequent latency measures. I am indebted to Gary Birch for designing and supplying this filter.

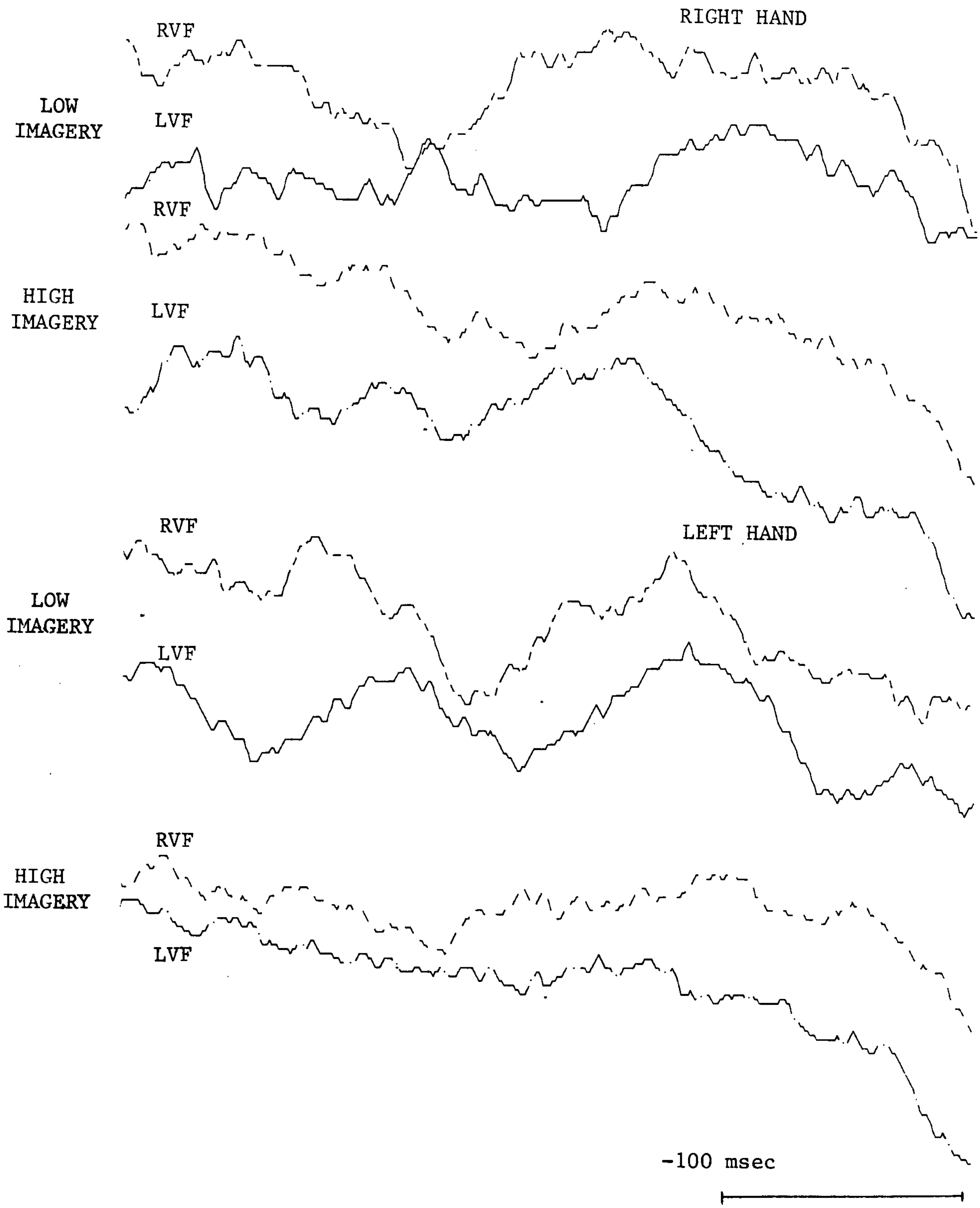

FIGURE 7. Grand mean back-averaged ERPs at Pz for words.

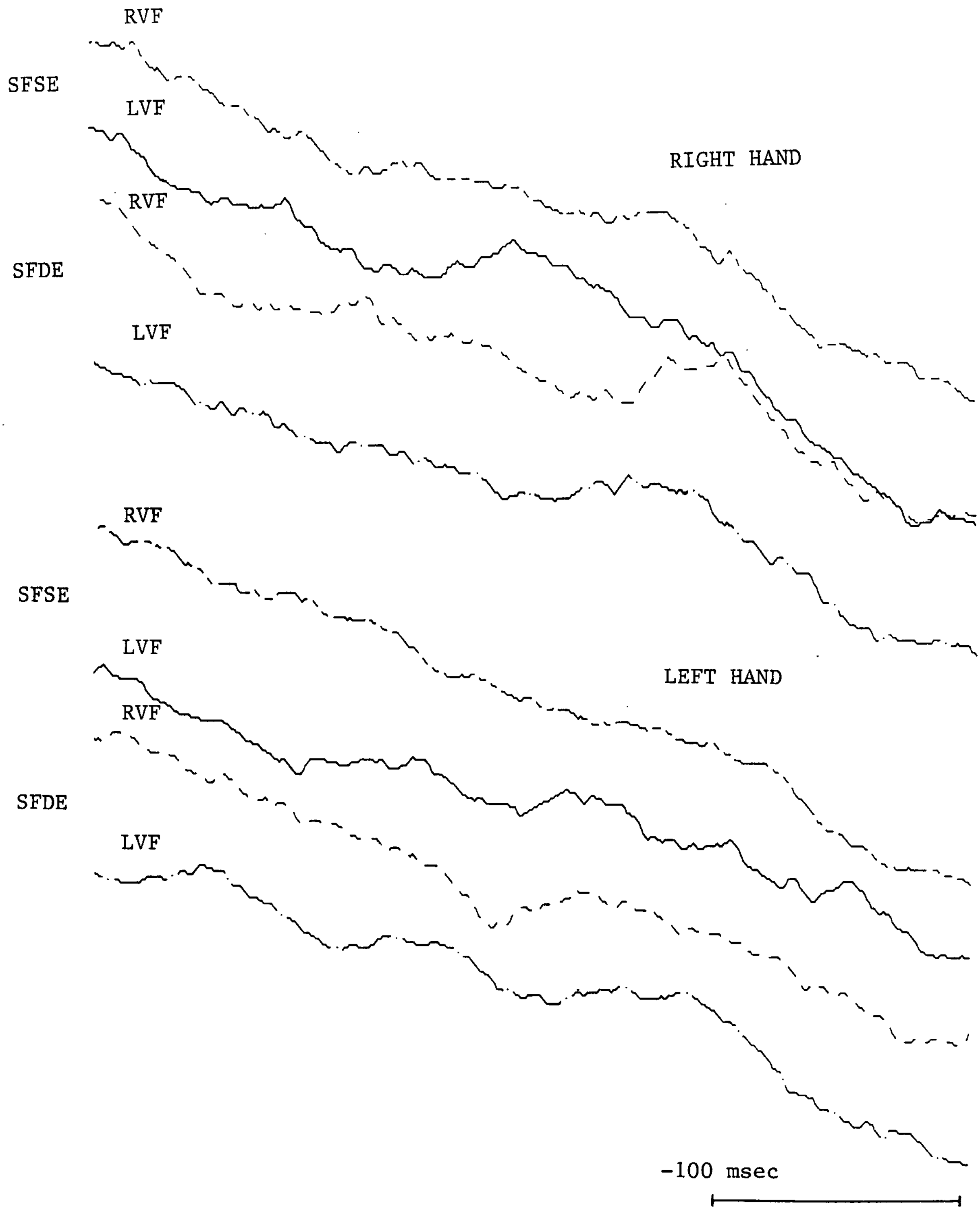

FIGURE 8. Grand mean back-averaged ERPs at Pz for faces.

were filtered at 20 Hz and the latency of the largest maximum in a (-80)-(-280) msec window was recorded.

B. WORDS

1) Reaction time (RT)

Overall accuracy was calculated for correct responses and false positives. Words were correctly responded to 65% of the time with only 8% false positives. Table IV shows these percentages for each visual field, word type and hand.

Median RTs were calculated for each subject in each condition and were submitted to a 3-way (Word Type x Hand x Visual Field) analysis of variance. This revealed a main effect for Word Type ($F(1,12)=7.01$, $P<.05$) and for Visual Field ($F(1,12)=9.21$, $P<.02$). Reaction times were faster for the RVF and for high imagery words. No other main effects or interactions approached significance. In particular, there was no evidence of a Word Type x Hand x Visual Field interaction ($F(1,12)=0.28$, $P>.50$). The mean RTs and standard deviations (S.D.) are given in Table V and are depicted in Figure 9.

The same analysis was performed on the median RTs calculated for those trials included in the forward and the back averages for each subject. This was done to ensure that the behavioural effects seen for all trials were still present for the subset of trials used in physiological analyses. The results for both the forward and back averaged data were essentially identical. Main effects for Word Type (Forward: $F(1,12)=8.41$, $P<.02$; Back: $F(1,12)=6.27$, $P<.05$) and for Visual Field (Forward: $F(1,12)=9.71$, $P<.01$; Back: $F(1,12)=8.90$, $P<.02$) remained the only significant effects.

2) P300 Latency

The latencies of the P3a and P3b for each subject were submitted to a 4-way (Response Type (Yes/No) x Word Type x Hand x Visual Field) multivariate analysis of variance. The Response Type x Hand interaction was the only multivariate F to reach significance ($F(2,11)=4.63$, $P<.05$). Univariate tests on each variable were significant only for the latency of the P3b ($F(1,12)=5.36$, $P<.05$). Tests of simple main effects for this variable (Kirk 1968), resulted in a significant main effect for Visual Field for Yes responses ($F(1,12)=5.41$, $P<.05$) but not for No responses ($F(1,12)=0.13$, $P>.50$). This interaction for P3b latency is shown in Figure 10 with RT collapsed across Word Type and Hand. The P3b occurs earlier to words presented in the RVF, as does reaction time.

3) RT-P300 Back Averages

The latency of the P300 prior to reaction time as determined by back-averaging was submitted to a 3-way (Word Type x Hand x Visual Field) analysis of variance. A significant main effect for Visual Field was found

TABLE IV

Percentage of words correct and false positives.

CORRECT

HIGH IMAGERY WORDS

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	77.8	65.8	74.4	67.9
S.D.	11.2	17.5	14.2	15.6

LOW IMAGERY WORDS

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	58.8	58.6	63.3	54.1
S.D.	11.7	15.7	12.4	11.1

FALSE POSITIVES

HIGH IMAGERY WORDS

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	10.3	9.5	11.1	11.1
S.D.	6.9	7.3	6.2	5.3

LOW IMAGERY WORDS

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	6.2	5.1	4.9	6.9
S.D.	5.0	4.7	3.4	5.0

TABLE V

Means and standard deviations for reaction times to words in msec.

HIGH IMAGERY WORDS

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	667	694	662	692
S.D.	79	66	84	88

LOW IMAGERY WORDS

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	684	701	683	692
S.D.	73	78	78	62

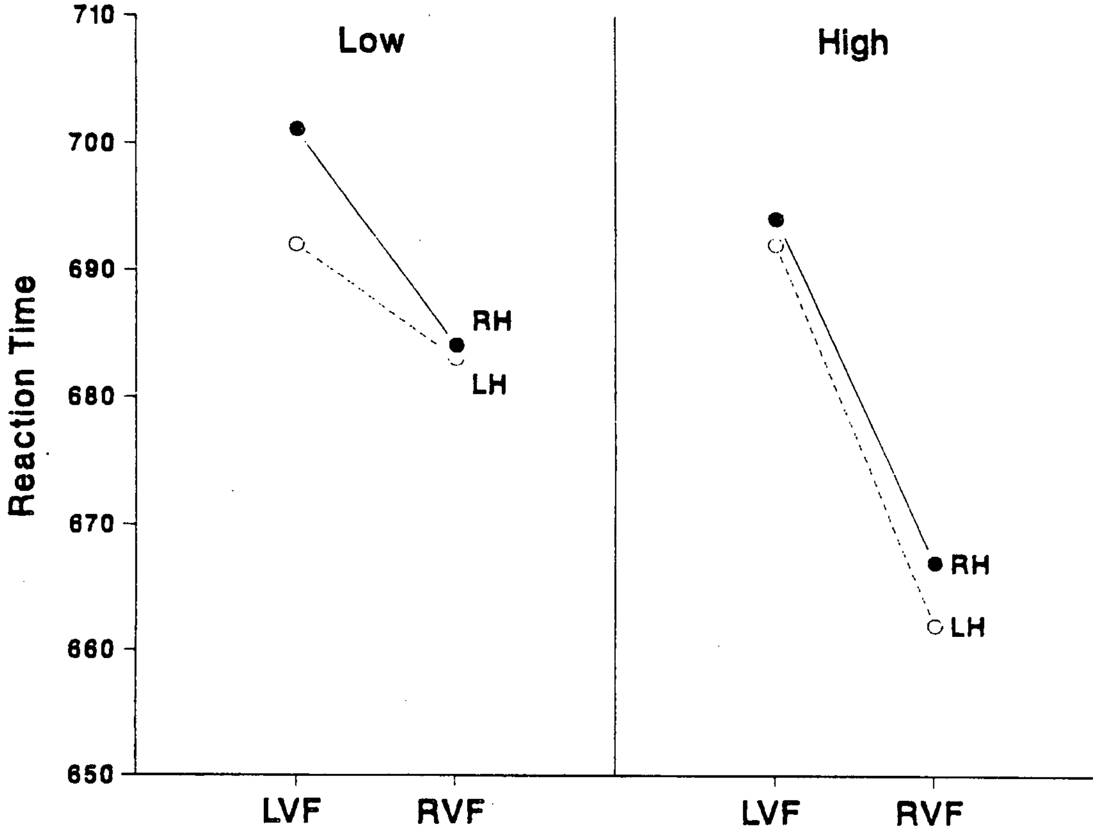

Figure 9. Reaction time to words. High: High Imagery; Low: Low Imagery; RH: Right Hand; LH: Left Hand; RVF: Right Visual Field; LVF: Left Visual Field.

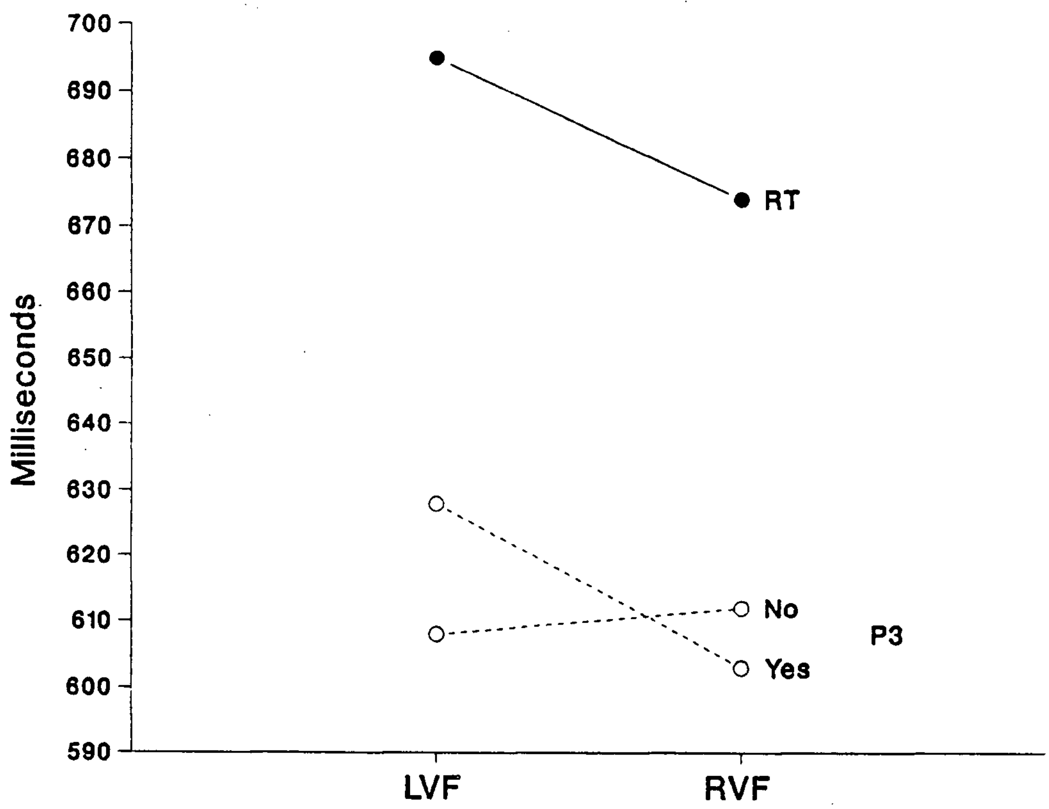

Figure 10. Latency of the P3b for words (Yes) and non-words (No) in the right and left visual field. Reaction time is plotted collapsed across Hand and Word Type.

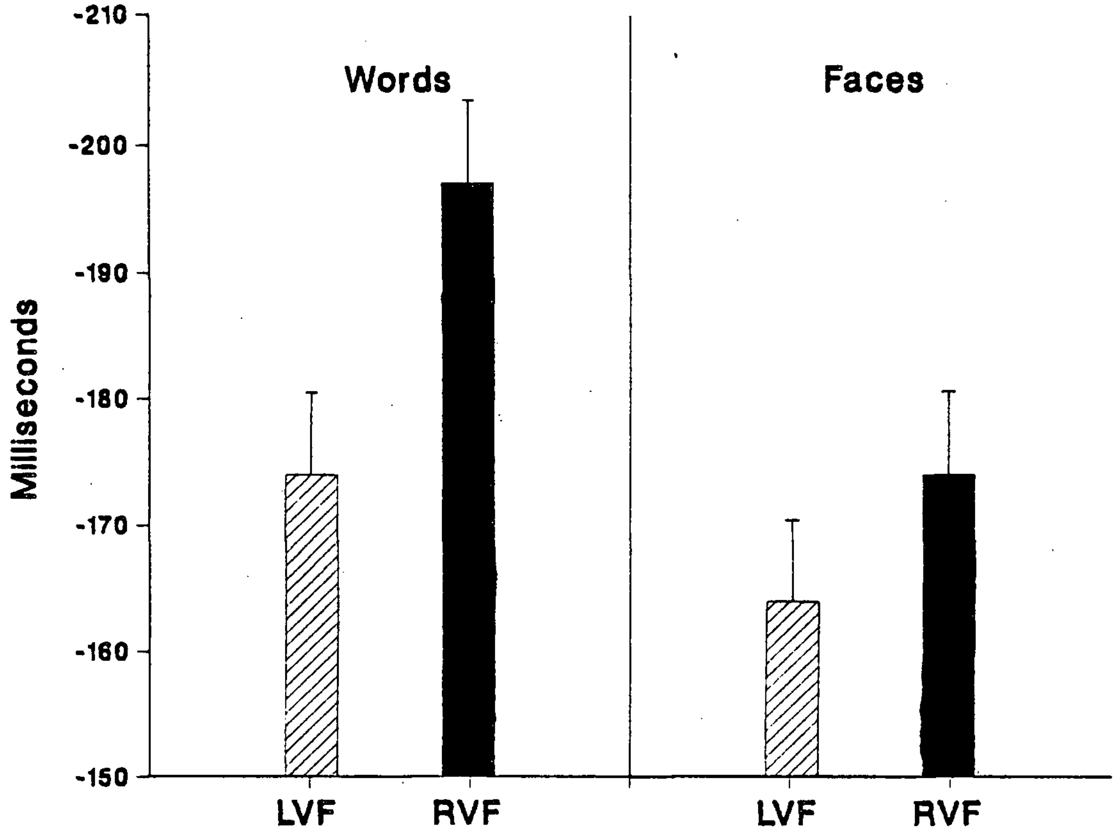

Figure 11. Latency of the P300 prior to reaction time as determined by back averaging (see text for details).

(F(1,12)=7.96, P<.02) and no other main effects or interactions reached significance. In particular, neither the Hand main effect (F(1,12)=0.01, P>.50) nor the Hand x Word Type interaction (F(1,12)=1.02, P>.30) approached significance. The RT-P300 processing duration was shorter for words presented in the LVF. This effect is illustrated in Figure 11.

C. FACES

1) Reaction Time (RT)

Overall accuracy was calculated for correct responses and false positives. Faces were correctly responded to 82% of the time with only 12% false positives. Table VI shows these percentages for each visual field, word type and hand.

Median RTs for face recognition were analyzed by a 4-way analysis of variance with Memory Load (NN, NH, NS and HS) as between subjects factor and Face Type, Hand and Visual Field as within subjects factors. Only the main effect for Visual Field reached significance (F(1,11)=7.67, P<.02) showing a RT advantage for the RVF. Mean RTs and S.D.s collapsed across memory load are given in Table VII and are depicted in Figure 12. As can be seen, neither the main effect nor any interactions involving Hand approached significance.

The same analysis performed on RTs for trials used to create forward and back averages produced similar results. In both cases only the Visual Field main effect reached significance (Forward: $F(1,11)=13.97$, $P<.01$; Back $F(1,11)=6.95$, $P<.05$).

2) P300 Latency

The latencies of the P3a and P3b were submitted to a 5-way (Memory Load x Response Type x Face Type x Hand x Visual Field) multivariate analysis of variance. As for RT, there was no effect of memory load. The only within-subject factor to reach significance was a Response Type x Face Type interaction ($F(2,10)=6.27$, $P<.02$). Univariate tests on the two variables were significant only for the P3a ($F(1,11)=10.93$, $P<.01$) and a test for simple main effects showed no significant effect of Face Type for Yes responses ($F(1,11)=0.15$, $P>.50$), but a highly significant effect of Face Type for No responses ($F(1,11)=21.38$, $P<.001$). This interaction is shown in figure 13.

3) RT-P300 Back Averages

A 4-way (Memory Load x Face Type x Hand x Visual Field) analysis of variance on the latency of the back averaged P300 resulted in a significant interaction between Face Type and Hand ($F(1,10)=8.41$, $P<.02$) but no other significant interactions or main effects. A test of simple main effects revealed no effect of Hand for Different expressions

($F(1,10)=0.28$, $P>.50$) and only a marginally significant effect for Same expressions ($F(1,10)=3.54$, $P<.10$). This interaction is shown in Figure 14. In view of the results for the lexical decision task it is interesting to note that the main effect for Visual Field approached significance ($F(1,10)=3.36$, $P<.10$), showing a shorter delay between P300 and button press for faces in the LVF (see Figure 11).

TABLE VI

Percentage of faces correct and false positives.

CORRECT

SAME FACE SAME EXPRESSION

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	87.5	85.1	89.1	84.5
S.D.	10.7	13.6	8.3	15.9

SAME FACE DIFFERENT EXPRESSION

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	76.5	77.8	74.7	82.4
S.D.	17.9	17.1	17.8	11.9

FALSE POSITIVES

DIFFERENT FACE SAME EXPRESSION

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	12.0	13.6	10.2	12.9
S.D.	12.1	14.1	16.3	16.6

DIFFERENT FACE DIFFERENT EXPRESSION

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	14.3	8.9	12.3	8.6
S.D.	10.2	11.3	16.5	8.2

TABLE VII

Means and standard deviations for reaction times to faces in msec.

SAME FACE SAME EXPRESSION

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	619	639	630	642
S.D.	63	65	70	75

SAME FACE DIFFERENT EXPRESSION

	RIGHT HAND		LEFT HAND	
	RVF	LVF	RVF	LVF
MEAN	619	639	618	640
S.D.	53	70	65	74

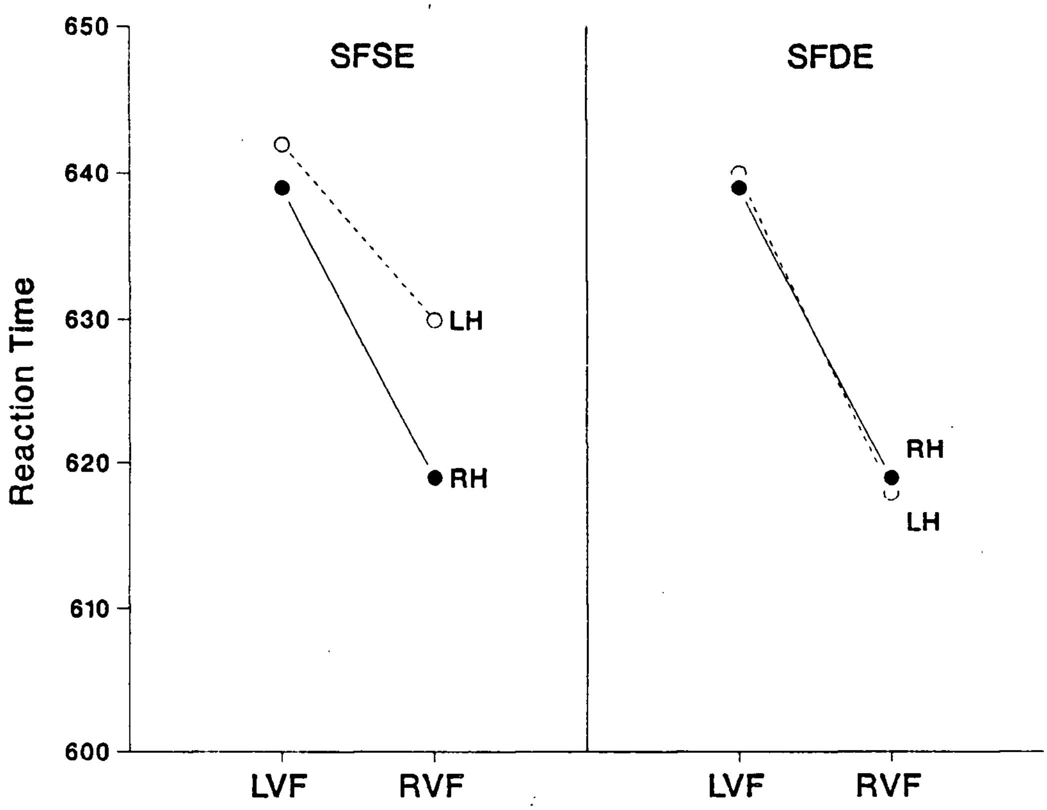

Figure 12. Reaction time to faces. SFSE: Same Face, Same Expression; SFDE: Same Face, Different Expression; RH: Right Hand; LH: Left Hand; RVF: Right Visual Field; LVF: Left Visual Field.

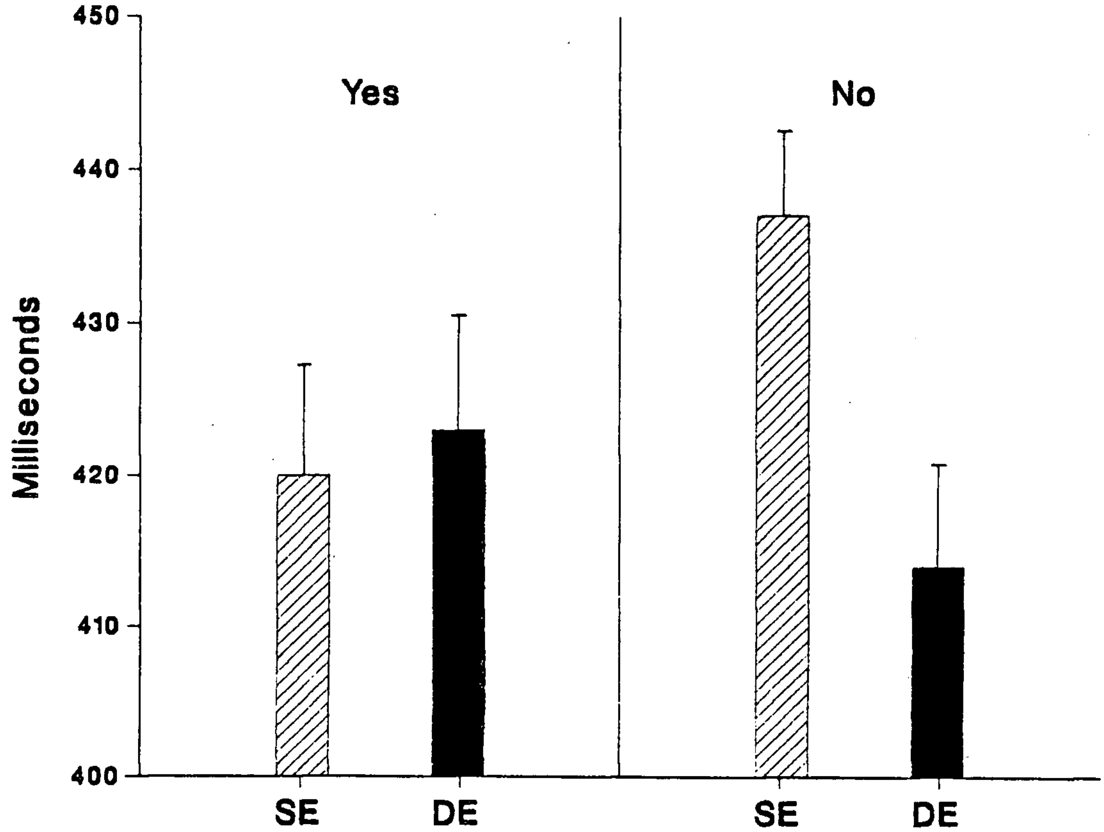

Figure 13. Latency of the P3a for Yes and No responses for faces with the Same expression and with a Different expression to those memorized.

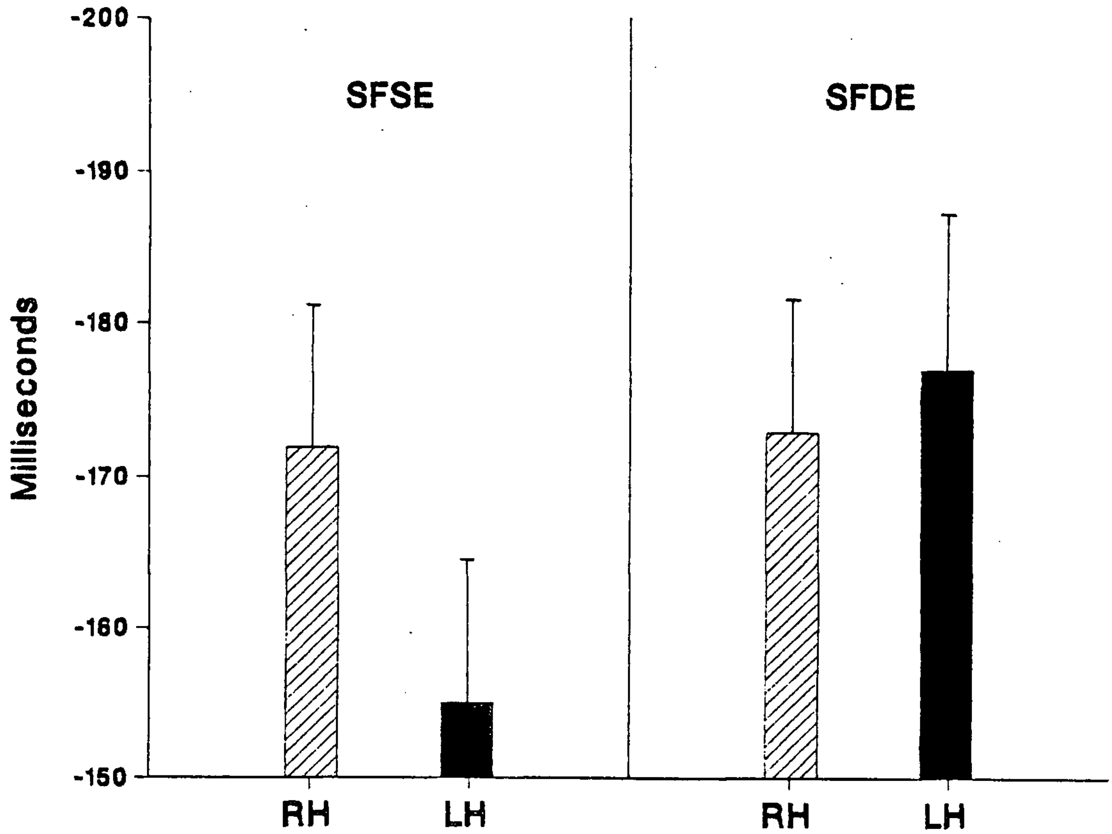

Figure 14. Latency of the P300 prior to reaction time to faces as determined by back averaging. SE: Same Expression as memorised; DE: Different Expression; RH: Right Hand; LH: Left Hand.

VIII. DISCUSSION

The aims of this study were two-fold: to assess the validity of using the P300 component of the evoked potential to measure the timing of lateralized cerebral processing, and to apply this technique to a facial recognition task. Since the question of validity must precede the application of the technique, the lexical decision task will be discussed first.

A. LEXICAL DECISION TASK

The lexical decision task was designed to allow confident inferences to be made concerning the relative contributions of the two hemispheres. Somewhat unexpectedly a strong RVF advantage was present for both high and low imagery words and there was no indication of a Visual Field x Hand interaction for high imagery words. In most studies these data would be interpreted in terms of the Callosal Relay model despite the failure to find a main effect favouring the right hand. It would appear reasonable to conclude therefore that the right hemisphere was required to process all the words in this task. As predicted, the P300 latency showed a comparable RVF advantage for Yes responses to both word types, and was completely uninfluenced by responding hand. The primary finding of this experiment, therefore, suggests that the P300 may be useful in revealing visual field advantages associated with lateralised stimulus processing.

A number of anomalous results remain to be accounted for however. The failure to find a reduced visual field advantage for highly imageable words is contrary to the data reported by Day (1977, 1979). He reported a VF x Word Type interaction for high and low imagery nouns and adjectives (Day 1979) and, although analyzed separately, it is clear that a similar interaction was present in his previous experiment using concrete and abstract nouns (Day 1977). It cannot be claimed that the present experiment was insensitive to imagery differences since a significant RT advantage was found for high imagery words, replicating a finding previously reported by Day (1979) and Shanon (1979). Several differences in methodology exist which may account for the discrepant result although any explanation must remain speculative at present. The quality of stimulus presentation in this experiment was less than ideal, with words varying in eccentricity and presented against a relatively dim background. However Hellige (1976) has reported data suggesting that degrading a linguistic stimulus improves LVF performance relative to the RVF. Such an effect should reduce or abolish the visual field advantage for both word types. Another difference was that the emotional value of the words used was explicitly controlled in the present experiment. If the highly imageable words used by Day were also rated as more emotional than the low imagery words, then this could have caused the reduced visual field advantage. A last possibility is that right hemisphere involvement in reading highly imageable words occurs only on the first presentation of that word. In this study the subjects read all words at the start of the experiment and each word subsequently appeared 8 times.

For Yes responses the P300 latency closely matched the reaction time data. For No responses however the P300 provided the only available measure of which hemisphere was performing the task. As Figure 12 shows, there was no significant difference in the latency of the P300 to non-words in either visual field, suggesting an equal ability in the two hemispheres to identify non-words. Leiber (1976) asked subjects to perform a similar task, to identify 4- and 5-letter non-words in the left and right visual fields, using RT as the dependent measure. She also found a RVF advantage only for Yes responses and found no difference for No responses. This suggests that the P300 latency may provide a valid measure of lateralised information processing whether or not a behavioural response is required.

Finally, it is worth noting that although high imagery words were responded to faster than low imagery words, no corresponding effect was seen for P300 latency. One interpretation of this effect would be that the locus of the

RT difference seen for high imagery words is not at the word recognition stage but at response selection and execution stages. Although such an explanation seems unlikely, neither Day nor Shanon have offered explanations for the RT difference at any stage. Alternatively the P300 may be too variable to measure a difference of only 12 msec reliably. The standard error of the P300 latency is no larger than that for RT, however, so this explanation also seems unlikely. Further research using the P300 would be useful to confirm the locus of this effect.Before discussing the back averages, and the appropriateness of the additive factors assumptions, the results of the face recognition study will be considered.

B. FACE RECOGNITION TASK

The RT data showed an unexpected but robust RVF advantage very similar to that seen for words (see Figure 12). A conventional interpretation of this data would suggest that the left hemisphere was performing the task unaided, a result at variance with a large number of other studies (eg Bertelson et al, 1979; Hilliard, 1973; Moscovitch et al, 1976; Rizzolati & Buchtel, 1977; Rizzolati, Umilta & Berlucchi, 1971). As discussed in the introduction, three factors were included which were expected to guarantee a LVF advantage. Involving long term memory (Moscovitch et al, 1976), emotional expressions (Suberi & McKeever, 1977) and the extraction of physiognomic identity (Bertelson et al, 1979) have all been shown individually to contribute to a LVF advantage. It seems likely therefore that an unexpected combination of factors in the present experiment combined in a way that allowed the left hemisphere to develop an efficient strategy for performing the task.

Sergent (1982a, 1983, 1984) has proposed that the LVF advantage seen in most studies of face perception is largely an artifact of stimulus characteristics and the testing situation. She has shown that identification of identikit faces can be performed in either hemisphere and tends to favour the left hemisphere when the faces differ by only a single feature or when their differences are predominantly in the upper half of the face. More recently (Sergent 1984) she has proposed that the left hemisphere processes the top-to-bottom configuration of a face holistically and is more sensitive to difficult visual discriminations while the right hemisphere is more dependent on the objective salience of facial features. Her studies all use identikit faces, however, which allow precise control of the feature similarity but which cannot be assumed to engage the same processing mechanisms as real faces. She has yet to demonstrate that her findings can be generalized to natural faces. Furthermore, were her findings to be generally applicable, one would expect to see a larger number of studies showing a left hemisphere advantage. In general, it is not that a narrow range of stimulus types, task difficulty, discriminability etc. is restrictive and leads to only a single consistent result, but that the uncontrolled diversity of the facial stimuli that are employed allow few inferences to be drawn concerning the mechanisms at work in a particular study.

Another study which found a RVF advantage for faces was Marzi and Belucchi (1977). They used slides of famous faces and it was assumed that the opposite field advantage derived from the familiarity of the face, which encouraged recognition using naming strategies, or from certain well-known features. Levine and Koch-Weser (1982) however have since found a LVF advantage for famous faces. That familiarity remains a significant determinant of visual field advantage has been demonstrated by Umilta, Brizzolara, Tabossi and Fairweather (1978) who found a RVF advantage for familiar faces but a LVF advantage for unfamiliar faces. In this case however familiarity involved looking at the faces daily for four days prior to the experiment. The experiment itself was carried out over 5 days.

It seems most likely therefore that the large number of repetitions (640 in all) and the small number of faces involved (12) allowed subjects to become familiar with all the faces rapidly and to perform the majority of the task using a strategy best performed by the left hemisphere. This interpretation suggests that the predicted asymmetries would have been present initially and would have changed through the course of the experiment. A similar practice effect has been shown to influence ear asymmetry in dichotic listening (Sidtis & Bryden, 1978). To test this, a further analysis was carried out on the first block of 64 trials completed by each hand. This constituted the second and the seventh block of trials (including practice trials) of the experiment. A 5-way analysis of variance with Beginning Hand and Memory Load as between factors and Face Type x Hand x Visual Field as within factors revealed only a significant 4-way interaction between Beginning Hand, Face Type, Hand and Visual Field ($F(1,7)=14.53$, $P<.01$). Simple main effects were examined but did not lead to an easily interpretable solution. Despite this result, it is still likely that a closer analysis of performance changes block by block may reveal the expected shift in lateralization. In particular, analysis of the first block of practice trials may prove fruitful.

The data for P300 latency were similarly unexpected, revealing no effects for the P3b, but a Response Type x Face Type interaction for the P3a (see Figure 13). The early P300 component named the P3a by Squires et al (1975) is clearly dissociable from the later P3b (Ruchkin & Sutton, 1983). It appears to be automatically elicited by rare or unexpected events and its amplitude is inversely related to the probability of a stimuli's occurrence (see Pritchard, 1981 for a review). The association of the early positive component in this experiment with the P3a is tentative and would be strengthened by a principal components analysis to reveal more clearly its amplitude and distribution. The latency change observed, with a shorter latency to Different Face-Different Expression stimuli than to Different Face-Same Expression, is consistent with the stimulus characteristics known to affect the P3a. This is because for the 12 subjects out of 16 who didn't memorize two neutral faces, the DFDE condition contained the least frequently seen expression and an unexpected (unmemorized) face. Both of these conditions would be expected to elicit a larger P3a. Unfortunately there are no reports of latency changes associated with this early P300 component, due largely to the paucity of reports dealing with the component itself. Further analysis of other electrode sites may provide evidence in support of this tentative interpretation.

These data would appear to provide poor support for the claim that the P300 may be useful in determining cerebral asymmetry, since no significant effects were observed for the component of primary interest. However, Figure 15 shows the P3b latencies for positive and negative responses together with reaction time collapsed across Face Type and Hand. The P3b shows a visual field asymmetry very similar to that shown by reaction time, although failing to reach statistical significance. As with words, No responses appear to have been performed equally well in either hemisphere. Since the

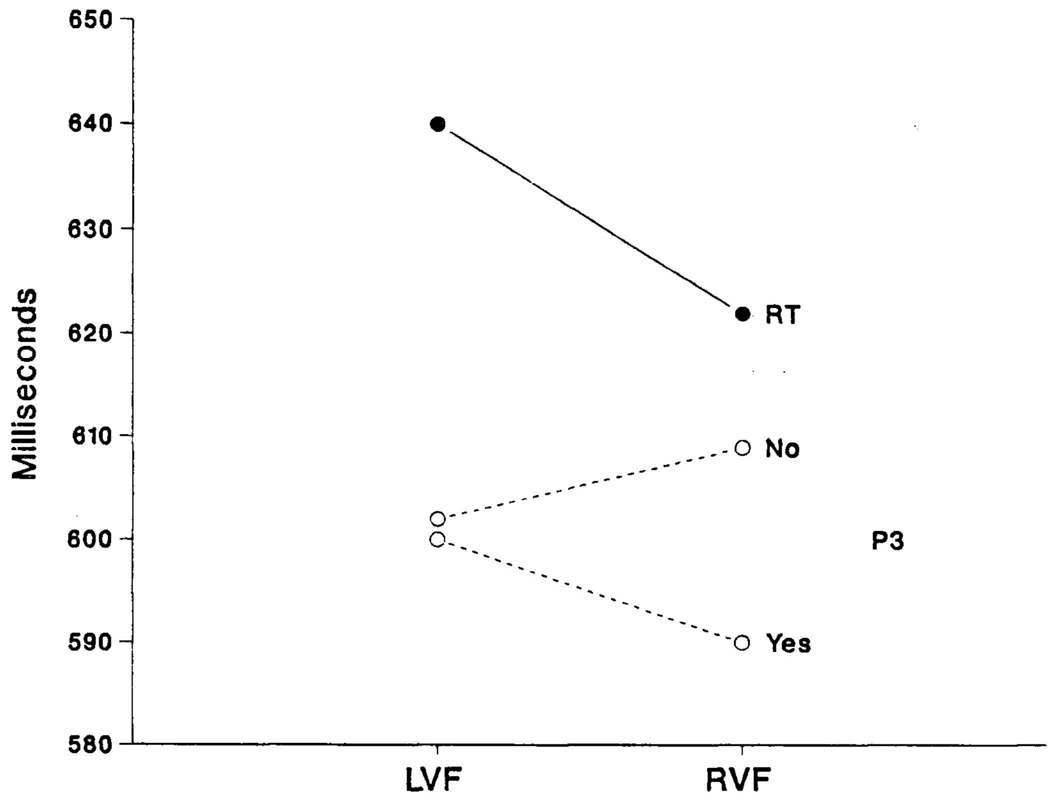

Figure 15. Latency of the P300 for Yes and No responses to faces. Reaction time is collapsed across Face Type and Hand

behavioural data revealed that there was a complex 4-way interaction occurring through the course of the experiment, this lack of statistical significance may be less important than the mean differences apparent in Figure 15.

C. Back Averages.

It was hoped to use the back averages as a brief method of producing P300 averages corrected for variations in stimulus evaluation time which in turn should be the cause of variations in reaction times. If all the assumptions of the additive factors models are met, then such averaging might produce better estimates of the P300. The Grand averages shown in Figures 8 and 9 suggest that no improvement in averaging the P300 has been achieved. Approximately 70 msec elapsed between the forward averaged P300 peak and RT but the most readily identifiable peak in the back averages occurs approximately 180 msec before the button press. Furthermore there is no evidence for an improvement in the signal-to-noise ratio which would be expected to occur with latency adjusted averages (Chase et al, 1984).

For the RT-P300 estimates, any main effect of visual field or a Visual Field x Hand interaction for low imagery words was considered evidence for the interaction of two stages of processing assumed by the model to be separate and independent and therefore evidence against the appropriateness of applying either model to the data. The lexical decision task provided strong evidence of a main effect resulting in a shorter RT-P300 interval for stimuli in the LVF. A similar effect was apparent for the faces, but failed to reach significance (Figure 12).

If the peak being measured could be confidently identified as the P300 then this evidence would be unequivocal. Doubts about this identification are compounded however by an alternative explanation for these data. Since RT varies considerably from trial to trial, different data segments are being averaged together. For trials containing fast responses, the 400 msec averaging epoch must begin at a point very early in the complete waveform, possibly before stimulus onset. As can be seen from the grand average wave forms (Figures 4,5,7 & 8) the ERP is dominated, at approximately 100 msec, by a negative wave (N100) which rapidly resolves as the later positive components emerge. Trials with fast reaction times will include this rapidly changing section of the N100 quite close to the centre of the averaged epoch. The faster the reaction times are on average, the further this descending portion of the N100 will encroach into the back average. As it does so it will sum with any other waves, and should it coincide with a slow positive wave similar to the P300, it will form a false peak where the two intersect. As RT varies with visual field, so will this peak created from the combination of two components.

This explanation may account for the visual field differences in the back-averages, but a Face Type x Hand interaction was also found to be significant (Figure 15). The smaller RT-P300 duration for the left hand in the SFSE condition would be predicted by the Callosal Relay model if the left hemisphere were doing the task exclusively and if all motor control were contralateral. Such a conclusion would be consistent with the RT data. However the failure to find a similar difference in the SFDE condition suggests that either the effect is not reliable or that both hemispheres are performing that task. This contradicts the RT evidence which implies left hemisphere dominance for both conditions. However, it is consistent with the prediction that judging identity across expressions would increase the contribution of the right hemisphere to the task.

D. CONCLUSIONS

The P300 component of the average evoked potential recorded from Pz has been shown to be sensitive to cognitive functions lateralized to the left hemisphere. This sensitivity almost certainly extends to right hemisphere functions. Use of this technique has at least two clear advantages over current methods for investigating the lateralization of cognitive function. For EEG recording, it bypasses many of the methodological problems associated with comparing recordings made from different electrode sites and making inferences concerning the generation of potentials in the two hemispheres. From a behavioural viewpoint, it allows for the first time the simultaneous assessment of lateralised function in both positive and negative conditions of a GO/NOGO task such as was used here. Until now this could only be assessed either by asking half the subjects to respond to one condition and half to the other or by obtaining both positive and negative responses from the same subjects. Such intrusive methods undoubtedly alter task demands in as yet unquantified ways.

This study also examined some of the assumptions made when applying an additive factors model to DVF-RT data. There was no evidence from forward averages of any interaction between separate processing stages, and the evidence from back averaging was equivocal and open to other interpretations. These findings would be clarified by the application of a more sophisticated data analysis technique, the Woody filter, to these data.

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APPENDIX A
Words used in the lexical decision task.

Low Imagery Words

WORD	I	FREQ	PL	NON-WORD
AIR	4.17	257	5.50	AIP
BARD	4.90	3	3.53	BURD
COST	3.57	229	3.32	COSE
DUTY	3.17	61	4.08	DUTS
FACT	2.20	447	4.20	FICT
FATE	2.37	33	3.47	FABE
FORM	4.30	370	3.91	FORS
GIST	1.97	1	3.46	GISE
HIDE	3.80	22	3.62	HADE
HOPE	3.83	178	5.46	HODE
HOUR	3.60	144	3.56	HOUT
IDEA	2.20	195	5.16	IDEN
ITEM	3.67	54	3.70	ISEM
JOKE	4.27	22	5.29	JIKE
LAW	3.73	299	4.17	LAZ
LINK	4.80	16	3.66	LONK
LORD	4.63	93	5.18	LOID
MIND	3.03	325	4.80	MIRD
SOUL	2.13	47	5.15	SOUB
UNIT	2.87	103		UVIT
MEAN:	3.46	134.9	4.27	
S.D.:	0.93	134.6	0.79	

High Imagery Words

WORD	I	FREQ	PL	NON-WORD
DIRT	>6	43	3.46	DILT
JAIL		21	2.28	JALL
BIRD		31	5.32	BIRT
GOLD		52	5.27	GULD
FORK		14	3.54	FORP
DOOR		312	3.70	DOAR
GEM		4	4.99	GAM
INK		7	4.05	INT
ARMY		132	2.38	ARBY
DUST		70	3.26	DUNT
SEAT		54	4.07	SOAT
STAR		25	5.48	STAL
CAT		23	4.48	CIT
CITY		393	4.10	CIDY
COIN		10	4.62	COWN
GIRL		220	5.20	GIRS
MEAT		45	4.61	MEST
SHIP		83	4.79	SHAP
BODY		276	5.19	BOTY
CAR		274	5.09	CAZ
MEAN:		104.4	4.29	
S.D.:		120	0.95	

I : IMAGERY RATING 1-7, Paivio et al (1968).
FREQ: FREQUENCY, occurences per million, Kucera and Francis (1967).
PL: PLEASANTNESS RATING 1-7, Toglia and Battig (1978).

APPENDIX B

Faces used in the face recognition task

MODEL	NEUTRAL	SURPRISE	HAPPY
GS	1-4	1-16	1-8
PE	2-4	6-2	2-12
EM	2-4	2-11	4-7
WF	2-5	2-16	2-12