This thesis is dedicated to the memory of my father,
Mervyn John Fine (1924-1985)

Some Aspects of Hemispheric Asymmetry and Face Processing

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ABSTRACT

The eventual aims of this thesis were threefold. The first was to investigate the patterns of impairments suffered by prosopagnosic subjects, measuring both reaction times and errors, with conclusions being drawn about the heterogeneity of the neurological disorder. Three prosopagnosic subjects were tested on a number of face processing tasks, investigating facial identity matching, facial expression matching and the perception of eye gaze direction. They were found to have different patterns of impairments, reflecting the different causes of their prosopagnosia.

The second aim was to investigate cerebral hemispheric asymmetry in normal subjects for both face processing and word processing. Using split-field tachistoscopic presentation of visual stimuli, facial identity matching and facial expression matching were tested, followed by making syntactical judgements for words and finally reading words out loud. No hemispheric differences were found for facial identity or facial expression matching, except where the faces to be matched only comprised internal features, when a right hemisphere advantage was found. The majority of the word processing studies elicited a left hemispheric superiority. It was also shown that words were recognised more easily when they contained fewer syllables, and were more common and familiar to the reader.

The third aim of the thesis was to test two additional subjects, who had been shown, on the basis of PET imaging, to have reversed cerebral asymmetry, specifically right hemispheric activity for linguistic tasks. These subjects were tested on the facial identity matching and word processing tasks. No hemispheric advantage for face processing was found, but either a right hemisphere advantage or no hemispheric advantage was found for both of them for word processing, whereas on the same tasks control subjects showed a significant left hemisphere advantage. As a result of this finding, it is suggested that one of the word tasks could possibly be used for further clarification when the results of the WADA test, used for assessing the language dominance of epileptics prior to surgery, are unclear. Alternatively, the results of such a task could be correlated with the results of PET and MRI scans to further investigate hemispheric asymmetry in a quantitative way, thus using converging evidence from both experimental psychological and neurological methods.

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LONG ABSTRACT

This thesis had a number of linked aims. Firstly, three prosopagnosic subjects were tested on a number of face processing tasks in order to characterise the pattern of their cognitive impairments, using both error scores and reaction time measurements. Secondly, neurologically normal control subjects participated in a number of experiments concerned both with face processing and word processing to investigate hemispheric asymmetry for these types of processing in normal adult brains. Thirdly, two subjects with reversed cerebral asymmetry were tested on face matching and word processing to investigate the gross pattern of their cerebral organisation for both word processing (shown to be in the right hemisphere by PET neuro-imaging) and face processing (unknown but hypothesised to be in the left hemisphere).

Chapter 1 reviewed the literature concerning face processing. Face processing involves an extremely important set of abilities, and there is already much research on how we use all the information from faces, with reference particularly to prosopagnosia, an inability to recognise familiar faces as a result of brain damage. In this chapter, both experiments on normal subjects and findings from prosopagnosics are reviewed, together with cognitive models which have been put forward to explain our face processing abilities, and evidence from lesion and recording studies on monkeys.

Chapter 2 reviews the literature concerning hemispheric asymmetry, both anatomical and functional. Split-brain studies and experiments which have been carried out investigating asymmetries in the normal human brain are both reviewed. Problems with laterality research are mentioned, and finally a section reviews the hemispheric asymmetry of face processing, combining the topics of both introductory chapters.

Chapter 3 reviews the experimental methods used and the experimental subjects tested in the thesis. As facial stimuli were needed for several of the experiments, the first section covers the image manipulation. Then the Turbo Pascal programs and procedures used in the thesis are explained. The statistics used throughout the thesis are then discussed. Finally the three prosopagnosic subjects and the two subjects with reversed cerebral asymmetry are described.

Chapters 4 to 9 are the experimental chapters. Chapter 4 covers the measurement of simple baseline reaction times so that the prosopagnosic subjects could be compared directly with the controls throughout the remainder of the thesis: it was found that only one prosopagnosic, **PH**, was markedly slowed.

Chapters 5 and 6 review facial identity matching experiments. Chapter 5 includes 5 experiments that were carried out testing the matching of Mac-a-Mug faces, either full faces or internal features in isolation. Chapter 6 reviews an experiment testing matching across view of photographs of inverted and upright real male faces by prosopagnosics, control subjects and subjects with reversed asymmetry. In controls, a right hemisphere (RH) advantage for face matching was only demonstrated when internal features were matched in the absence of external features (Experiments 5.3 and 5.6). The prosopagnosic subjects were impaired to different extents at facial identity matching (two significantly so). The prosopagnosic subjects were faster at matching inverted faces than upright faces (only one significantly so), suggesting a possible disproportionate impairment at matching upright faces, at least for one subject: this was not backed up by the error data, however. The two subjects with reversed asymmetry did not show any hemispheric asymmetry (in favour of either hemisphere) for face matching. Also reviewed in Chapter 5 is the first word processing task, which showed a non-significant left hemisphere (LH) advantage. This task is followed up by further tasks outlined in Chapter 9.

Chapter 7 reviewed facial expression matching tasks, together with a further facial identity processing task. All these tasks used pictures of real male faces and the matching was across view. No clear RH advantage was demonstrated in the controls for either identity or expression matching. The prosopagnosic subjects were all impaired at facial identity matching, but only two of the three tested were impaired at expression matching.

Chapter 8 reviewed two experiments that were carried out to investigate the perception of eye gaze direction in prosopagnosics and control subjects. All subjects found it harder to determine whether they were being looked at or not the smaller the angle of regard became. Two of the prosopagnosic subjects were severely impaired at this task, the third much less so. The subjects performed a task in which they had to say at which object from an array of possible objects a person in a photograph was looking. All three prosopagnosic subjects were impaired at this, tending both to overestimate and underestimate the angle of regard: the control subjects tended only to overestimate the angle of regard.

Chapter 9, the final experimental chapter, reviews the two remaining language processing tasks in the thesis. Both tasks were performed by control subjects and the subjects with reversed asymmetry. The first experiment involved deciding whether words presented laterally were nouns or verbs. This gave a LH advantage in the controls, no hemispheric advantage in one of the subjects with reversed asymmetry, and a RH advantage in the other subject with reversed asymmetry. It was also shown that common words were recognised and classified syntactically more easily than rare words. The second experiment required the subjects to read out tachistoscopic laterally-presented words. The controls showed a LH advantage, and both subjects with reversed asymmetry showed a RH advantage. It was also shown that reading was more accurate when the word to be read was shorter, more common, more familiar and looked less unique, although this effect of graphemic uniqueness may be due to the overriding factors of

frequency and familiarity. The effect of graphemic uniqueness was also found to interact significantly with hemispheric asymmetry, inasmuch as the LH makes fewer errors in recognising unique looking words than common looking words, but the RH does not show this difference between unique and common looking words. Finally it was posited that the second experiment could, in some cases, be used when the results of the WASA test are inconclusive, this test being used for assessing the language dominance of epileptics prior to their undergoing brain surgery.

Finally, Chapter 10 reviews all the findings in the thesis, points out criticisms of the methods and methodology used, and then suggests further experiments that could be carried out to answer the questions raised by the findings in the thesis.

List of Abbreviations Used in the Thesis

2AFC	two-alternative forced-choice
CIT	conditional interhemispheric transfer (model)
CT	computerised tomography
DPS	differential processing speed (model)
EDD	eye direction detector
fMRI	functional magnetic resonance imaging
FRU	face recognition unit
GSR	galvanic skin response
ISI	interstimulus interval
IT	inferotemporal (cortex) - Chapter 1
IT	interhemispheric transmission (model) - Chapter 2
LBD	left brain damage
LED	light emitting diode
LH	left hemisphere
LVF	left visual field
MRI	magnetic resonance imaging
MT	middle temporal (cortical area)
PALT	paired associate learning test
PET	positron emission tomography
PIN	person identity node
RBD	right brain damage
rCBF	regional cerebral blood flow
RH	right hemisphere
RT	reaction time(s)
RVF	right visual field
SAM	shared attention mechanism
SCR	skin conductance response
SD	standard deviation
SIU	semantic information unit
STP	superior temporal polysensory (cortical area)
STS	superior temporal sulcus

The following are not abbreviations but the initials of prosopagnosic subjects or subjects with reversed cerebral asymmetry who were tested in this thesis:

HJ
NR
PH
RL
SS

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CHAPTER 1 - INTRODUCTION TO FACE PROCESSING

1.1- Introduction

We can effortlessly recognise and discriminate among thousands of faces and through the course of our lives have much experience in doing so. This is quite a feat of perception, recognition and memory, as all faces have a similar overall form and may differ from each other in only subtle ways. They thus form one of our most common and numerous multi-exemplar categories. In addition, faces change over time as they age and can still be recognised even when facial hair or headgear are altered. Also, as for all objects, their recognition is irrespective of physical viewing conditions such as distance from the face (within reason), lighting and the angle at which the face is presented, suggesting a complex 3-D internal representation. It is much harder to identify people from the neck down or from the back than from the face. The fact that we can recognise faces so efficiently suggests that face recognition is an extremely important ability. Why should this be so? The answer may lie in the wide range of information which a face conveys, together with the fact that we have evolved good face processing mechanisms to make use of this information.

First and foremost it allows identification of the individual person. It also provides information about age and sex, and its expression gives an indication of the person's feelings and mood, sometimes allowing the possible actions that the person will perform to be deduced. A person's eye gaze direction tells us about their direction of attention, and speech comprehension is aided by lip-reading (Campbell 1992, Campbell et al 1986). Thus a great deal of non-verbal as well as verbal signals necessary for regulating social interactions are provided by the face.

Face recognition is phylogenetically older than verbal communication. We share with other primates some of our abilities of face and mimic recognition - non-verbal communication was presumably important to Australopithecines 1.5 to 2 million years ago (Grüsser 1984). Further

evidence for this lies in the fact that face cells have been found in sheep, as well as monkeys (e.g. Kendrick and Baldwin 1987).

A great deal of data has been collected from several sources concerning face processing and its mechanisms. Much work has been carried out on normal human subjects, investigating their abilities to perceive, recognise and match faces and facial expressions. There are also many case studies of people with brain damage to specific areas, causing deficits in these abilities. A person with a deficit in face recognition is said to suffer from Prosopagnosia (detailed below) and there are many documented cases. As well as single case studies, group studies of neurological patients are also very useful either for comparing groups with left brain damage (LBD) and groups with right brain damage (RBD) with neurologically normal subjects to investigate the overall pattern of deficits caused by unilateral brain damage (e.g. de Haan and Hay 1986, Schmitt et al 1997, Bruyer in Bruyer 1986) or for investigating the pattern of deficits over several patients (e.g. Young et al 1993). Note also that autistic children show some face-processing difficulties.

To complement these human experimental and neuropsychological data, physiological and neuroanatomical data have been collected from work on monkeys. In most of these experiments either a lesion is surgically made and the effect on a particular behavioural task noted, or recordings from single cells in specific brain areas are made during the performance of a behavioural task. In addition, there is some neuroanatomical evidence in human subjects, most of which comes from brain-imaging studies, such as CT scans, and more recently from PET and MRI, and from post-mortem autopsies of prosopagnosic patients. In one study, recordings were obtained from cells in the human brain in patients undergoing craniotomy under local anaesthetic (Ojemann et al 1992). In another study which used chronically implanted electrodes, "face modules" were found in the left and right fusiform and inferior temporal gyri of 24 patients with intractable epilepsy who were being evaluated for possible surgery (Allison et al 1994). Several classes of

visual stimuli were presented to the patients, but only the faces evoked a surface-negative potential, N200. The study also showed that stimulation of the same critical regions caused a temporary inability to name familiar faces. A further source of evidence in human subjects is the recording of ERPs (event related potentials) from the scalp using external electrodes to elucidate the cortical processing in response to faces. Various components of the ERP waveform, both positive and negative, have been shown to be related to face processing and recognition (Uhl et al 1990, Bentin et al 1996), unfamiliar face learning for subsequent recognition (Sommer et al 1991, 1995, Hertz et al 1994) and facial expression perception, both in infants (Nelson and de Haan 1996) and in adults (Vanderploeg et al 1987). ERPs have also been measured in prosopagnosic patients (Renault et al 1989) and non-human primates (Pineda et al 1994). All the studies show that there are certain components of the waveform which reflect various aspects of face processing, and are in some cases affected by things such as face inversion (Bentin et al 1996, Small 1986) or priming (Hertz et al 1994).

One possible problem with much of the data collected is that the paradigms used are, on the whole, very artificial and laboratory-based, rather than natural and ethological. This may be giving rise to deceptive data, as many of the tasks which are carried out make no use of other cues, such as social context or biological context such as the rest of the body, and in everyday life we are rarely forced to recognise a face with no additional cues. Therefore what is being investigated is various aspects of face recognition in the absence of other cues. However, making reaction time and error measurements in ethologically valid experiments is very difficult, as it is nigh on impossible to control the presentation of the stimuli, and for that reason thus particular problem was not addressed. One problem that was addressed to an extent, however, was that in many of the studies with normal subjects, unrepresentative samples such as university students are used, and in experiments with brain-damaged patients, the controls may not be well matched. Unfortunately, especially at the level of a thesis such as this, it is difficult to gain access to a wide range of control

subjects from all social groups and ages. It is to this study's advantage that the panel of subjects was not wholly made up of university students, although they were by far the largest proportion of the control subjects. Another problem inherent in much neuropsychological investigation is that patients cannot necessarily be classed together; for instance, it is now generally accepted that the term prosopagnosia embraces a heterogeneous class of different deficits, and any model or hypothesis put forward to explain one set of data may not easily explain the data from a second patient. Thus research in most areas of cognitive neuropsychology is of necessity convergent, combining information from many areas, and not just from data from patients.

1.2 - Prosopagnosia

1.2.1 - Descriptions

The term *prosopagnosia* comes from the Greek *prosopon* (face) and *gnosis* (knowledge) and was coined by Bodamer (Bodamer 1947). An agnosia is a general inability to recognise objects, and exists in several sensory modalities, including visual agnosia and tactile agnosia. Prosopagnosia could be described a form of visual object agnosia specific for one category of objects, the face (although whether prosopagnosia is specific for faces alone is a contentious topic and is discussed more fully in Section 1.2.2), and describes patients who, usually as a result of brain damage, are unable either to recognise previously known people from their faces (the retrograde deficit) or to learn new ones (the anterograde deficit) or both. The majority of prosopagnosics are impaired at both new face learning and recognition of previously familiar faces (e.g. **WJ** - McNeil and Warrington 1993, and **LH** - Farah et al 1995a), but there has been at least one documented case of a patient (**CT**) who is impaired at learning new faces, but relatively able both to recognise previously familiar faces and to learn new nonface objects (Farah 1996)

In addition to cases of acquired prosopagnosia, for instance as a result of brain damage from automobile accidents, there are also cases of developmental prosopagnosics, who have no acquired

brain damage after birth, but for reasons not altogether understood have similar symptoms to acquired prosopagnosics. There may also be other face-processing deficits, although the pattern of these deficits is by no means constant across patients. These other deficits, though not strictly prosopagnosia, are sometimes included under the umbrella of the term. However, a person is only said to be prosopagnosic if they are unable to recognise familiar faces, and patient ME, a severe amnesic, who was unable to identify faces on the basis of either names or any semantic information, was nonetheless normal at familiarity ratings of faces and names, and is therefore not to be labelled prosopagnosic (de Haan et al 1991a). Various case studies on prosopagnosics (both acquired and developmental) have been carried out (Campbell et al 1986, de Haan et al 1987a, Humphreys and Riddoch 1987, Campbell et al 1990, Damasio et al 1990, de Haan and Campbell 1991, Etcoff et al 1991, Campbell 1992, de Haan et al 1992, Heywood and Cowey 1992, Humphreys et al 1993, Takahashi et al 1995). De Renzi suggests that prosopagnosia is not really a unified disorder (De Renzi 1986) and that the precise deficits seen in any one case reflect the underlying brain damage, which differs from patient to patient.

Several different types of prosopagnosia have been put forward: pure associative prosopagnosia, for instance patient **EH** (Damasio et al 1990), where the patient has difficulty in ascribing an identity to a seen face but no perceptual problems; and amnesic associative prosopagnosia, where the patient cannot access the memories of the face linked to its identity through multiple modalities, for instance through seeing the face or hearing the voice, although again perception is unaffected (De Renzi 1986, Damasio et al 1990). As noted above, the lack of face recognition can sometimes be accompanied by deficits in other modalities causing a more general problem in identity recognition (Damasio et al 1990), but some prosopagnosics are still able to recognise people from one or usually several other characteristics such as their voices, gait, clothing, odour or other paraphernalia such as beard, moustache, hat or spectacles, such as patient MS (Cowey,

personal communication). An inability to assign correctly a face to the face category is rare (Ellis in Bruyer 1986) , and would be an indication of a more perceptual and less agnosic disorder.

1.2.2 - Specificity of Prosopagnosia

Thus prosopagnosia appears to be a form of visual agnosia, but pertaining to a very specific stimulus class - human faces. The pattern of deficits in neurological patients varies from patient to patient, and prosopagnosia is not always accompanied by visual agnosia for other objects, and vice versa. This, together with other evidence, which will be presented below, has led to researchers questioning whether face recognition is "special", i.e. qualitatively different from the recognition of other objects. In other words, does face recognition rely on a different system from object processing? In cognitive psychology terms, a "different system" necessitates functional independence, physical distinction and different information processing strategies (Farah 1996), and a number of researchers have put forward evidence for the existence of a distinct face processing system (e.g. Farah 1994, 1996, Moscovitch et al 1997). Before discussing the evidence, it is worth noting a distinction between two senses in which face processing might be 'special' (Hay and Young 1982, Bruce, 1995) - the dedicated process hypothesis and the unique process hypothesis. The former says that there might be processes specific to face processes which could be similar to the processes involved in the processing of other objects. The latter suggests that face processing involves unique processes, quite unlike those used in other object processing.

The evidence for face processing being special includes neurological data, brain imaging data and neurophysiological data. Prosopagnosia is sometimes accompanied by other agnosias (e.g. patient **HJA** described by Humphreys and Riddoch 1987), but it does not always coexist with visual object agnosia (e.g. Farah 1990, pages 71-72): there are cases of both prosopagnosics who can recognise other objects (de Renzi 1986, Farah 1996) and agnosics who can still recognise familiar faces (patient **CK**, Farah 1996). This double dissociation suggests different systems for face and object

processing, although it should be noted that double dissociations have to be treated with care (see in more detail in section 2.2.2). Brain imaging studies using ERPs, MRI and PET (e.g. Sergent et al 1992) have shown distinct loci for the cortical areas most active in face and object processing. The neurological data supporting this view includes single-cell recording and lesion evidence (see section **1.6**) which shows the existence in monkeys (Perrett et al 1982, 1984, 1988, 1992, Gross et al 1972, Gross 1992), sheep (Kendrick and Baldwin 1987) and man (Ojemann et al 1992) of areas rich in face cells - that is, cells which respond to faces or parts of faces disproportionately more than to other stimuli. Further evidence, championed by Farah and her colleagues, is the inversion effect, whereby inverted faces (turned upside down) are disproportionately more difficult to recognise than other inverted objects (e.g. Yin, 1969, Valentine, 1988, Farah et al 1995a). This is covered in much more detail in the introduction to Chapter 6, but together the above evidence suggest a different cognitive system for face processing from that for other object processing.

However, there are a number of counter-arguments to the above view. The main proponent of the view that face recognition is not "special" is Damasio, who states:

> "the notion that prosopagnosia is limited to agnosia for human faces proves easily falsifiable" (Damasio et al 1982, page 338)

He maintains that face or object recognition does not occur in a vacuum, but when evoked by a contextual cue (Damasio et al 1982). Thus it is claimed that it is not in fact a face that is being recognised but an object of personal historical significance (De Renzi 1986, Damasio et al 1982, Damasio et al 1990). For instance, Damasio and his colleagues cite patient **EH** who has impaired recognition of non-facial personal belongings, such as his clothing and his car, as being his own. One problem Damasio and colleagues (1982) point out is that it is potentially misleading to compare the recognition of faces and objects, because the comparison most researchers are making is between <u>whose face</u> and <u>what object</u>. Knowing that a face is that of, for instance, Margaret

Thatcher, is not the same as knowing that a particular object is, for instance, a hairbrush. The comparison they say is needed is between Margaret Thatcher's face and Prince Charles' hairbrush.

This brings us on to the counter-argument to Farah's view: that prosopagnosia is in fact a deficit in the discrimination of the individual exemplars in a multi-exemplar category (Damasio 1985, Damasio et al 1990), such that generic recognition is preserved, but specific recognition is not. The argument here is that although we have much experience of faces, faces are the most numerous multi-exemplar category in which the exemplars are all very similar and therefore the hardest to recognise should there be any deficit in our visual object recognition ability. There is evidence for this too, as there have been reports of farmers or birdwatchers who have become prosopagnosic and are no longer able to recognise their individual animals - again multi-exemplar categories of which they have much experience (Bornstein 1963, Bornstein et al 1969, Assal et al 1984). Bornstein (1963) states:

> "One of our patients lost the ability to identify birds which previously had been well known to her. She had practised bird watching as her hobby from early childhood. During her illness she repeated spontaneously 'All birds look the same.' "

It is noteworthy that Assal et al's (1984) patient's prosopagnosia partially recovered, but his "zooagnosia", as Assal and colleagues called his inability to recognise his cows, did not. However, as Farah (1990) points out, it is probably more difficult to recognise cows than people, and Assal's patient did not completely recover from his prosopagnosia. Therefore it is hard to say that this is clear evidence for human faces being qualitatively different from other objects, including animal faces. There is a recent counter-example of a man who became a farmer after a stroke and can now recognise and name his sheep significantly better than people familiar to him (McNeil and Warrington 1993), but this is only one half of the clear double dissociation needed to distinguish between human and animal faces in terms of processing. Also some prosopagnosics have problems in identifying animal species, cars and flowers as well as faces (de Haan and Campbell

1991, Damasio et al 1990). Another counter-example, however, is described by Farah and colleagues (Farah et al 1995b), who report a prosopagnosic patient, **LH**, who is disproportionately impaired at matching faces compared with matching other visual stimuli from categories containing many similar exemplars, such as chairs and eyeglasses. There is another, very recent example (Henke et al 1998) of a prosopagnosic patient who has no difficulty recognising exemplars of non-face categories, either living or non-living.

Thus there are conflicting views and some evidence for each. However, partly on the basis of the recent patient data and the new neuroimaging data, the current view of most researchers is that face recognition is "special" (Farah 1996) at least in terms of the dedicated process hypothesis, but not necessarily in the stronger sense of its being unique (Bruce 1995). This specificity for face processing is taken into account in the various cognitive models which have been put forward to explain face processing (see section 1.4). However, the degree to which the deficit is specific for faces only differs from person to person, depending on the extent and location of the underlying brain damage, and there will be different patterns of agnosia and within-category discrimination deficits.

1.2.3 - Locus of Damage

A great deal of investigation into the areas of the brain in which damage is necessary and sufficient to cause prosopagnosia has been carried out using post-mortem autopsies and brain imaging during life. It is generally agreed that damage to the ventromedial occipito-temporal region is necessary, including the lingual and fusiform gyri, cuneus, right splenial outflow, parahippocampal gyrus and either or both anterior temporal areas (Jeeves 1984, De Renzi 1986, Sergent et al 1992). However, there has been much dispute over whether this damage must be bilateral or can be unilateral. In the early days of research on prosopagnosia it was thought, based on purely clinical data, that right hemisphere brain damage (RBD) only was required to produce prosopagnosia, and this view was

further strengthened by the right hemisphere (RH) advantage in many face recognition tasks (see section **2.5.1**) together with the high occurrence of left visual field (LVF) deficits (Meadows 1974).

However, this view was challenged, and a careful review of the literature, much of it based on autopsy, suggested that bilateral damage was necessary (Damasio et al 1982, Damasio and Damasio 1986, De Renzi 1986). Damasio and Damasio (1986) analysed the results of autopsies on eleven prosopagnosic patients, all of whom had functionally symmetrical bilateral occipito-temporal damage. Bilateral, rather than unilateral, damage is usually found at autopsy, but it is not always symmetrical: there is often more RBD than LBD (left hemispheric brain damage) and thus more LVF defects. Also, the LBD is not always occipito-temporal. RBD can occur without prosopagnosia in the absence of LBD but such patients still perform poorly on tasks of visual perception, especially those involving faces (De Renzi 1986). De Renzi put forward five cases, three with a diffuse perceptual disorder and two with a more amnesic disorder, all of whom showed bilateral damage. In some cases where there is bilateral damage at autopsy, an earlier *in vivo* CT scan showed only RBD, suggesting that there may be some functional, though not anatomical, LBD, such as hypometabolism. In many cases this has not been verified with the more sensitive MRI and PET scans. Others have also shown bilateral damage (Torii and Tamai 1985, Damasio and Damasio 1986, Ettlin et al 1992). Ettlin et al put forward a strong case in favour of the necessity of bilateral damage in one patient who had massive RBD but no prosopagnosia, suffered a focused left hemispheric (LH) infarct and was then shown to be prosopagnosic. This paper also highlighted the problems of CT scans. A CT scan taken 3 months after this LH infarct showed it to have cleared up, but the patient was still prosopagnosic. This suggests that CT scans are not sensitive enough to expose some of the kinds of damage involved in prosopagnosia, and Ettlin also points out that those cases previously documented as being due to a unilateral pathology were based on CT data. One study in support of bilateral functional damage with only unilateral anatomical damage (Marciani et al 1991) reports a patient who had only unilateral posterior RH

damage but an abnormal EEG bilaterally. This patient's prosopagnosia was transient, and had improved greatly within two months, at which point the EEG in the LH had also returned to normal, suggesting that the functional damage in the LH was linked to (or responsible for) the prosopagnosia.

In support of unilateral damage, there are a few prosopagnosics who show only RBD (Landis et al 1986, 1988, Michel et al 1989) according to both clinical and radiological evidence, but in most of these cases the prosopagnosia tends to be transient. However, even these may not be convincing without functional imaging data, such as MRI or PET. A recent survey of Western and Japanese literature showed 27 cases of prosopagnosia with MRI or CT scans with damage restricted to the RH and 4 cases of acquired prosopagnosia after unilateral RH neurosurgery (De Renzi et al 1994). These do seem to substantiate the earlier claim that RBD can be sufficient to cause prosopagnosia. But this raises the question: if unilateral RBD can cause prosopagnosia, then why is it so rare? De Renzi's current view (De Renzi et al 1994, De Renzi 1993) is that the degree of hemispheric asymmetry of face recognition varies across right-handed subjects and that only those with a high degree of lateralisation are likely to become prosopagnosic after RBD, as in these cases the LH cannot compensate. This does present researchers with a problem, however, in that if there is substantial inter-subject variability, then it could be argued that the use of half-field studies in laterality research becomes questionable: how can one look for an effect that occurs to a different extent in different subjects, and is possibly absent in some subjects, without knowing whether the subjects being tested are strongly or weakly lateralised for that process? In other words, if face processing is more strongly lateralised to the RH in some people than in others, then it must be theoretically possible to test a group of subjects, none of whom in fact have a RH advantage for face processing, on a lateralised face-processing task, find that the results show no hemispheric asymmetry, and thus conclude that the processes being tested are not after all lateralised towards the RH. However, this might be an erroneous conclusion, as in the example shown: it is not that

the process is not lateralised to the RH, but merely that the subjects used in this particular study are unusual in their lack of asymmetry. One way of addressing this is to test a large enough group of subjects, in the hope that if over the whole population the process is more lateralised to the RH than the LH, then it is less likely that a group of subjects such as those described above will be found. Another point in favour of De Renzi's view is that it could explain why some laterality studies of face processing do not find a RH advantage, whereas for instance, a much greater proportion of laterality studies of language processing find a LH advantage, presumably because language processing is more strongly lateralised than face processing in the population as a whole. The relevance of De Renzi's view to this thesis is that it must be assumed that if he is right, then a large enough proportion of the subjects tested must have face processing lateralised to the RH for an effect to be found, and conversely, if an effect is <u>not</u> found, it is not evidence that the task and processes used for that task are not lateralised to the RH, but that one source of the absence of such a laterality could be the inherent lack of laterality of the subjects used.

Data from commisurotomy (split-brain surgery) patients show that both hemispheres can recognise faces, although the right hemisphere (RH) is generally more efficient (Jeeves 1984, Levy et al 1972). This supports the view that bilateral damage is necessary to cause prominent prosopagnosia. It should be borne in mind, however, that patients requiring commisurotomy for the relief of intractable epilepsy could well have long-standing abnormal patterns of cerebral dominance; these results should therefore be treated with caution. This is covered in more detail in section **2.5.1**.

1.3 - Experiments on Normal Subjects and Prosopagnosic Patients

Broadly speaking, three areas of research will be covered in this section. These are:

1. face and facial identity processing
2. facial expression processing
3. perception of eye gaze, or angle of regard.

1.3.1 - Face and Facial Identity Processing

A range of experiments have been carried out both on prosopagnosic patients and on normal control subjects. Such experiments have two main aims: firstly to determine the mechanisms of face processing in normal (mostly right-handed) adults, and secondly to investigate in detail the deficits which occur in prosopagnosia. Four broad areas of experimentation will be described here.

Face recognition involves judging whether a face has been seen before or not and may therefore access long term memories as well as requiring apperceptive and recognition processing. Face categorisation by sex or age, or even sorting visual stimuli into face and non-face categories, involves some *semantic physiognomic judgements* being made about the face and is not therefore solely apperceptive, but there is no long-term memory component. Face identification includes deducing whose the face is and either naming the person or being able to describe some information about them that is equivalent to naming them. Face matching, on the other hand, is more of a perceptual and short-term memory process as it involves stating whether two faces seen simultaneously or subsequently are the same or different.

Performance on these tasks can be measured in a number of ways, which include speed (reaction times) and accuracy (number of errors made). A number of different task paradigms are also used, including yes / no decisions (e.g. "Is this face of the same person as the one you just saw?"), forced choice techniques, where the subject is required to choose which of the possible targets is the

correct one (e.g. "Which of these three faces is the same age as that one?"), or in the case of identification, an explicit naming of the required information (e.g. "Who is the person in this photograph?"). These techniques and response measurements are also used in expression perception and eye gaze perception experiments (see sections 1.3.2 and 1.3.3) and some of them are used in the experiments reported in this thesis.

Although speed and accuracy are both indicators of task performance, they do not always show the same pattern of results. A subject asked to respond as fast as possible on a particular task is likely to make a greater number of errors than a subject asked to respond as accurately as possible, but the latter subject will probably have substantially longer reaction times. Both subjects have performed as 'well' as they can, but the task instruction will have affected their result pattern. This is termed the 'speed-accuracy trade-off', and can affect data interpretation. For this reason it is necessary to keep the response instruction constant for all subjects in an experiment, and in the case of this thesis, all subjects were asked to respond "as quickly and accurately as possible", putting emphasis on both aspects of responding.

Some cases of brain damage could affect cognitive abilities, measurable as a slowing but without a concurrent decrease in accuracy. One possible reason for this is that the brain-damaged patient realises that they have a problem (e.g. in face recognition) and devises a different strategy to compensate (e.g. match on the basis of features, or recognise by non-facial cues, such as speech) which may take longer (Young et al 1993). To test this it would be necessary to measure both speed and accuracy, as error data alone would not be sufficient to determine whether there is in fact a cognitive deficit. Also, any general cognitive slowing should be taken into account when determining whether a particular cognitive ability is impaired in comparison to other cognitive abilities, and such a conclusion may be more easily reached from the error data than the reaction time data.

1.3.1.1 - Face Recognition

In face recognition tasks, subjects are usually shown pictures of faces and asked to say whether they are familiar or not. Typically, half the set of stimuli is either of famous people or personal acquaintances of the subject (which may include the subject himself) and half faces of strangers. The results of such tasks normally show that prosopagnosics cannot recognise faces whereas normal subjects can (Tranel and Damasio 1985, Bruyer 1986, Campbell et al 1990, Damasio et al 1990, de Haan and Campbell 1991, Etcoff et al 1991, Grüsser and Landis 1991). For instance, **SS** is a developmental prosopagnosic who has been extensively tested by de Haan and Campbell (1991), and is further tested in this thesis. This subject was found to be normal for recognition of famous names but performed at chance for recognition of famous faces. It has been shown that patients with RBD have more trouble with face recognition than those with LBD or normal controls (Bruyer 1986). One suggestion is that deeper storage leads to better recognition, as proposed in Craik and Lockhart's "levels of processing" framework (1972) - we recognise people with whom we have had a lot of contact more easily than those we have only met once (Bruyer 1986). Note however, that there are many theoretical problems with their framework, for instance that it is difficult to find an independent measure of processing depth, and thus it is not exactly current thinking; Bruce (1988) says that

> "The notion of simple depth of processing .... appears unsuccessful as a general principle in face perception and memory." (page 65)

instead suggesting that the encoding instructions and contextual change between encoding and retrieval are important in determining recognition ability. But this does not appear to be so for patients with RBD and prosopagnosics, who may have problems with laying down the initial memory traces as well as with accessing memories - this would be termed anterograde prosopagnosia. Face recognition requires the extraction of invariant physiognomic characteristics, i.e. characteristics of the face which allow its identity to be worked out irrespective of view, lighting or facial expression, for instance.

1.3.1.2 - Covert Face Recognition

One area which has been investigated concerns whether there is any covert recognition of faces without the awareness of the subject. There are several well-documented occurrences of cognitive processing taking place without conscious perception. There is, for instance, the phenomenon of blindsight (Weiskrantz 1986, Cowey and Stoerig 1991a, 1991b), in which patients have damage to their primary visual cortex causing a scotoma - an area of blindness. However, when forced to decide whether a stimulus has been presented in the scotoma, they perform almost perfectly, although they maintain they are guessing and perceive nothing, thus showing that they can process visual stimuli without being aware of seeing them. There are also examples of patients with anterograde amnesia affecting their episodic memory who are nonetheless able to learn skills, such as the Tower of Hanoi problem (Cohen 1984), the stylus maze, on which the celebrated amnesic patient **HM** was tested (e.g. Corkin 1968), and the pursuit rotor, an apparatus which requires the subject to track a moving target on a turntable with a stylus (Cermak et al 1973). On repeated presentations of the tests the amnesics are unaware that they have previously seen them, although their increased level of performance shows that they have learnt and laid down memory traces which they cannot consciously recall. This shows the distinction between explicit memory, which requires conscious recall for its use and is impaired in amnesics, and implicit memory, which does not require conscious recall for its use, and is usually intact in amnesics. Priming studies on normal subjects have also shown that subthreshold stimuli presented to the subjects can affect subsequent cognitive performance, for instance in the case of semantically related primes decreasing the reaction time on a lexical decision task (e.g. Nebes et al 1989).

There are a number of techniques for investigating covert recognition. These include both physiological and behavioural methods and they are designed to show that cortical processing of the stimulus is taking place of which the subject does not have conscious awareness.

The physiological methods involve the direct measuring of a physiological, or autonomic, response which differs according to whether cortical processing is occurring or not. On recognition of a familiar or emotionally evocative stimulus there is often a change in the conductance of the skin, and this skin conductance response (SCR), also called a galvanic skin response (GSR), in the absence of overt recognition shows that processing is occurring. Another physiological method involves recording where the eyes are looking, and the scanpaths they take when looking at a picture or scene. Scanpaths of faces have been measured using eye position monitoring (Rizzo et al 1987). This study found that familiar faces gave less predictable scanpaths than unfamiliar faces, even when there was no overt recognition. A further method is the measurement of ERPs, which has already been mentioned briefly in Section 1.1. During overt recognition of faces there are certain components of the ERP waveform, such as the P300 component, which reflects the processes underlying this recognition; this component has been found in response to known faces in a prosopagnosic patient who showed no overt recognition (Renault et al 1989). Pupillometry is another technique which is an obvious candidate for investigating covert recognition, although it has not as yet been used. The pupil size is monitored and, as this is under the control of the autonomic nervous system (like the SCR), there is a change in the pupil size, which dilates when the subject is presented with a familiar, emotionally provocative stimulus.

The behavioural methods used to demonstrate covert recognition include the paired associate learning test (PALT), priming tests, matching tests and interference. In paired associate learning name-face pairs are presented to the subject. Half of the faces are paired with the correct names, and half with the incorrect names. Typically, there is a facilitation effect for learning correct pairings compared with learning incorrect pairings, or for deciding whether a name is familiar or not when preceded by the face of the same person as a probe. The presence of these effects without overt recognition is evidence for covert processing. It has also been found that known faces

are matched faster and more accurately than unfamiliar faces, even in the case of some prosopagnosic patients. Priming involves having previously seen the target stimulus, this prior experience assisting recognition; interference involves incorrect name face-pairs making recognition of the name or retrieval of semantic information about it harder due to the incorrect face, even in the absence of any overt face recognition.

Using these methods, it has been shown that some prosopagnosics show autonomic responses to faces (Bauer 1986). For instance, a measurable GSR was obtained when two patients who claimed not to recognise faces were shown famous faces, whereas there was no measurable SCR to unknown faces (Tranel and Damasio 1985, 1988). However, patient **LH** did not show any skin response (Etcoff et al 1991). Paired associate learning tests did not indicate any covert recognition for **LH**, nor **SS** (de Haan and Campbell 1991), nor **MS** (Newcombe et al 1989). An example of a prosopagnosic who does show covert recognition is **PH**, who matched known faces faster and more accurately than unfamiliar faces (de Haan et al 1987a, 1987b, 1991b, Young and de Haan 1992). Another example of a prosopagnosic who shows covert recognition is **PC**, on the basis of ERPs (Renault et al 1989). The fact that some of these patients show covert recognition and some do not again suggests that face recognition may be thought of as a series of cognitive processes (see Section 1.4 for more details) and that prosopagnosia is caused by a range of brain damage resulting in different parts of the process of face recognition being affected, or that whatever underlies covert awareness varies greatly between different brains. In addition to the above evidence, covert recognition of faces has also been demonstrated in normal, non-prosopagnosic subjects who show increased electrodermal activity to subliminal presentation of familiar faces in comparison to unfamiliar faces (Ellis et al 1993).

1.3.1.3 - Face Categorisation

Unlike face recognition and identification, face categorisation is something we can do with unfamiliar faces. The sorting of faces by sex or age, or even into face and non-face categories has been investigated. Brain damage to the RH can cause a deficit in face/non-face discrimination (a sort of facial decision task; compare the lexical decision task) and age and sex estimation (Bruyer 1986). However, prosopagnosics do not usually show such problems (Tranel et al 1988). **LH** was able to say whether stimuli were faces or not for both upright and inverted faces (with upright or inverted features) and in fact performed more accurately than controls when the faces and the features themselves were inverted. His judgements of age, sex and likeability were also normal (Etcoff et al 1991). **SS**, however, shows poor judgement of age and sex (de Haan and Campbell 1991). One subject, **T** (Campbell et al 1986) showed normal age judgements, but was uncertain about sex judgements of faces, suggesting either a possible difference in the processes, or that the former task was easier that the latter.

1.3.1.4 - Face Identification

Identification of faces requires recognition and either naming or description. This may involve putting the face into context, in other words remembering where the face is likely to have been seen in the past, context often assisting recognition and identification (see Section 1.4), and retrieving biographical information. There are many people who recognise someone but cannot remember their name. This anomia for faces, when severe, is most likely to be associated with a LH lesion. Marzi suggested that neither hemisphere is superior for face naming (Marzi et al 1985), but Hanley has described a patient, **NP**, with anomia for both object names and proper names from faces, who had a unilateral LH lesion (Hanley 1995). This suggest that face naming is probably more lateralised to the LH, and more likely to be affected by LBD. After commisurotomy there can be an anomia for faces, as the naming is generally a LH process but the face recognition is mainly a RH process. It is hard to tell whether it is possible to have an anomia for faces as well as

an agnosia for them as prosopagnosics cannot name what they cannot recognise, but they do not generally suffer from an anomia for other objects. Note, however, the case described by Brennen et al (1994) of a woman who could name people from pictures of their faces whilst not being able to give any semantic information about them: this is an extremely rare exception (see section **1.4**).

1.3.1.5 - Face Matching

Face matching can be done for unfamiliar faces and is different from recognition. Face-matching tasks require the subject to judge whether two stimuli shown simultaneously or successively are of the same face. They may be either identical stimuli, in which case the task is really that of stimulus matching (Hay and Young 1982, Bruyer et al 1987), or may differ in one or more aspects, such as view or lighting, as in the Benton and van Allen Facial Recognition Test (e.g. de Haan and Campbell 1991), orientation - upright or inverted (Yin 1969) - or facial expression, as in the Landis Face Matching Test (e.g. de Haan and Campbell 1991). Those tasks where the stimuli are identical can theoretically be performed by matching the patterns without resorting to creating internal 3-D representations. whereas those tasks where the stimuli are not identical require the formation and processing of this internal 3-D representation but do not require any memory (other than possible working memory) ability unless there is a large interstimulus interval (ISI) between the presentations of the two faces. Hay and Young (1982) and Bruyer et al (1987) thus argue that to investigate face matching, the two pictures of the face to be matched should not be identical even when they are of the same person - there should be a change in some other aspect, such as view or lighting. In the real world, we will never see exactly the same face on more than one occasion due to the ever-changing nature of the world and, among other things, the ageing of faces. For this reason, the experiments in this thesis, except for the pilot experiments in Chapter 5 in which Mac-a-Mug face drawings were used, two faces which are 'the same' (identity, or expression) in fact vary in some other aspect, be it view, identity or expression.

The performance on such tasks for prosopagnosics differs from one patient to another, but is generally poor compared with data from normal subjects. However, before presenting prosopagnosic data it should be noted that a deficit in unfamiliar face matching and an inability to recognise familiar faces do not always occur together. Malone and his colleagues (1982) described just such a double dissociation: one patient was impaired at unfamiliar face matching, but his transient prosopagnosia disappeared, whereas the other patient was prosopagnosic for the faces of both relatives and famous people, but his ability to match unfamiliar faces improved until it was in the normal range. This suggests a possible different between the processing of familiar and unfamiliar faces. The experiments in this thesis all use unfamiliar faces as stimuli, but the prosopagnosic subjects (unlike Malone et al's patient) are all prosopagnosic for <u>familiar</u> faces.

Patients **SS** and **KD** (de Haan and Campbell 1991) and **LH** (Etcoff et al 1991) all show a moderate impairment on the Benton and van Allen test, and performance worsens when a memory component is introduced by adding an interstimulus interval. One case study of a patient with anterograde and retrograde prosopagnosia showed that although face matching was only slightly impaired, a 5-second delay before the probe was displayed caused the patient to respond at chance (Etcoff et al 1991). If prosopagnosia is a memory disorder, not a perceptual disorder, then the recognition delay in experiments could be very important (Damasio et al 1982). As stated earlier, however, different perceptual and mnestic types of prosopagnosia have been documented, so a delay between the presentation of the probe and the presentation of the target to be matched might not always cause an additional deficit. Patient **PH** does show some covert ability in matching faces, as he matches familiar ones faster than unfamiliar ones.

Often the problem with face matching for prosopagnosics is that their ability to match is only moderately impaired but they take much longer to complete the task. When prosopagnosic patients and RBD patients without prosopagnosia were tested on a tachistoscopic face-matching task, it was

found that the prosopagnosic patients were better for matching faces at unlimited duration, but worse for a short duration stimulus (Christen et al 1985). Young et al (1993) suggest that this may be due to the use of idiosyncratic strategies to compensate for the problem which the patients are aware they have - one such strategy is to match on the basis of individual features serially, which takes longer. As mentioned earlier, for many of the tasks at which prosopagnosics appear to perform normally or with only a slight impairment, it is therefore important to measure reaction times to see whether these are disproportionately longer compared with non-face tasks, which would give an indication of a different processing strategy, as in the above case. One possible explanation for this strategy is to accept the view of some laterality researchers (e.g. Hillger and Koenig 1991, Tanaka and Farah 1993) that the LH is more efficient at local, serial processing in comparison to the RH, which tends to be more efficient at global, parallel processing, and that in these patients with RH damage, the LH is still able to match the faces, but not using the overall configuration. However, other research suggests that there may be no qualitative difference between the ability of the two hemispheres to match faces, only a quantitative one (e.g. de Haan and Hay 1986). The role of the LH is enlarged upon in Chapter 2, and this idea of local processing will be covered in more detail.

1.3.2 - Facial Expression Processing

Many facial expressions are universal across cultures and are produced very early in life, suggesting possible innate mechanisms, for both facial expression production (Ekman 1973, Grüsser 1984) and perception (Bremner 1994, page 195). Facial expression is usually a good signal of emotional state, and may indicate likely actions and even level of arousal. Many prosopagnosic patients do not have any problems in recognising facial expressions (Tranel et al 1988), but some do, such as **HJA** and **GK** (Humphreys et al 1993) and **SS** (de Haan and Campbell 1991) who scored 15 out of 24 on naming expressions in the set of Ekman faces. **SS**'s expression matching was only slightly impaired, but note that the control subjects' results were at ceiling.

Etcoff has found that in many cases expression recognition is poor whereas expression matching is normal, suggesting that there is a deficit in the link between facial expression and a knowledge of the emotion it signals (Etcoff et al 1991). Ojemann and his colleagues have shown that stimulation of the middle temporal region (MT) of the right hemisphere during craniotomy disrupts the ability to label facial expressions (e.g. Fried et al 1982). Another group of brain-damaged individuals who show some facial expression recognition difficulties is autistic children. They have problems recognising more derived and subtle expressions such as boredom and embarrassment (Boucher 1993).

One factor that can influence facial expression recognition is whether the expression is static (in a photograph) or dynamic (in real life or on a video). It has been shown that the recognition of expressions from dynamic point-light displays of faces is quite accurate (Bruce and Valentine 1988). Humphreys and his colleagues found a double dissociation between the recognition of static and moving faces using Bruce and Valentine's technique (Humphreys et al 1993). One subject, **HJA**, a visual agnosic with achromatopsia (an inability to perceive colour due to brain damage, in the absence of any ocular impairment) and prosopagnosia, who has little problem with expression recognition in everyday life, showed poor expression recognition for Ekman faces, but performed as well as control subjects on recognition of expression in the dynamic point-light displays. **GK**, who has bilateral brain damage and suffers from visual disorientation and phonemic paraphrasia (the production of unintended syllables and words in speech), is not prosopagnosic and has no problem with either face recognition or expression recognition for Ekman faces. However, he performs at chance for the dynamic light-dot faces. This suggests either that there may be two separable mechanisms for recognising static and dynamic facial expressions or that expression perception, like all other visual perception, relies to an extent on the two visual systems (the ventral and dorsal streams) and that the perception of all moving stimuli, even facial expressions, is different from the perception of all static stimuli. The perception of motion as opposed to static

stimuli may be even more complicated. For example, two motion-blind patients (**AF** and **LM**) who have damage to cortical area V5 / MT and are impaired at detecting motion and coding motion direction or speed have been shown to be able to perceive 'biological motion' using the Johansson illusion (Vaina et al 1990, McLeod et al 1996). In this procedure points of light are attached to the joints of a person who then performs biological actions such as walking, and the subject is asked to determine the action from the movement of the points of light without reference to the body which is rendered invisible by the lighting conditions (Johansson 1973). Vaina et al (1990) also demonstrated that the patient **AF** was able to detect structure from motion for non-biological objects, in this case a rotating 3-D cylinder in a field of random dots where the structure of the cylinder is visible only as a function of the coherent motion of the dots.

1.3.3 - Perception of Eye Gaze

Both monkeys and humans are supremely good at determining in which direction someone is looking, and specifically whether they are being looked at or not. Our acuity for detecting a deviation in eye position is as little as 0.18mm at a viewing distance of 122 cm - i.e. 30.4 seconds of arc (Anstis et al 1969). A lateral rotation of the eye by as little as 1.67° can be detected correctly 75% of the time (Ehrlich and Field 1993). There are several possible reasons why our acuity for eye gaze direction is very good. A primitive function of the detection of eye gaze direction may have been to allow an organism to detect that it was about to be attacked. In many non-human primates, including adult male baboons, gorillas and macaques (Baron-Cohen 1994), a mutual stare is a threat gesture and is important in establishing the hierarchy of the group: struggles for dominance are often ended when one animal if forced to avert its gaze. This would not be possible unless both the dominant and subordinate primates were aware they were being stared at. In the higher primates (including humans) steady gaze also occurs as part of grooming, greeting and in facial expressions, and not only to elicit fear. Perrett has carried out a great deal of research on eye

gaze detection, especially in primates, and suggests that gaze direction is important in general social attention and hence bonding between individuals (e.g. Walsh and Perrett 1994).

Another role of eye gaze perception may be to direct attention. If two people are in conversation and looking at each other's faces, then if one suddenly moves their eyes to the side and keeps them there, the other person's attention is often diverted to where the first is looking. Baron-Cohen describes this in terms of his Eye Direction Detector (EDD) and Shared Attention Mechanism (SAM) (Baron-Cohen 1993, 1994). He talks about the difference between the dyadic representation of the EDD and the triadic representation of the SAM. The EDD representation is dyadic in that it consists of two entities - the viewer and the viewed: the examples Baron-Cohen gives include *"Mummy sees the bus"* and *"I see Mummy"*. The triadic representation of the SAM includes an 'embedded element' (Baron-Cohen 1994, p. 531) specifying that both the self and the other person are attending to the same third object: again, his examples include *"I see [Mummy sees the bus]"* and *"Mummy sees [Daddy sees me]"*. In these examples one person is able to determine what other object the second person is looking at. These triadic representations can be built up after the age of about 14 months, and are lacking in, for instance, autistic children. Our abilities could also be inherited from non-human primates, who required an early indication of danger to warn them against predators. Also, eye direction often correlates with the goal of the next action, the current desire and the intended referent during speech.

The perception of eye gaze, or angle of regard, may be thought to be merely a task of visual discrimination, requiring a high visual acuity, but it has been shown that in some patients with prosopagnosia and also in monkeys with selective lesions to areas in the temporal lobe, eye gaze perception is impaired whilst visual acuity and other complex visual discriminations are spared. Thus some specific processing may be required to convert merely seeing the position of someone's eyes to being able to work out where they are looking. This could be disrupted in prosopagnosia,

implying that it is a process linked with face processing in general. The perception of eye gaze is also a spatial process which probably requires the activity of the parietal lobe. A reciprocal temporo-parietal projection has been documented which might be active in such a task (Harries and Perrett 1991).

Campbell and her colleagues carried out a 2AFC (two-alternative forced choice) task on two prosopagnosic patients, normal human controls and monkeys (Campbell et al 1990). The subjects had to choose which face out of two presented had frontal eye gaze, i.e. was looking at the subject. The monkeys learnt the task well but a lesion of the superior temporal sulcus (STS) in the region of the so-called face cells impaired their performance (see also Heywood and Cowey 1992). This is covered more fully in section **1.6.2**. One of the prosopagnosics, **KD**, showed normal levels of performance for angular deviations greater than 10°, and below 10° her performance followed that of normal subjects performing the task on inverted faces, for which the level of performance is lower than that for upright faces. The other prosopagnosic, **SS**, a developmental prosopagnosic (de Haan and Campbell 1991), was unable to do the task at all, performing at chance even when the angular deviation of the face not looking forward was as much as 20°. Most of **SS**'s errors were due to responses based on the direction of the head, not the direction of the eyes.

What are the cues for the direction of eye gaze? The perception of gaze direction of one and two eyes have been compared, and a single eye was found to give rise to large biases and errors (Ehrlich and Field 1993). They conclude that it is the relative positions of the irises and pupils in the two eyes which are used, and that these remain fairly constant from person to person, a necessary attribute for an eye gaze cue. Baron-Cohen (1994) argues that we can determine the position of someone's eyes using the aforementioned EDD which detects the relative proportions of white and dark regions (sclera and iris / pupil respectively), and that the EDD detects both eye position and eye movement.

1.4 - Models of Face Processing

The wealth of experimental data from investigations both on normal subjects and on neurological patients has allowed cognitive psychologists to put forward possible models to explain how faces are processed. As has already been pointed out, there is a range of types of information that can be gained from face processing, and any model put forward should be able to account for all these different abilities. A number of models have been proposed, including those by Hay and Young (1982), Ellis (in chapter 1 of Bruyer 1986), Bruce and Young (1986) and Burton et al (1990), and see Tovée and Cohen-Tovée (1993) to see how cognitive models relate to neural substrates. Farah's views (1994, 1996) on the specificity of face processing have already been mentioned, and these are relevant inasmuch as the evidence she presents argues for separate face processing and object processing systems. Due to pressures of space only the latter two models will be described in detail here, although there are many similarities between them.

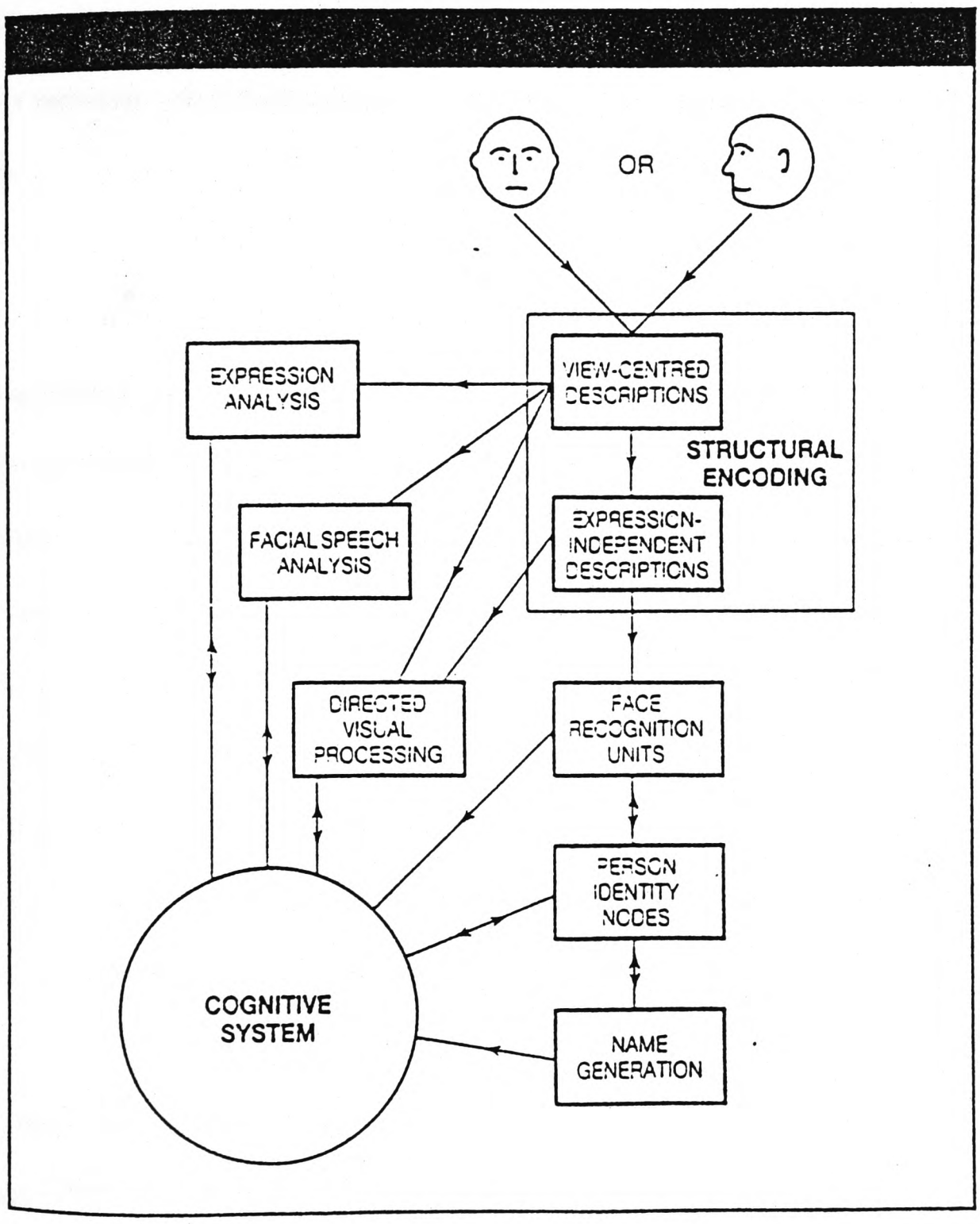


Figure 1.1 - The model of face recognition proposed by Bruce and Young (1986)

The most significant model was put forward by Bruce and Young (1986). This model is illustrated in Figure **1.1**. It has a number of components which I will briefly describe. Firstly, as for any visual object, the face must be structurally encoded so that the face can be recognised as a face, enabling further processing to occur. Any patient with an impairment at this level is likely to have a widespread apperceptive agnosia, not just for faces, and may also have some early perceptual and acuity problems. No information about the identity of the face or its expression is extracted at this stage.

As far as face recognition is concerned, the actual task which is classically impaired in prosopagnosia, the right-hand side of the model shown in Figure **1.1** is relevant. The stage following structural encoding is that which contains the face recognition units, or FRUs. This contains view-independent representations of familiar faces, and it is assumed that on meeting a new person for the first time a FRU is formed for that person. At this stage no semantic information about the person is accessible, only that the person is familiar. Prosopagnosics are typically impaired at this stage, in that they are not aware of finding faces of known people (possibly including their own) familiar. If you recognise someone but cannot remember where you met them or anything about them it is likely that this stage is activated, but no further along the cognitive path of the model.

The third stage concerns the actual identification of the person whose face is seen. Bruce and Young (1986) call the units used to achieve this the person identity nodes, or PINs; these contain information about a person which can be used to identify that person uniquely. This information may be that person's name, or may equally be semantic information about them, for instance that the person is an MP, an actor, or "my neighbour two doors down the street". Note that information other than that related to the faces is also accessed when working out someone's identity, such as the person's gait, voice, clothing or perfume, and also paraphernalia, such as baldness, glasses or a

beard. Context can also assist person identification: for example, you would be much more surprised to see your bank manager at a night-club than in the bank, and in circumstances such as the former the identification of someone is often more difficult. When prosopagnosics are tested on tasks investigating the PINs, it is often found that they have a good semantic knowledge of people when the questions are based on those people's names, but poor access, or in some cases no access, to such information when they are asked to give information about people whose faces are shown. For instance, **SS** is fast and accurate at discriminating between familiar and non-familiar names and classifying famous names by profession, but cannot do either task when shown the faces of the same people.

The same model illustrates the hierarchical nature of face processing, pointed out by Young (1994), which is shown by the errors people make. We must first recognise the face as familiar, then recall other details about the person, and finally remember their name. It is unusual to remember someone's name from seeing their face without being able to remember a single piece of semantic information about them. This has, however, been documented, for instance in the case of a 74 year old woman suffering from dementia of the Alzheimer type who, for a number of faces, consistently produced the correct name whilst giving either incorrect categorical information about the person or none at all (Brennen et al 1994, unpublished lecture). This patient also showed naming without comprehension on object identification tasks, suggesting that this pattern of processing was not specific to faces in her case. This finding is difficult to explain in terms of Bruce and Young's model, but it is extremely unusual.

The model should also explain the findings that covert processing of faces can sometimes occur, as outlined above in Section **1.3.1.2** for patient **PH** (de Haan et al 1987a). Such covert processing could be explained if the FRUs are activated but below the threshold of consciousness. Not all

prosopagnosic patients show covert recognition of faces: **SS** shows none, for instance (de Haan and Campbell 1991).

The left-hand side of Figure **1.1** shows the other abilities we have that rely on face processing. These include expression analysis, facial speech analysis (i.e. lip-reading to assist speech understanding, which we all do subconsciously), what Bruce and Young call directed visual processing, such as age and gender identification, and also the ability to match specific features. What is not covered in this version of the model is eye gaze perception, although this has been incorporated into later models. What the model does suggest, however, is that these abilities such as expression perception, identity recognition and lip-reading are dissociated from one another, and evidence for this lies in the different patterns of face-processing deficits that prosopagnosic patients have. For instance, Young (1994, page 4) documents a double dissociation between

> "some brain-damaged patients who remain able to understand emotional facial expressions, despite being unable to recognise familiar faces .... [*and a second group*] with impaired comprehension of facial expressions even though the identities of the people can be recognised."

Later models have been proposed to account for findings from priming studies and also to incorporate the growing area of neural networks and distributed systems. In semantic priming tasks, the recognition of a face is aided and therefore speeded up by the previous presentation of a related prime, an example being that Prince Charles' face is more quickly recognised if preceded by Princess Diana's face (related) than by Judy Garland's face (unrelated). Bruce and Valentine carried out a face familiarity task (the subject is asked 'is this face familiar?') and showed that reaction times were decreased by the prior presentation of related primes (Bruce and Valentine 1986).

Burton et al's model (Burton et al 1990) shown in figure **1.2**, gives a neat account of these priming effects. The model is an interaction activation model where the units are connected by modifiable

links which can either excite or inhibit each other. There are multiple 'pools' of units, including names, FRUs, PINs and a pool of semantic information units (SIUs). The strongest links are between the name, PIN and FRU for a particular person. The major difference between this model and Bruce and Young's (1986) is that the PINs do not hold the semantic information themselves but provide an interface to the SIUs. Priming is explained by the following example. When Prince Charles' face is presented, his FRU is activated, activating his PIN and therefore his SIU - 'royals'. The increased activation of the 'royals' SIU increases the activation of Diana's PIN, although not to threshold. However, it is now easier to recognise a photograph of her due to the increased activation of her PIN.

With the exception of Brennen's patient described above (Brennen et al 1994), it is normally easier to remember semantic information about someone than their name using their face as a cue. A number of possible reasons have been put forward to explain this. The simplest is that the name is further up the hierarchy or processing than the semantic information, such that the semantic information acts as a further cue to the name. This is the view taken by Bruce and Young's model (1986). Another explanation has more recently been put forward by Burton and Bruce (1992), who found that subjects were slower at retrieving names than semantic information. However, they suggested that they were not stored separately from one another, but that as the names were unique, whereas the semantic information was generally shared between more than one person (e.g. actor) a greater activation was needed to retrieve the name. This was tested using an interaction activation model, and Burton and Bruce succeeded in showing that after 50 cycles of the model, the level of activation for a name was lower than that for five pieces of semantic information. Cohen (1990) suggests an alternative explanation, that rather than the uniqueness of names accounting for the increased difficulty in their retrieval, this increased difficulty in retrieval is due to the meaninglessness of the names. In other words, the fact that someone is a 'politician' or an 'actor' tells us something meaningful about them, but that the fact that someone is called 'John' or

'Marilyn' or 'Ethelred' tells us nothing meaningful about them other than ascribing an essentially arbitrary label to them. Whatever the reason, it is accepted that it is indeed harder to name someone than give some semantic information about them, and this is likely to reflect a lower level of activation for the name than for the semantic information.

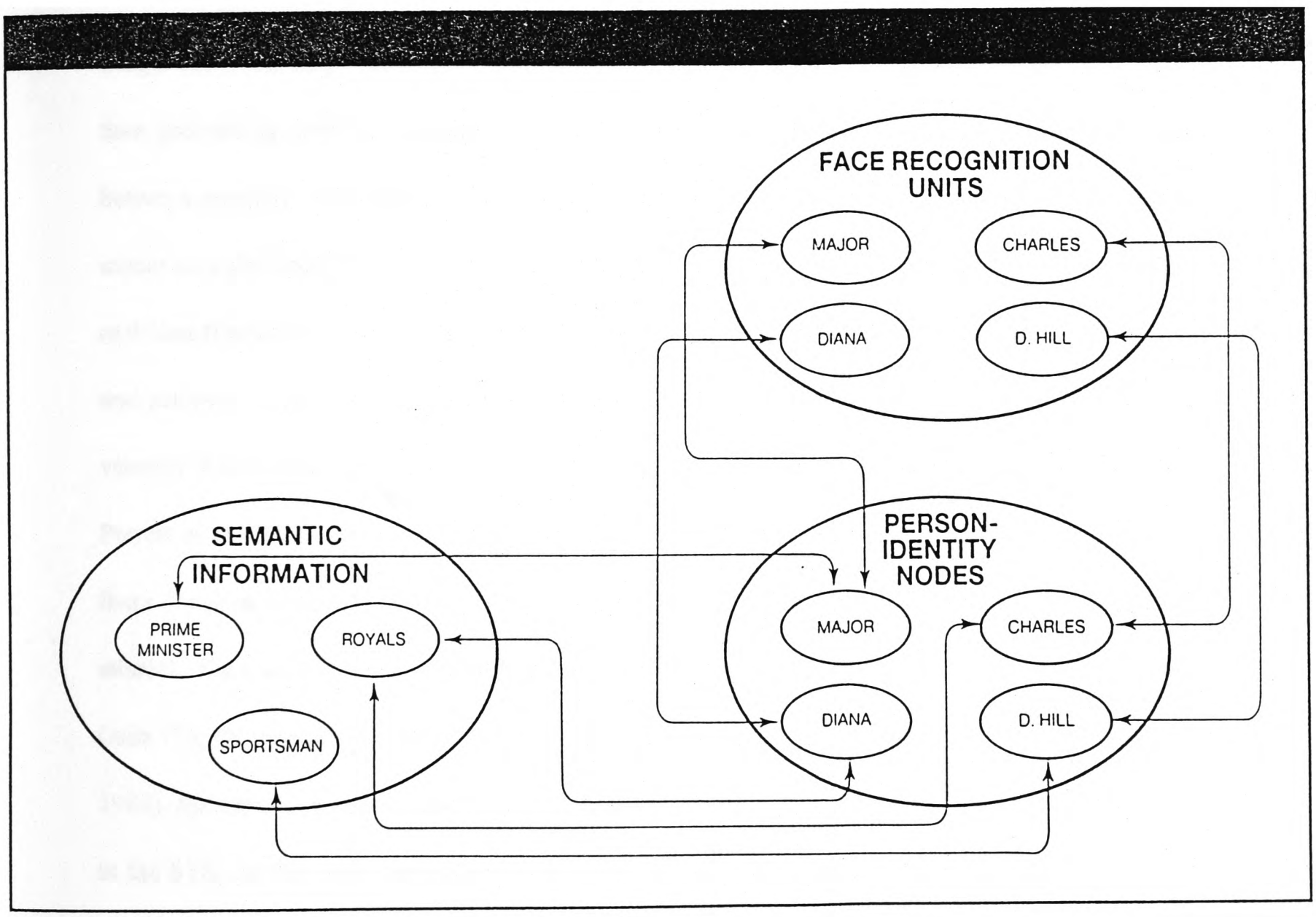


Figure 1.2 - Modified version of the Bruce and Young (1986) model. Adapted from Burton et al (1990)

1.5 - Cerebral Asymmetry

There are many differences between the two hemispheres for various aspects of face processing, both in normals and in prosopagnosic patients, with respect to the differential effects of damage to the left and right posterior cerebral cortices. As this section relies on a discussion of hemispheric asymmetry in a broader sense, it is left until the later part of Chapter 2, in section **2.5.1**.

1.6 - Primate Experiments

1.6.1 - Neuroanatomy and Face Cells

Single-cell recording studies have shed some light on the areas of the monkey brain involved in face processing, although it should be borne in mind that there are certainly some differences between monkey and human neuroanatomy. It is thought that neural coding occurs to a great extent as a distributed network, by sparse population coding, rather than by the old 'grandmother' cell idea (Desimone 1991, Young and Yamane 1992). Thus memories and percepts are stored in and activate a population of cells. It is, however, still possible to record stimulus preferences for visually driven cells, and the so called 'face cells' and 'hand cells' (Gross et al 1972, Gross 1992, Perrett et al 1982, 1984, 1988, 1992) are cells which show a disproportionately high response to faces (or parts of faces) and hands respectively compared with their responses to all other visual stimuli. Face cells have been found in primates in both hemispheres in the inferior temporal area (area IT), the superior temporal sulcus (STS), the basal accessory nucleus of the amygdala (Rolls 1984), the ventral putamen and the arcuate gyrus in the frontal lobe. Face cells are most prevalent in the STS, on the upper banks in area TPO of the superior temporal polysensory area (STP), and on the lower bank and lip of the sulcus in area TEm (Desimone 1991). Face cells have also been found in sheep (Kendrick and Baldwin 1987) and more recently in humans undergoing craniotomy, active in face-matching or facial-expression-naming tasks (Ojemann et al 1992). Ojemann and his colleagues used extracellular microelectrodes which recorded either from single cells or from a few

cells. Populations of these face cells were found in the RH in the superior and medial temporal gyri.

There are possibly many populations of cells coding different attributes of the stimuli. For instance, STS cells respond mainly to facial expression whereas cells in the IT gyrus respond mainly to facial identity with only a 7% overlap in one study (Hasselmo et al 1989, Rolls 1992). Cells have been found which are responsive to one individual, being invariant across expression, orientation, colour and size (Perrett et al 1984). This study also found cells responsive to facial expression and others responsive to head view. These different populations reflect the underlying different neuronal substrates implicated in, for instance, expression and identity recognition, and help to explain the existence of a double dissociation between the two processes in human patients (e.g. Young 1994). Populations of cells in area STPa responsive to direction of gaze have also been described by Perrett and colleagues (e.g. Walsh and Perrett 1994).

1.6.2 - Lesions

The existence of these face cells prompted suggestions that prosopagnosia is caused when a corresponding area in the human brain is damaged. To investigate this further, various lesion studies have been carried out. Both areas IT and STS have been shown to contain face cells and different studies have lesioned them and investigated the behavioural effects.

Lesioning area IT causes general deficits in object recognition (agnosia) and in learning and remembering visual stimuli (Gross 1992, Gaffan et al 1986). Eacott and colleagues (1993) showed that IT lesions impaired monkeys on post-operative shape discrimination learning. These papers suggested that the IT is generalised for shape discrimination and identification and not specific to faces. Horel (1993) disagrees: he reversibly cooled IT in monkeys and showed that there was a severe impairment in monkey face discrimination when there was only a difference in the internal

features. However, he did not use non-face control stimuli where there was also a difference in internal features, and such a control would be needed to be certain. It is likely that the face cells are so distributed that a lesion in this area will always have a more generalised effect, and this does not explain the (extremely rare) cases of 'pure' prosopagnosia in humans, and primate IT lesions are unlikely to be a good model for prosopagnosia..

When area STS is lesioned, however, a different pattern of results is found. As mentioned earlier, Heywood and Cowey (1992) bilaterally lesioned area STS in monkeys and their residual face-processing abilities were investigated. The post-operative monkeys were not impaired at face / non-face discrimination, selecting the odd face from a group, delayed matching to sample for faces, discrimination between novel and familiar faces or specific face identification. Thus removal of this face-cell area produced little or no impairment in face-processing tasks, on which a group of four prosopagnosic patients showed severe difficulties. There was, however, a large effect on eye gaze perception with the monkeys showing an impairment in such tasks. This suggests that the removal of the face-cell area STS in macaques is not a good model for human prosopagnosia. Eacott et al (1993) also removed STS and showed that the monkeys were impaired at discriminating eye gaze direction. However, STS removal also impaired the monkeys at 2-choice pattern discrimination for both shape and orientation, suggesting that the STS may have a role in general pattern discrimination, of which eye gaze direction perception is just an example. Note that Eacott et al (1993) looked at post-operative learning whereas Heywood and Cowey investigated post-operative retention of a pre-operatively learned ability.

The above sections illustrate one problem with human-monkey brain homology and the uses of primate models in investigating human conditions. The areas damaged in prosopagnosia are bilateral ventromedial occipito-temporal (but see section **1.2.3**), and it is not known fully which areas in the monkey are homologous to these. It was thought that it might be the STS, but the

above findings suggest that this is not so. It has been suggested that the human equivalent of the STS may be Wernicke's area, which is involved in the comprehension of heard speech (Desimone 1991). If this were so, it could be that both Wernicke's area and the STS in monkeys are areas for the comprehension of social communication signals, be they speech or eye gaze or facial expression. There is little other literature touching on this as yet, but it would be very interesting to know whether, for instance, Wernicke's aphasics have any difficulty in the perception of eye gaze.

1.7 - General Conclusions

There is a great deal of experimental and anecdotal data concerned with face processing from a variety of sources. A number of conclusions can be reached from the data. The right hemisphere in normal right-handed adults is superior for face-recognition and face-matching tasks, and one possibility is that such tasks are achieved by global, holistic processes, in other words where the whole face and its overall configuration are processed together, without processing the individual features. Note however that this is a sensitive area, and the evidence for such a distinction is somewhat controversial - this is discussed in more detail in Chapter 2. Brain damage to the ventromedial occipitotemporal area in the RH at least, and possibly co-occurring LH brain damage, can cause prosopagnosia, a deficit in familiar face recognition, which is sometimes accompanied by other face-processing deficits, such as facial-expression recognition and the perception of gaze direction. In general, 'pure' prosopagnosia is rarely found, and most patients have other neuropsychological deficits. Unilateral LH damage does not tend to lead to prosopagnosia. Monkey data have shown the existence of 'face cells' in the temporal cortex and other areas which are responsive to an increasingly complex set of stimuli, up to that of an individual face. These cells have now also been documented in humans. Cognitive models have been proposed to account for the findings from neurological patients and normal control subjects.

The experiments which have been carried out have answered many questions but have posed still more, some of which will be tackled in this thesis. For instance, does the RH advantage extend to the perception of gaze direction? Do prosopagnosics who have shown normal error data on face-matching tasks perform them significantly more slowly than normal adults? Is there a proportion of individuals (either left-handed or right-handed) with reversed cerebral asymmetry who have their face-superior hemisphere on the left? To what extent does the perception of another's eye gaze cause an internal shift in the viewer's own attention? Some of these questions are investigated in later chapters.

CHAPTER 2 - INTRODUCTION TO HEMISPHERIC ASYMMETRY

2.1 - Introduction

The two halves of the human brain, and indeed the brains of other species, are not identical, either anatomically or functionally. There are several differences both in their structure and also in the processing strategies they employ. There are also a number of sources of evidence for the differences between the hemispheres. This chapter outlines some of those differences and relevant evidence.

2.2 - The Nature of the Asymmetry

It has long been known that the two hemispheres in humans are not identical, either anatomically or functionally. There is a great deal of nomenclature concerning the differences between the two sides of the brain. Terms such as hemispheric asymmetry, cerebral lateralisation and cerebral dominance have all been used. The following sections will outline the anatomical and functional differences between the hemispheres.

2.2.1 - Anatomical Differences

Anatomical asymmetry between the two cerebral hemispheres of the brain was described a number of times during the 19th century, but these observations were generally ignored or dismissed until the 1960s when Geschwind and Levitsky (1968) described irrefutable anatomical asymmetry in a large number of human brains. They reported that the **planum temporale** just posterior to the auditory cortex was larger in the LH in 65% of brains studied, and on average 1 cm longer than its counterpart in the RH. Since then many other differences have been found and are well documented and reviewed in Kolb and Whishaw (1990). These include more grey matter in the LH, a more gently sloped **Sylvian fissure** in the LH, different **frontal operculum** (Broca's area) organisation on each side, reflecting different underlying functions, and the distributions of certain

neurotransmitters. It is also notable that the details of anatomical asymmetry are affected by both sex and handedness. Note also that no two brains are identical.

2.2.2 - Functional Differences

A major source of evidence for functional asymmetry in the brain comes from neurological patients and has been known about for over a century. In 1861 Broca described an area in the left hemisphere (LH) concerned with speech production which did not have a counterpart in the right hemisphere (RH). Many studies have shown that in most right-handed people and 70% of left-handed people the speech and language areas of the brain are situated in the LH. Studies on patients with unilateral brain damage and split-brain patients (see below), together with studies on normals, have all helped to give an overall picture of the differing roles of the two hemispheres. In general, the LH is superior for language processing and damage can cause aphasias. The RH is superior for spatial processing and musical appreciation: damage can cause agnosias, spatial alexia (e.g. Ardila and Rosselli 1994) and amusia. In addition to this, research has shown that there is a RH advantage for face processing and damage to the ventromedial occipito-temporal area (together with some LH damage) causes prosopagnosia and sometimes other face-processing deficits. Much of the evidence for this RH bias towards face processing will be described later, in Section **2.5.1**. Note that although both hemispheres are specialised for certain processes, this is a relative and not an absolute specialisation. For instance, the RH does have some speech function and the LH has some face recognition ability in right hemispherectomised patients (Bradshaw 1989). Of course, the removed RH may have been severely damaged during infancy, provoking an abnormal representation of facial perception in the intact LH.

Another way of looking at cerebral asymmetry is not in terms of the tasks for which each hemisphere is specialised, but in terms of the way in which each hemisphere processes incoming data. This is a theoretical framework which suggests that, in general, the LH tends to use local,

analytical, feature-by-feature processing whereas the RH uses more holistic, global processing. In other words, the LH is described as processing incoming stimuli bit by bit, in a temporally serial way, whereas the RH is described as processing stimuli all at once, looking at the overall meaning without resorting to analysing parts of the stimulus. The evidence for this distinction is not clear, however, and there exist both studies which support and those that disagree with such a dichotomy. As with many psychological dichotomies, those studies supporting this framework agree that there is not a clear cut distinction, but rather a general favouring towards analytic, local processing for the LH and holistic, global processing for the RH. Studies which argue for such a distinction include those by Sergent (1982) and Hurtig (1982) who used Navon figures and complementary non-verbal stimuli respectively, and Christen et al (1985), Hillger and Koenig (1991) and the studies by Farah (e.g. Tanaka and Farah 1993) , all of which argue for global, holistic face processing in the RH, and which are described in more detail later in this chapter.

However, there are a number of studies which have failed to show such a distinction, including those by Trope et al (1992), van Kleeck (1989) and Magaro and Moss (1989), which suggest that both hemispheres are capable of analytic and holistic modes of processing, and that the results of many of the studies may be due at least in part to the precise nature of the task and stimulus material and the instructions given to the subject. Van Kleeck (1989), however, failed to show a distinction in his own study of Navon figures, but did present evidence for the existence of such a distinction when he carried out a meta-analysis of a large number of previous papers investigating this issue, suggesting that such a distinction is present but very slight and difficult to demonstrate.

This approach can be argued to support the RH's role in face processing, as some of the experiments described later in this chapter will show. A third way of thinking about the cerebral asymmetry is to consider that the LH extracts meaning and the RH extracts shape. However, there

is some evidence for associative processing of emotional facial information in the RH (Landis et al 1979), suggesting that this idea is a gross over-simplification.

Patients with lateralised lesions and those with commissurotomies (patients who have had their corpus callosum severed as a means of controlling epilepsy, often termed split brain patients) show a range of different neuropsychological symptoms and impairments, and it is from this source that a great deal of the evidence for lateralisation of function has been collected. Of great importance here is the **double dissociation** method for demonstrating lateralised function, a term coined by Teuber (1955), where one group of patients with, say, left-sided brain damage, shows a range of deficits different from those shown by a group of right brain damaged patients, and there is no overlap in the deficits shown by the two groups. However, the existence of a double dissociation has to be treated with care, and many flawed conclusions can be reached concerning localisation of function (Shallice 1988). Shallice argues in his book *From Neuropsychology to Mental Structure* that there are both assumptions that have to be made and problems of mis-interpreting data. The main assumptions are that the mental systems being investigated are modular, and that the effects of different types of damage to any particular subsystem can be considered to lie on a continuum. His other main point is that to be sure of showing the dissociation between two systems, patient A has to perform better that patient B on task 1, but worse that patient B on task 2, and that it is not correct that patient A has to perform better at task 1 than task 2, whereas patient B has to perform worse on task 2 than task 1. Double dissociations are an accepted part of neuropsychology, but with the provisos mentioned.

A relatively new method for demonstrating functional asymmetry is brain imaging using PET (positron emission tomography) and fMRI (functional magnetic resonance imaging). These techniques allow the active brain to be investigated *in vivo* in a relatively or completely non-invasive way, and show which areas are more active during specific tasks - the more active areas

have a greater regional cerebral blood flow (rCBF) and yield greater PET and fMRI signals. These imaging techniques are useful for both localisation and lateralisation of function. They are also of use in determining the loci of brain damage in patients (along with CT scans for structural damage) and can show regions of poor activity and locally decreased or increased levels of neurotransmitters. For instance, PET has been used to indicate that the basal ganglia of Parkinsonian patients are low in dopamine by using radioactive ligands which bind to dopamine receptors, such as fluorodopa (e.g. Menza et al 1995).

Functional asymmetry in normal subjects has also been heavily investigated using a range of techniques, including dichotic listening tasks and tachistoscopic visual field studies (see section 2.5). These studies make the assumption that if one hemisphere is specialised for a certain process or function, then sensory input directly to that hemisphere will be processed more rapidly and efficiently than sensory input to the opposite hemisphere, which then has to be transferred across the corpus callosum to the specialised hemisphere, resulting in a longer processing time and also possibly a greater error rate due to the increased chances of stimulus degradation during interhemispheric transfer. There are some important issues to note when designing and interpreting the results of laterality studies in normals, which are discussed in more detail below.

Another interesting area is that of reversed asymmetry. It has been shown that 70% of left-handed people show a normal left hemispheric specialisation for language functions, and 15% show no hemispheric specialisation for language functions, but the other 15% show what is called reversed asymmetry. One study that demonstrated this was by Rasmussen and Milner (1977) who investigated language dominance during the administration of sodium amytal (the Wada test) prior to surgery to decrease the symptoms of epilepsy. Those with reversed asymmetry had language areas in their RH, not their LH. It would be very interesting to know whether such people have areas specialised for face processing in their LH rather than their RH. There are few cases to date

of left-handed prosopagnosics, e.g. the patients of Aptman and colleagues (1977) and Levine (1978), both of whom suffered from prosopagnosia as a result of either RH or bilateral damage, and the amount of data is small on face-processing experiments on left-handed normal subjects. However, this thesis investigates two right-handed subjects with RH language areas.

2.2.3 - Individual Differences

The problem of understanding lateralisation is complicated by the fact that laterality of function can be affected by both environmental and genetic factors and that there is a great deal of individual variation in the pattern of left-right differences (Kolb and Whishaw 1990, Chapter 16). Both anatomical and functional lateralisation have been shown to vary as a function of handedness and gender - it is thought by some that the cerebral organisation of some left-handers and females is less lateralised than in right-handers and males, for instance. [Note, however, that in Chapter 5 experiments are outlined in which laterality effects were not lessened by the inclusion of left-handed subjects.] However, handedness is rarely absolute, differing between tasks, leading to the necessity for handedness questionnaires covering multiple tasks (e.g. Oldfield 1971). According to one study by Annett (1970), left-handedness varied from between 6% for cutting with scissors to 17% for dealing cards. The study by Rasmussen and Miller (1977) cited in the previous section suggests that the majority of left-handers (some 70%) may still have as strong a lateralisation as right-handers. On the subject of gender, it has long been accepted that there are cognitive and behavioural differences between males and females (e.g. MacCoby and Jacklin 1974), and from much of the earlier research, Bryden (1981) concluded that females appear to show a lesser degree of lateralisation, but that this might depend on the strategy used by the subjects.

2.2.4 - Asymmetry in Nonhumans

Once it was realised that functional asymmetry was not only found in language processing, investigations into the cerebral asymmetry of other species were carried out. Anatomical

asymmetry has been found in a number of other species, including amphibians (differences in the size of various hypothalamic nuclei in frogs), rats, cats and primates. There is now some evidence that some other species, such as non-human primates, show handedness, but evidence of functional asymmetries in non-humans has been elusive. However, examples do exist, e.g. the LH of songbirds appears to be responsible for their songs: if the left hypoglossal nerve of canaries is severed, bird song is disrupted, but not so for the right hypoglossal nerve (Nottebohm 1971). There is also some evidence for a critical period and plasticity in the canary brain: if the left hypoglossal nerve is severed before the onset of the spring song, the bird's ability to develop singing remains largely unaffected, and evidently the RH takes over the role of processing the bird song. This is similar to the findings that damage to the human LH early in life can result in reasonable development of language abilities in the RH. More recently, Fagot (1992) has reviewed evidence for cerebral lateralisation of function in a range of species, including birds, rodents, cats and primates. The existence of similar anatomical asymmetries in primates to those in humans suggests that human cerebral asymmetry did not evolve as a result of language.

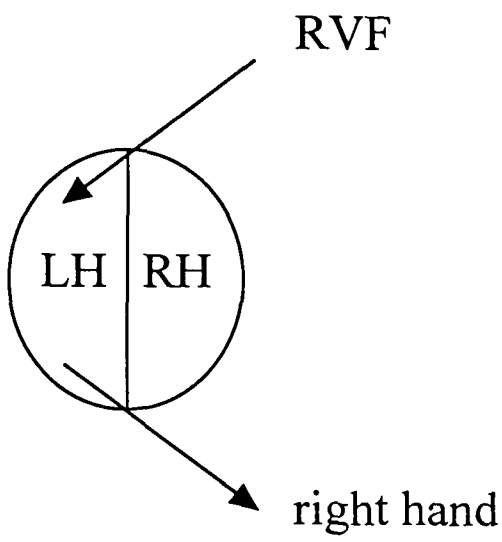
2.2.5 - Problems with Laterality Studies

Efron (1990) is very scathing about studies of hemispheric specialisation, and brings to light many of the problems that face neuropsychologists running such experiments. Although his criticisms are too strong for some researchers, there are indeed many problems associated with using reaction time and error data in laterality studies.

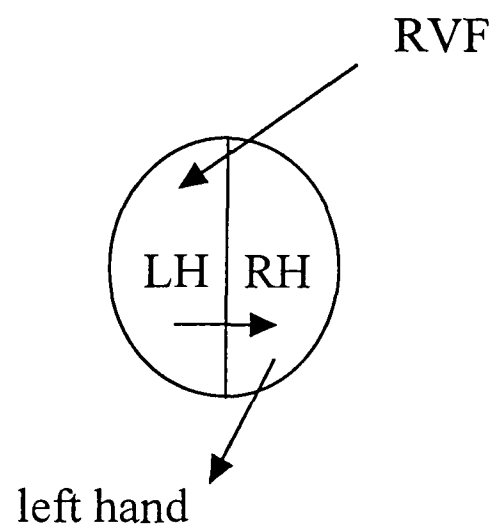
The first of these is that the difference in reaction times that many researchers are looking for are of the order of 10 to 20 ms over a task that takes, for instance, 500 to 1000 ms, and that to get a statistically significant result for such a small change, many subjects or at least many trials are needed, and the methodology and conditions have to be monitored very carefully.

Efron notes many factors which affect right / left asymmetry, relating to the subject, the stimulus and the methodology. One important factor I would like to emphasise is the response required by the subject. In all tasks related to hemispheric specialisation, the subject is required to make some response to a stimulus, and it is on the basis of these data that the asymmetry is determined. For every trial, stimulus input, stimulus processing and motor output must occur. The input hemisphere is controlled by which visual field or ear the stimulus is delivered to, and the output hemisphere is also controlled by the response determined by the experimenter. However, the processing hemisphere is worked out on the basis of the stimulus input, not the motor output. For example, consider a language task in which the subjects have to match a central face to a briefly presented lateral face, and the response required is manual, where one hand is used to respond if the two faces are the same and the other hand if they are different. If the hand used in a particular trial is on the opposite side to that on which the face is presented, then the input and output hemispheres will be different, irrespective of which side is more specialised at processing (Figures 2.1b and 2.1c). This could lead to an increase in basic reaction time compared with trials where the input and output hemispheres are the same and also specialised for the task (Figure 2.1a), and a decrease compared with trials where they are the same but not specialised for the task (Figure 2.1d). This is more easily illustrated in diagram 2.1.

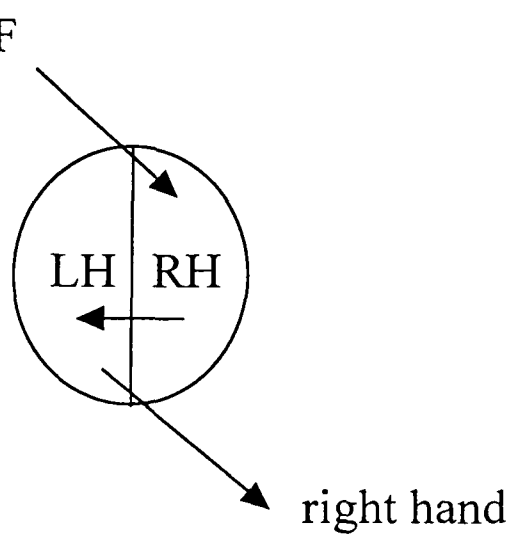
However, given the new evidence which has come to light since Efron's book (1990), due mainly to the technological advances which have been made, there is now, I think, indisputable evidence for hemispheric asymmetry, which cannot satisfactorily be argued against on methodological terms. This evidence is very reproducible and includes brain neuro-imaging data (fMRI and PET scans) and extracranial recording (ERPs). As long as the methodology is controlled carefully and enough subjects are used, there is no reason not to continue laterality research, particularly with this new technology available.



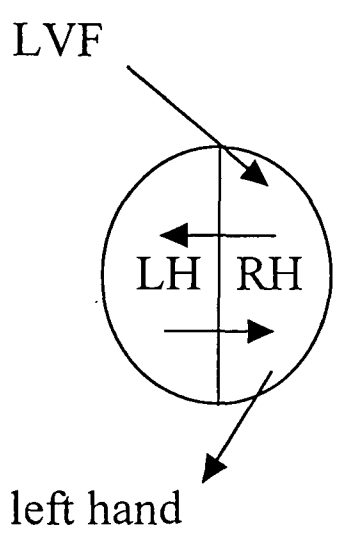
2.1a - 2 steps



2.1b - 3 steps



2.1c - 3 steps



2.1d - 4 steps

Figure 2.1 - The pathways for information in a hypothetical linguistic task with LH superiority requiring a manual response

2.3 - Advantages and Disadvantages

One valid question to ask is why hemispheric asymmetry has evolved. It must be advantageous overall to have survived. We now know that it is not found only in humans, so language is no longer thought to be the main cause of laterality. Note that when the literature talks about hemispheric asymmetry it mostly refers to cortical differences, not subcortical ones.

2.3.1 - Advantages

The evolution of two 'different' brains allows for more capacity and a wider range of brain functions and strategies, thus allowing more complex and 'higher' behaviours to evolve. In other words, if there were two identical brains, one would be to an extent redundant. Note of course that although the two sides of the brain in humans may have different specialisations, such as language and spatial processing taking place primarily in the left and right hemispheres respectively, much of the sensory and motor processing is essentially of an identical nature in both sides of the brain, the only difference being which half of space or the body is served: for instance the left hemisphere of the brain deals with vision in the right visual field and movements of the right half of the body.

Another advantage of hemispheric asymmetry is linked to the wiring that is necessary in the brain. A large proportion of the LH is given over to language processing, and if language were split half in the LH and half in the RH, the wiring problem and increased transmission time as the neural information was passed from one hemisphere to the other would both be huge. It is thus much more efficient and sensible to design a brain with lateralised functions, such as language and other cognitive abilities, which do not relate to one side of the body more than the other. From the point of view of the neural wiring it is usually the case that adjacent regions of the brain carry out closely linked functional processing, thus necessitating fewer and shorter interneurone tracts. In humans the corpus callosum contains between 200 million and 800 million fibres (Kolb and Whishaw 1990), and immense number, and were it not for the fact that evolutionary pressure had kept this

number down by lateralising functions as described, the wiring problem would be unmanageable (Cowey 1979).

2.3.2 - Disadvantages

The absence of a second 'backup' copy of the brain structures leaves it a very vulnerable organ to injury. Consider that the loss of one kidney or lung may have an effect on a patient which will be lessened by the presence of the other working organ. However, if a head injury or stroke results in destruction of an area of brain tissue, the functions in which that area has a role (or functions in which fibres passing through that area have a role, if they are destroyed) may be impaired or lost altogether. For instance, damage to Broca's and Wernicke's areas in the left hemisphere of humans may cause difficulties in language comprehension and production - aphasias. These are not well compensated for by the right hemisphere, and language ability may be lost. Another example is that of damage to the striate cortex in one hemisphere which leads to a visual field defect (an area of blindness) in the contralateral visual field. This cannot be compensated for by the other unaffected hemisphere. Note that this 'backup' is not likely to be an evolutionary reason for bilateral symmetry, but rather an effect. It is unlikely that there would be any evolutionary pressure favouring bilateral representation. However, it should also be noted that the brain is capable of some flexibility and plasticity, and therefore compensation for and recovery from neurological damage does to some extent occur. Neuropsychological rehabilitation, which relies on this plasticity, is now a fast-growing area of research.

2.4 - Split-Brain Studies

In 1940 a report appeared (Erickson) which described the spread of epileptic discharge from one cerebral hemisphere to the other in monkeys by way of the corpus callosum. It had also been noted that tumours affecting the corpus callosum decreased the spread of epileptic discharge between the two cerebral hemispheres in humans. These findings paved the way for a new treatment for

epilepsy: the split-brain operation. Also called commissurotomy, the operation consists of cutting some or all of the fibres in the corpus callosum (and sometimes also the anterior commissures) which connect the two hemispheres. The first such operations were carried out in the early 1940s by William van Wagenen (van Wagenen and Herren 1940), and were not seen to have much effect on the patients' everyday lives, although the epileptic seizures were indeed controlled.

In the 1950s Myers and Sperry made some remarkable discoveries that were of supreme importance in the field of hemispheric asymmetry study (Myers and Sperry 1953). They cut both the corpus callosum and the optic chiasm in cats which resulted in visual input to the left eye entering only the left hemisphere and visual input to the right eye reaching only the right. When cats with the optic chiasm sectioned (but not the corpus callosum) were trained on a visual discrimination task, they were able to carry out the task using either eye after one-eyed training. However, those cats with sectioned optic chiasm and corpus callosum were unable to transfer from the trained eye to the untrained one, as no information in one hemisphere was available to the other. The cats needed full retraining on the second eye to learn the same visual discriminations. Myers and Sperry concluded that sectioning the corpus callosum had prevented the flow of information from one hemisphere to the other. In effect, only half a brain had been trained.

Sperry and his colleagues (e.g. Sperry and Gazzaniga 1967) then carried out extensive testing on patients who were given complete commissurotomies (which were more successful in keeping the epilepsy in check than the partial commissurotomies which van Wagenen had carried out in the 1940s) which ultimately led to Sperry's being awarded the Nobel Prize in Medicine in 1981. Their tests involved having patients fixating a central dot so that visual stimuli could be presented to one visual field at a time, for a short enough time that the patient was not able to saccade to the stimulus to bring it into central view. Also the patient was able to feel underneath the screen a number of objects with either hand, which were hidden from view by the screen. One such

experiment was as follows: when an object was shown in the right visual field (RVF) and the patient was asked what the object was, he or she would answer verbally. On the other hand, if the object was presented in the left visual field (LVF) and the patient was asked what was seen, the patient could not say what was seen, and might reply that nothing had been seen. However, if the patient was then asked to feel a number of objects with the left hand and select the one just seen by touch, the correct choice was made, even though the patient still could not say what was being held in the left hand.

The explanation for this is as follows: the left hemisphere (LH) in the majority of people is dominant for language tasks. The visual system and the somatosensory system are both crossed such that the LH processes information from the RVF and the right hand, and vice versa. When the object was shown in the RVF, the image was processed by the speech hemisphere, the LH, and the patient was able to name the object. However, when the object was presented in the LVF, the RH processed the image and the LH did not have access to the information, so that the patient could not say what was seen. However, the RH was able to match the visual stimulus with the tactile stimulus which the left hand detected, even without the subject's being able to say what the object was. Thus the two hemispheres are to an extent kept separate.

In everyday life, of course, split-brain patients do not face this type of problem. They are able to scan the visual scene such that anything they are looking at will be processed by both hemispheres, albeit not simultaneously. There are, however, a few subtle deficits which have been documented. Several patients have reported difficulty in learning face-name pairs. This could be due to a disconnection between the language abilities of the LH and the face recognition abilities of the RH. Deficits in solving geometric problems have also been reported, as has anecdotal evidence for a lack of dreaming and poorer memory in some patients. However, the lack of dreaming has not

been confirmed by further research, and the poorer memory may be due to underlying hippocampal damage in some patients.

The laboratory studies of split-brain patients have yielded a great deal of information about the abilities and processes carried out by the two hemispheres, which when added to the information about patients with brain damage to one hemisphere and lateralisation studies in normals, give a much clearer picture of the differences between the two hemispheres.

2.5 - Asymmetries in the Normal Human Brain

The investigation into the differences between the two halves of the brain in neurologically normal subjects has been carried out in several ways. One of the most extensively used methods takes advantage of the crossed visual pathways, which naturally splits the visual field into left and right halves, each of which projects to one hemisphere only, the one contralateral to the visual hemifield. Visual stimuli are presented very briefly in one visual hemifield, with the subject maintaining central fixation, and thus the input is lateralised to one hemisphere only. This lateralisation of processing and any processing advantage or disadvantage it allows lasts for a very short time, only tens of milliseconds, due to the connections between the two hemispheres, but this appears to be long enough to enable researchers to compare the abilities of one hemisphere with those of the other.

A second and related method uses the crossed nature of the auditory pathways. In a similar way to the visual system, auditory information delivered to the left ear projects more strongly to and is processed first by the right hemisphere, and vice versa. A method known as dichotic listening is used, where different auditory stimuli are presented to each ear simultaneously, and the subject's task is to report what is heard. The auditory pathways are a little more complicated than the primary visual pathway as there exists an ipsilateral auditory pathway in addition to the

contralateral one which gives rise to the above effect. What is believed to happen is that the contralateral pathway is stronger than the ipsilateral one, and when auditory information is delivered to each ear simultaneously, this difference in strength is exaggerated, such that the information in the ipsilateral pathway is suppressed. This model was put forward by Doreen Kimura, who did much of the pioneering work in dichotic listening in the early 1960s (e.g. Kimura 1967).

Kimura used pairs of spoken digits as her stimuli. The members of each pair were aligned for simultaneity of onset. The subject listened to three successive pairs and then had to report the six digits heard. Kimura found that patients with left temporal damage performed worse than those with right temporal damage, a not surprising result considering the linguistic nature of the task and the linguistic advantage of the left hemisphere. Regardless of the position of the brain damage, patients tended to report those digits heard in the right ear more accurately than those heard in the left ear, and this pattern was also found in normal subjects.

Additional support for Kimura's model of dichotic listening comes from two other findings. The first is that the right ear advantage reverses in subjects found on the basis of the sodium amytal test to have speech controlled by the right hemisphere rather than the left hemisphere (Kimura 1961). Kimura tested 120 patients who had had surgery for epilepsy and it was therefore known which of their hemispheres was dominant for language. Those with LH language dominance showed a left ear advantage, and those with RH language dominance showed a left ear advantage, and this was generally independent of handedness. This finding is important in establishing the validity of the dichotic listening task as a measure of brain asymmetry. The second finding is that the ear advantage varies as a function of the nature of the stimuli presented. For instance, in subjects who show a right ear advantage for verbal stimuli, a left ear advantage has been found for those auditory stimuli believed to be processed primarily by the right hemisphere, for instance musical chords and

melodies. Note that this is a slightly circular argument as the basis on which such musical stimuli are believed to be processed by the right hemisphere primarily is the result of tasks such as those from dichotic listening tasks. In a sense both the validity of such tasks in uncovering the inherent differences between the two hemispheres and the differences themselves can only be deduced from the existence of convergent evidence from many different methods. In other words there is no one task or method which will show without doubt which hemisphere is superior for a given cognitive function. In this case, data from aphasic and amusic patients are very important.

There are many factors affecting the results of hemispheric asymmetry tasks in normals, and some of these apply also to the interpretation of patient data. One major source of confusion is the individual differences between people over a range of attributes: gender, age, handedness, IQ and naïveté on cognitive tasks, for instance. There are additional factors of the task: the exact nature of the stimuli, the instructions, the motivation of the subject, the procedure to be carried out and the response output required, and these have been reviewed in some detail by Sergent and Hellige (Sergent and Hellige 1986, Hellige and Sergent 1986). Patients with brain damage give rise to yet another source of variation in results. All normal brains differ slightly to start with (another source of individual variation), and the actual areas of brain damage in any one patient is exceptionally unlikely to be the same as the affected areas in a second patient. So for instance, a group of four aphasic patients with left hemisphere damage will all differ slightly in their anatomical damage, their functional damage and their exact symptoms. Nature is a poor surgeon, and strokes and closed head injuries will give rise to slightly different patterns of brain damage and subsequent neurological symptoms. Another aspect of variation in brain damaged patients is that of compensation by other intact parts of the brain. This depends to a large extent on the age at which the brain damage occurred: the earlier in life the more likely that compensatory mechanisms will have developed. For instance, the damage to the blindsight patient **GY** occurred early in life, and Gazzaniga suggests that this may underlie the blindsight abilities he has (Gazzaniga et al 1994).

Linked to this idea of compensation is the plasticity of the brain and its ability to find new strategies to cope with and minimise any cognitive deficits caused by the damage. Two examples are the recovery from left unilateral neglect caused by right parietal damage, and the abilities of prosopagnosic patients to recognise people by means of cues other than their faces. Differing strategies can confuse the results of psychological experiments, for instance in the face-matching task (see Chapter 7) using photographs of Israeli men, many subjects said that they were matching the faces on hairline rather than the internal facial features. This was not the purpose of the task as it was designed, but it is possible that the recognition of hairline plays a large part in everyday facial recognition.

One last important point is that within-subject replication of experiments does not always lead to statistically similar results. In other words the same subject could carry out precisely the same task on two successive days and show a significant left hemisphere advantage on the first day and no significant hemispheric advantage on the second day. Possible sources of this difference include the points made above, and in addition, the fact that the subject may have been naïve on the first day and practised on the second, differences in the levels of fatigue and possibly hormones, and also things like the temperature of the room and the time of day. Although many of these factors can be controlled for (except the practice effect) it is still possible to find a lack of reliability between sessions.

All these points illustrate how difficult it is to carry out tasks investigating hemispheric asymmetry reliably, and that all results must be treated with caution. The strongest evidence for hemispheric asymmetry and cerebral dominance comes from converging evidence from many sources all agreeing that one hemisphere seems to be dominant for a certain task or process. For instance, it is now widely accepted that in the majority of people (about 96% right-handed and 70% left-handed people) the left hemisphere is dominant for linguistic abilities. This relies on convergent evidence

from the effects of unilateral brain damage and aphasia, split-brain studies, tachistoscopic visual tasks and dichotic listening tasks in normals, brain imaging in normals and patients, using techniques such as PET and fMRI, and also the sodium amytal test used before epilepsy brain surgery.

Note that the size of the RVF advantage in studies involving verbal tasks tends to be larger than those LVF advantages found in non-verbal tasks such as face recognition or spatial memory. Partly for this reason the functions of the right hemisphere have proved much more elusive than those of the left.

The existence of some people with reversed dominance, i.e. right hemisphere dominance for language, is very interesting but can be problematic for hemispheric asymmetry studies. For instance, in this thesis, two such subjects, **RL** and **HJ**, are tested on a tachistoscopic verbal task (Experiment 9.2), and both show the right hemisphere advantage as predicted from their PET scans. However, an assumption that had to be made in that experiment is that the control subjects used (all right-handed) were left hemisphere dominant for language. PET scans were not available for them, and it was not possible to carry out such scans. The control subjects' data were combined, and the existence of any right dominant linguists in the sample would decrease the overall left hemispheric language advantage. However, the results could also be viewed by subject, and if any of them had shown an unexpected LVF advantage, the next step would have been to PET scan them, if possible. This was not in fact necessary.

A number of models of hemispheric asymmetry have been put forward to explain why there are any differences in performance between the two visual fields. One, known as the direct access model, assumes that information will be processed by the hemisphere that receives it, regardless of the differences in ability between the two hemispheres. This model predicts superior performance

for information that reaches the appropriately specialised hemisphere first. Another, known as the relay model, assumes that information is processed by the hemisphere best equipped to process it, and that information presented initially to the non-specialised hemisphere would have to reach the specialised hemisphere by way of the commissures such as the corpus callosum. This would take time and cause possible loss of clarity of information, both of these factors leading to poorer performance than if the information had been delivered directly to the specialised hemisphere. In both of these models, asymmetries emerge in any task where the hemispheres do not have equal capacities to begin with, but which of the two models reflects the real situation is difficult to determine, as they both have the same overt effect.

The models described above are similar to those outlined by Umilta (1986), who describes the Interhemispheric Transmission (IT) Model proposed by Rizzolatti et al (1971) and the Differential Processing Speed (DPS) Model proposed by Geffen et al (1971). The IT model is similar to the relay model, above, and assumes that only one hemisphere is equipped to process whatever stimulus is incoming, be it a face or a word, for instance, and that therefore the increased reaction time and increased error rate for stimuli delivered to the visual field ipsilateral to the specialised hemisphere (and therefore delivered initially to the contralateral hemisphere) will be due to the interhemispheric transfer of information. The DPS model is similar to the direct access model, above, whereby the hemisphere receiving the information processes it, and the more specialised hemisphere is more efficient and therefore both faster and more accurate. However, Umilta et al (1985) have suggested a compromise model, called the Conditional Interhemispheric Transfer (CIT) Model. The assumptions made by the IT model and the DPS model are almost certainly false: the IT model assumes that one hemisphere is incapable of processing some types of material at all, and the DPS model assumes that automatic transfer of information from one hemisphere to the other across the corpus callosum is immaterial and therefore the processing is confined to the

hemisphere of entry of the stimulus. Umilta explains the CIT model in terms of face processing and its RH superiority:

- face processing occurs in both hemispheres irrespective of which visual field the face stimulus is presented to
- the sum of interhemispheric processing time plus RH processing time is usually shorter than LH processing time

Thus there are two parallel processes occurring, one in the RH and the other in the LH, for the case of face processing, the latter process being completed in a time onto which T, the interhemispheric transmission time must be added. The model predicts that the faster of these two processes will dictate the reaction time, which in much of the face literature is the one for the LVF / RH and for verbal material is the one for the RVF / LH.

2.5.1 - Hemispheric Asymmetry of Face Processing

This section combines ideas from both of the first two chapters so far to cover the hemispheric asymmetry of face processing in normals.

2.5.1.1 - Experimental Evidence

The general paradigm for experiments investigating hemispheric differences in data processing is to present a tachistoscopic (brief duration) stimulus, such as a photograph or drawing of a face or another object, to only one visual field by controlling fixation, and hence presenting it to only one hemisphere (the contralateral one to the visual field). The task may require that a judgement is made on that one stimulus, or it may be a discrimination judgement between that stimulus and a prior, simultaneous or subsequent centrally presented stimulus. The reaction times (RT) to make this judgement and the errors made are recorded and compared for the two hemispheres. If the

RTs are significantly shorter for stimuli presented to one hemisphere than for those presented to the other hemisphere, then it is inferred that the faster hemisphere is processing the data more efficiently than the slower, and it can be said to be specialised for that task. In general, most tachistoscopic split visual field studies on normals have shown that there is a LVF and therefore a RH advantage for face recognition and matching which is absent for the processing of other objects (Bertelson et al 1979, Bruyer et al 1987, Burton and Levy 1991, Christen et al 1985, Hillger and Koenig 1991, Landis et al 1979, Levy et al 1972, Marzi et al 1985, Tanaka and Farah 1993), although there is a small literature which shows a right visual field and therefore a left hemisphere (LH) advantage for naming faces (Marzi and Berlucchi 1977). It is possible that this could be due to the necessary LH involvement in giving a verbal response. Studies on commissurotomised (split-brain) patients show that face recognition is faster in the LVF than in the RVF, but that both hemispheres can recognise faces. This suggests that the RH is specialised for face recognition but that the LH is not unable to do so (Damasio and Damasio 1986).

Bruyer et al (1987) hypothesised that the processes underlying stimulus matching or recognition differ from those underlying face matching or recognition. The former tasks require the matching of two identical stimuli and can in theory rely on a single stimulus recognition by a template-matching process. In the latter tasks, however, the second stimulus differs from the first in some way, and the subject has to elaborate the inner representation of the face by extracting some invariant physiognomic characteristics to decide, for instance, whether the two different views belong to the same face or not. To test this, Bruyer and his colleagues instructed subjects to judge whether two briefly presented faces (one central and one lateral), which were either full face or profile, belonged to the same person or not. He hypothesised that matching a different view would increase the laterality of processing towards the RH. This was the result found - there was a LVF superiority for face recognition but only when the stimuli differed across views, not when they were identical. Only error rates were measured, not RTs. This has not been repeated comparing

matching different views of faces and different views of other objects, but if a RH advantage is not found for other objects, this would be strong evidence for a RH superiority. Bertelson and his colleagues (1979) also reported a LVF advantage for matching faces of different orientations (full face versus three-quarter profile) but not when matching two faces both in profile. As already mentioned in Section 1.3.1.5, for this reason, all the face matching experiments using real faces contained in this thesis (not the Mac-a-Mug experiments in Chapter 5) were always across view, so that it was true face matching and not stimulus matching which was being tested.

Burton and Levy (1991) carried out two experiments. The first involved a tachistoscopic study in which a central full-frontal face was matched to a subsequent profile presented to one visual field. It thus required true face matching. When the subjects were split into two groups by their average RTs on a median split, only the fast group showed a RH (LVF) advantage. This group also showed a significant interaction of visual field and profile direction such that medially looking faces (a right looking profile in the LVF and vice versa) were faster than outward looking profiles. The slow group may have shown a different processing strategy and it is possible that a configurational representation of faces is only realised when the level of arousal is high enough. The second experiment they carried out concerned hemispheric asymmetry in processing facial emotion. They showed subjects in a free vision task pairs of chimeras which were mirror images of one another and had a neutral expression on one side and a smile on the other. The subjects were asked to choose the happier face, and the faster group (only) chose the chimeras with the smiling half on the left (going into their RH preferentially) significantly more of the time, suggesting a RH superiority in processing facial emotion. Again, the fact that only the faster group showed this pattern suggests that facial expression processing is a mainly configurational process and may require a fairly high level of arousal.

Christen et al (1985) carried out a tachistoscopic face-matching experiment on 6 patients with RBD, 3 of whom had prosopagnosia and 3 of whom did not. It was found that at unlimited stimulus duration the prosopagnosics performed better, but at progressively shorter durations the non-prosopagnosics performed better. This was explained in terms of LH compensation by the prosopagnosics - feature-by-feature matching - which required a long time. It is thought that prosopagnosics may use verbalisable (LH) features such as glasses and beards as aids in remembering faces but that such strategies require time. The non-prosopagnosics were better than the prosopagnosics at matching facial expressions at unlimited duration - the prosopagnosics had problems with processing affective information. The non-prosopagnosic deficits were likely to be of a more general apperceptive nature. One question this does raise is that if face processing is bilateral, how did Christen have three unilateral prosopagnosics and how can LH compensation occur with LH damage? The answer to the second point is that the LH damage is not always ventromedial occipito-temporal, and as has already been discussed in Section **1.2.3**, there is some evidence that unilateral RH damage may be sufficient to cause prosopagnosia.

Hillger and Koenig (1991) carried out a face-matching experiment, using a central target and a lateral probe. All stimuli consisted of a pair of eyes and eyebrows, a nose and a mouth, but no external features. There were four tasks. The first was to judge whether the probe and target were the same or different when they were either identical or differed in all features. In this case a RH superiority was obtained (faster RTs). In the second task the different stimuli now differed on only one feature. Now a RH advantage was obtained for those trials where the faces were the same and a LH advantage for trials where they were different. This was explained by saying that as the faces could only differ in one feature, the stimuli had to be processed feature-by-feature rather than holistically. Such a method would favour the LH. However, the fact that a RH advantage was found for the 'Same' trials disagrees with Bruyer's hypothesis (Bruyer et al 1987) that stimulus matching (which is what happens here) is not carried out more efficiently by the RH. The third

task was the same as the second except that all the stimuli were inverted (i.e. turned upside down). In this case the RTs were longer and the error rate higher, and performance mediated by the LH was marginally although not significantly faster than that mediated by the RH for both the 'Same' and 'Different' trials. The effect of inversion on face processing will be dealt with later, in Section **2.5.1.3**. The fourth task investigated the role of the LH. The stimuli were now either 'Same' which meant that they had one identical feature in common, or 'Different' which meant that they shared no common features. To do this task a feature-by-feature matching strategy was necessary which would be expected to be done by the LH. The 'Same' trials and overall all the trials showed a LH advantage.

Thus they showed that face processing has a RH advantage when the matching is normal, but when a piecemeal feature-by-feature matching strategy is forced, this changes to no advantage or even a LH advantage. This implies that normal face processing employs a global strategy based possibly on the configurational arrangement of the features. It could be argued that as faces differ only in minute ways, a more feature-by-feature strategy would be expected in normal face recognition, but one response to this is to say that it could be the minute differences in the configurational relationship of the features that are noticed, rather than the minute differences in the features themselves.

Landis et al (1979) wanted to test the idea that the RH is specialised for apperceptive judgements, i.e. of shape, whereas the LH is specialised for associative judgements, i.e. of concept. They investigated this by asking subjects to match two simultaneously presented stimuli (one in the centre and one laterally) which were either both objects or both faces. The subjects were asked to say whether a frontal stylised drawing and a photograph profile had the same 'meaning' i.e. the same use (e.g. a corkscrew) or the same expression (e.g. happy). A manual response was required only for a 'Same' response. For matching facial expression a LVF (RH) advantage was found, but

not for matching sex of the face, or orientation of the face. For matching objects, a RVF (LH) advantage was found. This suggested that associative processing is stimulus dependent, and that when it is emotional expressions that are to be matched, the RH is superior.

Levy et al (1972) carried out an experiment investigating commissurotomy patients. The patients were shown chimeras (composite pictures made of halves of 8 possible faces) and then asked to match what they had seen with the 8 original faces. They consistently chose the face whose chimeric half they had seen in their LVF (RH), suggesting again an advantage for face recognition in the RH.

Marzi and his colleagues (1985) used one set of face stimuli for three tasks. The faces had all non-facial cues removed except for hair. The subjects were asked to decide the sex of the face, whether the face belonged to a famous person or not and if so to identify the famous person. Only the famous / non-famous decision resulted in a RH superiority for 13 of the 30 subjects - neither of the other two tasks showed any hemispheric superiority.

2.5.1.2 - The Holistic Nature of Face Processing

One indication of the holistic nature of face processing is illustrated in the face superiority effect. This refers to the fact that facial features are recognised in the context of a face disproportionately more efficiently than when alone, in comparison to recognition of parts of non-face objects. For instance Tanaka and Farah (1993) showed that features from upright faces were identified in the faces disproportionately more easily than when presented singly in comparison with features from inverted or scrambled faces. De Gelder (1993) has also shown a face superiority effect in adults and children, although this effect is not shown in autistic children, who generally show a LH advantage for most tasks. There is, however, a difficulty with this, which is that a similar effect can be shown for words, called the word superiority effect. This refers to the fact that individual

letters are identified more readily in letter strings when the strings form words or pseudo-words (which sound as though they could be words, e.g. "mave") than when they do not. It is difficult to explain this in terms of holistic processing, especially as holistic processing is being argued as a RH strategy, but it is clear that word recognition most certainly shows a LH advantage. This suggests a possible problem with the use of the holistic / analytic framework for explaining cerebral asymmetry. Farah (1994) explains this:

> "The word superiority effect, by which letters embedded in words are perceived better than *letters* presented in nonwords or alone, might appear to imply that words are perceived holistically, without decomposition into letters. However, its implications are weaker than this. It implies only that, in addition to individual letter representations, word or letter-cluster representations are also activated, and that the activation states of the latter representations influence those of the former." (page 141)

In recognition of faces the features of importance depend on whether the face is already known. In familiar faces, the inner features are more important, but in unknown faces there is no difference between the importance of the external and internal features (Ellis et al 1979). This presumably explains why masking the eyes and mouth disguises identity well. In all cases the whole face is recognised more easily than when some of the features only are presented (Campbell and Walker 1993). There are several possible reasons why the inner features are more memorable in known faces. The inner features yield more information concerned with things other than the identity of the face, such as expression and lip-reading, and therefore in a face whose identity is already known, the inside of the face is scanned more than the outside. This leads to a greater depth of processing and memorability. Also, the external features are easier to disguise, with hairstyles, facial hair and hats, than the internal features which are relatively stable. Thus it is of ecological advantage to remember the internal features better. A face recognition task was carried out on children using known classmates and other unfamiliar children's faces. It was found that although children above the age of 9 years (as adults) showed an internal feature advantage for known faces, those under 7 years showed an external feature advantage, suggesting a different strategy in

infancy and early childhood, where the head shape may be coded as for other objects. Autistic children have yet another processing strategy, relying much more on LH featural and analytical analysis and they show no advantage even for whole face recognition over partial face recognition. They also lack the inversion effect, described below.

2.5.1.3 - The Inversion Effect

It is much harder to recognise upside down (inverted) faces than it is to recognise upright ones, and this difficulty appears to be disproportionately greater for faces than for other objects. This has been termed the inversion effect, already mentioned above several times, and it is another indication of the holistic nature of face processing. The area has been reviewed by Valentine (1988). One of the first experiments investigating this effect was carried out by Yin (1969). He carried out a memory task where his subjects viewed first an inspection set of visual stimuli and then a test set. The sets were either faces, houses, aeroplanes or men in motion, and the two sets were either both upright, both inverted, or one of each. Reaction times were not measured, but error rates were, and it was found that inverting the face caused a greater increase in the error rate than inverting the other objects. This might suggest that faces are processed to a high degree automatically, and that the penalty for automaticity is inflexibility. When the inversion effect was studied in each hemisphere separately, using a tachistoscopic study, it was found that inverting the faces removed the RH superiority, suggesting that natural face processing is holistic in nature and favoured by the RH, but the inversion of faces causes a loss of configurational information, making global processing much harder, and therefore the faces are processed in a more analytical way (Hillger and Koenig 1991). The inversion effect has also been reported for dogs in people with a high level of expertise about dogs (Diamond and Carey 1986). There is thus some dispute over whether the inversion effect lends strength to the view that faces are unique, or whether it occurs for any set of similar exemplars with which a person is very familiar and processes to a large extent automatically.

The inversion effect has also been demonstrated in Japanese monkeys (*Macaca fuscata*) by Tomonaga (1994) who, using a sensory reinforcement procedure, showed that the monkeys preferred looking at upright pictures of Rhesus monkey (*Macaca mulatta*) faces compared with inverted pictures of Rhesus monkey faces, and that this difference was greater for Rhesus monkey faces than for other stimuli, suggesting a disproportionately large inversion effect for faces. For some reason the inversion effect was larger for Rhesus monkey faces than for own-species faces. An inversion effect was however not found by Bruce (1982) who tested cynomolgus monkeys (*Macaca fascicularis*) on a range of discrimination and transfer tests. The different findings in these two experiments could be due either to the different species or to the different procedures used. Neither paper investigated any possible hemispheric differences such as those documented in humans, but Bruce does suggest, to explain his findings, that perhaps the RH mechanism we have for face processing is not as developed in the monkeys tested.

One interesting aspect of the inversion effect is its effect on the perception of eye gaze. As noted in Section **1.3.3**, normal subjects and some prosopagnosic subjects only show a decrease in performance with face inversion for angular deviation of less than about 5 to 10°. This suggests that the perception of eye gaze, as it is relatively unaffected by inversion, is probably not a holistic but more a local process. This is unsurprising, as it is only the eyes which are the cue to gaze direction. It would be interesting to investigate hemispheric differences in the perception of eye gaze to see whether there is no RH advantage, as would be expected if the task were indeed local.

In conclusion, the superiority and inversion effects, together with the tachistoscopic experimental data above, suggest that face processing occurs in a mainly automatic and holistic way, and is favoured by the RH.

CHAPTER 3 - EXPERIMENTAL SET-UPS AND EXPERIMENTAL SUBJECTS

3.1 - Overview

This chapter contains a brief overview of the equipment and programs which were used for all the experiments described in this thesis, together with a review of the statistical procedures used. Detailed methodology is described in more detail in the experimental chapters in the thesis. In the final sections of this chapter the prosopagnosic subjects and special subjects used are discussed.

3.2 - Programming and Image Manipulation

3.2.1 Turbo Pascal Programming

All the experiments bar the two using actual photographs (experiments **7.1** and **8.2**) were run on a PC computer using the programming language Turbo Pascal. Programs were written both to control the tasks and collect the data, and also to analyse the data collected to a certain extent.

3.2.2 Facial Image Manipulation

Many of the tasks in the thesis involved looking at faces presented on a computer screen and making some decision about them. This necessitated showing facial images on the screen controlled by the Turbo Pascal programs. There were a number of different types of facial image and different sources, and this meant that there were in the end a variety of ways of manipulating them to fit in with the programming procedures. These are described in the relevant chapters.

3.3 - Reaction Time Measurement

The majority of the experiments recorded the time taken to make a response to a visually presented stimulus. This necessitated an accurate way of measuring reaction times. As different computers were used for different experiments, and the running speed of all computers varies slightly, it was

decided that the internal computer clock would not be accurate or reliable enough to record the reaction times to millisecond accuracy.

Therefore a 'timer board' was used. This was designed by and built in the electronics department. It consisted of an 8 bit board which fitted into the computer and had a connector at the back to which could be attached either a pair of response buttons or a microphone (see below). It was accessed by a Turbo Pascal unit and a number of Turbo Pascal procedures. These procedures included loading the clock into the program memory, setting the clock to zero and reading a value from it at certain points in the program. The timer board also made it possible to set delays and inter-trial intervals of known and pre-set lengths which were independent of the computer's running speed.

Another difficulty in many reaction time measurement experiments is the additional time taken by the computer to draw the stimuli or carry out other processing which impedes its ability to monitor for a response continually. The experiments in this thesis solved these problems in a number of ways. Firstly, in the early experiments (in Chapter 5 and Appendix E) the stimuli were all drawn in black on a black background, and the palette of colours was changed when the timer was started. This change in palette is much faster than the time taken to draw the stimulus, and for these purposes was assumed to be instantaneous. Of course, if it does take time, the amount of time taken can be assumed to be constant from trial to trial and subject to subject and thus any additional time will be constant. For later experiments which displayed .IMG or .PCX graphics images, TurboPascal procedures were used which accessed the VGA procedures directly, firstly by blanking the VGA screen and then drawing the stimulus without its appearing, and then by making the stimulus appear by un-blanking the screen when the raster was always in the same place on the screen, so that there was never any variation in the (nearly zero) time taken to display the stimulus.

As far as the monitoring of the response was concerned, all the programs were written such that when a response was expected there was no other procedure occurring, such as stimulus display or further calculation. Thus the monitoring process was continuous and millisecond accuracy for reaction times was possible.

Thus the TurboPascal procedures used allowed the accurate recording of reaction times for all the experiments in this thesis where reaction times were measured.

3.4 - Turbo Pascal Procedures: Reaction Time Measurement and Tachistoscopic Stimuli

The majority of the Turbo Pascal programs were of one of two types, and all programs in any one type had similar structures. This meant that instead of writing new programs from scratch it was much easier to write procedures which could be varied slightly and used in each program. The two types of program used, experimental and data analysis, are briefly described below.

One important aspect of the programs and experiments carried out in this thesis concerns the nature of the stimuli. In many of the experiments, lateralised stimuli were presented to the subjects so that an investigation into hemispheric asymmetry for processing the stimuli could be carried out. In order to test hemispheric asymmetry using tachistoscopic visual stimuli it is necessary to restrict the stimulus to only one visual hemifield. To achieve this, the subjects were asked to maintain central fixation during the experiments and there was usually a fixation cross or point present in the centre of the screen on which they could focus. In addition to this, the brevity of presentation of any lateralised stimuli made foveation very difficult. Eye position of the subjects during the course of the experiment was not monitored using a camera, but the instructions together with the brevity of presentation were thought to be enough to impede foveation. In most cases the stimuli were presented for under 200 ms, occasionally slightly more. This would have been long enough for the subjects to fixate the lateralised stimuli using express saccades, but the likelihood of these

was kept low by the experimental procedures used. Express saccades are favoured if the subject knows where the target will occur and also if the fixation cross disappears before the target comes on - i.e. no temporal overlap (e.g. Cavegn and d'Ydewalle 1996). In my experiments, however, the fixation cross did not disappear until after the lateralised stimulus was presented, and also, in all cases, the subject had no prior knowledge as to the side on which the next stimulus would be displayed, as the order was randomised.

The majority of the experiments were 2-alternative forced choice (2AFC) tasks in which the subject had to decide which of two possible responses applied to the stimuli shown in any one trial and then give the appropriate response. These programs were written to run the actual experimental tasks, displaying the stimuli on the computer screen, detecting the responses, measuring the reaction times and saving the raw data to files on the disc. The exact nature of the image presentation and also the data saved to file varied between programs. Different programs saved some or all of the following:

- trial type (e.g. same / different : noun / verb)
- visual field (left / right)
- inter-stimulus interval (ISI) for experiment **4.1**
- delay for experiments **5.5** and **5.6**
- response button or key pressed
- whether the subject's response was correct or incorrect

This information was of use to the statistical procedures in the data analysis programs, which gave a primary analysis of the raw reaction time and error data for each subject so that tables or graphs could be produced and more advanced statistical tests be carried out. Usually they calculated the number of errors and mean and median reaction times for correct trials, both for all correct trials

and also by trial type and visual field. Some programs detected any outliers (method described below in Section **3.5**) and removed them, then carrying out a second analysis in the same way as the first on all correct trials which were not outliers.

3.5 - Statistical Procedures Used

The majority of the experiments involved measuring reaction times and error rates for responding to visually presented stimuli, whether by manual or verbal response, so most of the statistics involved manipulating and analysing reaction times and numbers of errors. In all cases only reaction times for correct trials were used. The main reason for this was that the reaction times for incorrect trials would be likely to have a much larger variance due to the range of possible reasons for responding incorrectly to a trial. Examples include blinking during stimulus presentation with the subsequent need to guess the response, or a momentary lapse of concentration, causing a greatly increased reaction time. It was thought that if only the correct trials were used in reaction time determination this would not be a problem. The only time when this might not have been a good idea was in cases where prosopagnosic subjects made a high proportion of errors so that there were in fact very few correct trials to base the reaction times on - these cases are highlighted in the text of the relevant chapters. A further reason for using only the correct trials in measuring reaction times is that this method is used to a considerable extent in the relevant literature.

There are a number of ways of analysing reaction times, and during the course of the thesis several methods were used, partly as a way of comparing them, until a most efficient method could be settled upon. For this reason the statistical procedures are not precisely the same in each of the chapters - sometimes a second method will be used in addition to the first.

Before describing the procedures used it is worth mentioning a little about reaction times. Reaction times (RTs) are an exceptionally important performance measurement in cognitive

psychology, as they give an index of cognitive performance efficiency (along with error rates) which introspection is not able to elucidate. Therefore a great proportion of the current literature measures reaction times and analyses them using some method to determine levels of significance. An important aspect of reaction times is their distribution. In general reaction times are not normally distributed, but tend rather to have quite a large positive skew. This is because there may be some trials which take much longer than the average (I will enlarge on the use of this word in the following paragraphs) due to a momentary lack of concentration or loss of attention on the part of the subject, or the need for a double press of the response key or button because the first time it was not pressed hard enough to register. However, there will be no trials shorter than 0 ms, so the mean tends to be artificially raised. Loss of concentration on only one trial can give rise to a reaction time of several seconds, and this is capable of altering the average RT quite a significant amount. Therefore I had to decide which particular measure of the average to use.

The first possibility was to use the mean RT. However, this is the one which is most affected by the positive skew, and therefore even though everyone's mean reaction times will be higher than expected, they may not be affected by the same amount in different subject's cases, leading to atypical data where any significant effects present could be hidden by the effects of the positive skew. For this reason, and the fact that raw mean RT data are not generally used in current research, it was decided not to use raw mean RTs in this thesis.

Therefore one method that was tried (and programmed into some of the TurboPascal procedures) was the removal of outliers followed by a calculation of the new mean RT which was then used for further analysis. The method used to calculate the outliers is outlined in Howell (1992) but will be explained here.

The reaction times are sorted into order and the median (middle value) and upper and lower 'hinges' are calculated - these are the medians of each half and are closely related to the first and third quartiles. From these the H-spread (or interquartile range) is calculated. Then upper and lower 'fences' are worked out which fall 1.5 times the H-spread above the upper hinge and 1.5 times the H-spread below the lower hinge respectively. Any values which fall outside these two fences are termed outliers and are removed by the TurboPascal programs. The new mean values are then used.

A third possible method was to transform the reaction time data prior to analysis in order to make their distribution more normal by using a log transform. This is a more complicated method from the point of statistical manipulation and was not used in the end.

After scanning the relevant literature for the methods used the one finally selected was to use the median reaction time instead of the mean, which removed the problem of outliers. The median is lower than the mean (a sign of the positive skew) and it is assumed that the median reaction times are reasonably normally distributed over a population of subjects. Note that for this method the outliers were not first removed because it is not necessary to do so.

Each of the experiments measuring reaction time had a design that contained a number of factors, usually two, which were often the visual field in which the tachistoscopic visual stimulus was presented and the trial type (this differed between experiments and will be explained in each experimental write-up). When looking at the control data, what was of interest was the difference in error rates and reaction times as a function of these factors. For this reason what was normally done was to use a within-subjects repeated measures design MANOVA (multivariate analysis of variance) carried out on a PC computer using SPSS for Windows. The design usually contained 2

within-subjects factors (visual field comprising 2 levels and trial type comprising usually 2 or 3 levels). A sample SPSS syntax file for a repeated measures design MANOVA is shown:

```
manova lvf_d lvf_se lvf_si rvf_d rvf_se rvf_si
/wsfactors = field(2) trial_type(3)
/wsdesign.
```

where the six items after the word 'manova' are each combination of the visual field and trial type. This particular design (taken from Chapter 7) uses two levels of visual field (left and right) and three levels of trial type (different, same expression, same identity). The reader is referred to experiments **7.2** and **7.3** for more details. This allowed me to analyse the control data for main effects of field and trial type and also interactions between the two.

The error data were at first analysed in a similar way using MANOVAs to investigate main effects and interactions. The error data could either be left as raw numbers of errors (this worked as long as each of the different combinations of trial type and visual field contained the same number of trials) or converted to percentage errors, which for instance was necessary in the expression matching experiments outlined in Chapter 7. However, whichever measure is used there is also the question as to whether the number of errors made is a normally distributed variable. A reaction time measurement has in theory a minimum (0 ms) but no theoretical maximum, allowing a large positive skew. The number of errors, on the other hand, has both a theoretical minimum (no errors or 0%) and a theoretical maximum (all trials are responded to incorrectly or 100%). If the task difficulty is set appropriately then the error data ought to be normally distributed. However, if the task is too easy there will be a 'ceiling effect' and the number of errors will be positively skewed; if the task is too hard there will be a 'floor effect' and the number of errors will be negatively skewed. One possible way of coping with this problem is to treat the data non-parametrically,

using a χ_2 test: this was not however used in the thesis. Non-parametric tests are not as powerful as parametric ones, possibly missing effects that are detectable with parametric tests. Also, in some experiments, for instance **7.2** and **7.3**, there were different number of trials in each of the cells, making a χ_2 test unusable. A further reason is that many of the papers in the literature treat their error data parametrically, and use ANOVAs for the error data analysis. A second method is to transform the data first before using ANOVAs, either by a square root transform, an arcsin transform or a log transform. Even so, some literature treats the errors as normally distributed, analysing them parametrically without first transforming them.

What was done in the end was to analyse some error data both with and without transforms and look at the effect on the ANOVA significances. This was done for the analyses in Chapter 7, and their results are shown in Appendix D.1. In a thesis such as this, consistency of method is an important aspect (although it alters during the course of the research due to new information and methods being learnt) and therefore I wanted to use a transform on all or no occasions for the error data. Of course, each set of error data for the different experiments show different distributions, and therefore different transforms could be used for each set of data to normalise them; this is not sensible and therefore a compromise was made. In the end it was decided not to use the log transform, as there was little difference in the results in Chapter 7 whether the transform was used or not, so it was assumed for the purposes of the thesis that the error data was sufficiently normally distributed for ANOVAs to be carried out without prior transformation. Note that a log transform is problematic where there are any data values of zero. The logarithm of 0 is not an acceptable number, and therefore any analyses done in this way would be subject to missing values. Given the relatively small number of data points I had, it was not thought a good idea to remove any of them. Therefore what was decided was to carry out a log transform on the percentage of errors plus 1, thus ln(error percent + 1). This had the effect of marginally increasing the number or proportion of errors made by the control subjects as well as making the error data more normally

distributed. This could have had a marginal effect on the F values from the ANOVAs. When this was done, the raw data were also analysed to be compared with the log transformed (and altered) data.

In Experiment 9.2 the error data for reading words in the two visual fields were investigated as a function of various aspects of the words: frequency, familiarity and graphemic uniqueness. As these variables had many different values (not just 2 or 3), ANCOVAs were used (analysis of covariance), again using SPSS for Windows.

The other aspect of the thesis was the comparison of either neurological patients or single case studies with reversed cerebral asymmetry (see later in this chapter) with the control data. As the prosopagnosic subjects and subjects with reversed asymmetry were treated as single case studies, ANOVAs were therefore not possible. Instead their results were compared with the control sample means using t-tests:

$$t = \left| \frac{value - \mu}{\sigma} \right|$$

where *value* is the number of errors or reaction time that the prosopagnosic subject or subject with reversed asymmetry had obtained, μ the mean value for the control subjects and σ the standard deviation of that mean. When reaction times were being compared, μ was the mean of the control subjects' median reaction times.

As multiple cases (either 2 subjects with reversed cerebral asymmetry, 3 prosopagnosic subjects, or all 5) were compared with the control data, it was decided to use Dunnett's modified two-tailed t-test, which controls the familywise error rate for repeated comparisons. For this t_d was used instead of t. Any result was deemed significantly different from that of the controls if the t_d value calculated was greater than the value given in the table of t_d values in the appendices in

Howell (1992). For each case where a result was significant the level of that significance was given. When Dunnett's t-statistic is used, the k value (number of means, including control) is quoted. Separate t-tests were used for reaction times and errors.

3.6 - Prosopagnosic Subject Case Studies

Three prosopagnosic subjects were tested on a variety of tasks concerned with face processing. They have all been written about extensively in the past but an overview of the three of them will be given here. The experiments they participated in were **4.1**, **6.1**, **7.1**, **7.2**, **7.3**, **8.1** and **8.2**.

3.6.1 - Prosopagnosic Subject SS

Note: at the request of this prosopagnosic subject I have used fictitious initials and have not referred to some of the previous publications about the subject's other cognitive performance on the grounds that they are potentially misleading. The gender of this subject is also not being revealed in this thesis.

SS is a right-handed 33-year old who has developmental prosopagnosia. **SS** has normal colour perception (Campbell et al 1990) and a higher WAIS verbal IQ (140) than performance IQ (102). Anecdotally **SS** has never been able to recognise faces except for the most familiar ones, and clothing, voice and mannerisms are of great importance in aiding person recognition. **SS's** face processing abilities were tested thoroughly by de Haan and Campbell (1991).

On judgements of face familiarity, similar to lexical decision tasks, **SS** performed at chance for both famous faces and faces of people personally familiar but normal on recognising famous names. **SS** was also at chance on an unfamiliar face matching task (the Warrington Recognition Memory Test) where a set of faces are first inspected and then half are shown with new faces: **SS** could not tell if the faces had previously been seen (28/50). When words were used in a similar

memory test, **SS** was perfect (50/50). **SS's** semantic knowledge of both famous people and work colleagues was normal, suggesting there is a deficit at the level of Bruce and Young's face recognition units (FRUs) (1986). Further testing showed no evidence of covert face recognition using a picture-name familiarity priming procedure.

SS is able to do some face tasks normally, albeit slowly - specifically Benton and van Allen's face matching task (1973) which involves matching a black and white photograph of a face to one of an array of other photographs of faces taken under different view and lighting conditions, thus requiring the construction of a 'view-independent' representation. **SS's** performance on simultaneous matching is much more accurate than that of patients with acquired RH lesions, on the borderline of control performance, and reaction times were fairly normal (scoring 39/54). However, performance on immediate matching (two faces presented one after another with an ISI of 1 second) was poor both for identical views and different views, suggesting a possible memory problem. On a face decision task, in which the subject is asked whether the stimulus presented is a face or not, **SS** performed normally. On the Mooney face task, where the task is to decide the age and sex of human faces with the shadows rendered black and the highlights white, **SS** was poor but within the normal range of controls aged 65-75 (scoring 27/40). Gender judgements of photographs of real faces were impaired compared to normals (scoring 33/48).

The face decision task could be done by checking the individual features rather than the holistic configuration, and the Benton and van Allen task could have been achieved by looking for an invariant local feature, such as a mole: it is noteworthy that the abnormally long reaction times suggest a local feature-by-feature search. **SS's** problems with the Mooney faces may reflect problems in creating three dimensional representations, which may be less necessary in the face decision task, and indeed **SS** has more difficulty processing information from photographs than in real life situations.

SS's within-category discrimination abilities were again tested by de Haan and Campbell (1991). **SS** was still found to be impaired at spontaneous naming and forced-choice recognition for both flowers and motorcars. It is possible that this was due to a lack of experience with motorcars, but an ability to name only one type de Haan and Campbell suggest indicates a recognition deficit for that class even in someone not very familiar with car types. **SS** was reasonably accurate at object recognition and naming where there were no intra-category confusions.

Another important deficit **SS** shows is the inability to discriminate direction of eye gaze in photographs (Campbell et al 1990). **SS** was able to discriminate the odd one out of three sets of concentric circles, the inner circle of one pair being in a different orientation. However, this could not be translated to the three-dimensional representation of the face and eyes to determine eye gaze direction. The inability to perceive the direction of eye gaze in photographs might be explained by problems in establishing a spatial framework into which information about salient features might fit. In other words, there is a difficulty in holistic, configurational perception of faces, whereas two-dimensional local feature perception is unimpaired. Face perception and related tasks such as eye gaze perception are particularly demanding of configurational information extraction.

Personal contact with **SS** has demonstrated various methods for aiding recognition of people without having to resort to face recognition - **SS** engages one in conversation as soon as you both meet, so that your voice assists recognition. **SS** also makes use of clothing, mannerisms and external paraphernalia, such as glasses or a beard.

To summarise, then, **SS** has problems, probably especially in photographs, with face processing tasks, including most notably familiar and unfamiliar face recognition and eye gaze perception. However, **SS's** semantic knowledge about famous people and colleagues is intact. **SS** is able to

match the Benton and van Allen faces, probably on the basis of feature matching, seen as abnormally high reaction times, and also performs normally at face decision tasks. **SS's** object recognition skills are to an extent impaired, especially from unusual views and within-category discriminations.

SS is included in this thesis as a prosopagnosic subject with impaired facial identity recognition and matching, and also poor eye gaze direction perception.

3.6.2 - Prosopagnosic Subject PH

PH is a 33 year old male who was the victim of an motorcycle accident in August 1982 at the age of 19. He suffered multiple peripheral injuries and his right arm was traumatically amputated. He also suffered a severe closed head injury. Before the accident he had been right-handed. He was in a coma for at least 12 days and a CT scan from that time showed "some generalised cerebral oedema with no specific intracranial haematoma" (de Haan et al 1987a).

Just over three years after the accident medical examination revealed as his main problems: poor concentration and memory; pains in his right shoulder and leg; occasional headaches; and unusual feelings in the phantom right hand which had been lost.

His neurological problems included: poor long-term memory as tested by the Wechsler Memory Scale stories and drawing complex line drawings from memory; poor visuospatial processing, including impaired pathway learning on a visually guided maze (Ratcliffe and Newcombe 1973) and visualising the structure of a 3-D block-building from line drawings; and severe visual recognition problems, mainly for faces and other categories of ambiguous figures. His short term memory was normal for both verbal and non-verbal items, with a digit span of 6. He was able to decide whether a line drawing was a face or not but was impaired on the Mooney test, where the

task is to decide the age and sex of human faces with the shadows rendered black and the highlights white (21/40).

He was profoundly prosopagnosic, being unable overtly to recognise any familiar faces (except Margaret Thatcher and then only on one occasion) out of the hundreds shown him during testing. He could not classify faces as famous or non-famous (18/36 correct) but was however able to classify people as famous or non-famous from their written names accurately (29/32 correct). He was equally unable to name motor cars (3/33) or flowers (0/26) and showed some object agnosia (20/36 on the Oldfield-Wingfield object naming test) while this performance improved considerably when the objects were verbally described. This suggests a generalised agnosia, both for faces and other objects, especially multi-exemplar categories, and argues against a straightforward memory problem. On the basis of anecdotal evidence (untested) **PH** uses voices as a main cue to recognition. His ability to recognise people from their names but not their faces suggests a similar impairment to **SS's** at the level of Bruce and Young's FRUs (1986).

Another important finding was that **PH** shows covert recognition of familiar faces. De Haan and colleagues (de Haan et al 1987a, 1987b, 1991b) carried out several tasks investigating covert face recognition using face matching, interference and learning tasks for true or false face name pairs, and were able to show that **PH** matched familiar faces faster than unfamiliar faces, was distracted by false face-name pairs in a name categorisation task, and was better at learning true pairings of faces and occupations or names and occupations than false pairings. All of this is conclusive evidence for **PH**'s covert processing of faces. It is also pointed out that this covert recognition occurred for faces of people whom **PH** had only met after the accident, showing that face learning is still intact. However, de Haan et al (1991b) also showed some covert recognition of cars and flowers, on which he was extremely impaired at overt recognition, as well as faces.

Matching of identical views of unfamiliar faces was slow but accurate. Where there was a change in view between the two faces to be matched, the level of his performance dropped, but he was still able to do the task to an extent. Similarly, matching and identifying facial expressions were impaired compared to normals but **PH** was able to do such tasks to a limited extent. It is important to note that his reaction times are slow even on tasks on which he is accurate, and de Haan and colleagues suggest this "reflects a general impairment due to closed head injury and is not specific to tasks involving faces" (de Haan et al 1987a). Thus it is worth emphasising the importance of error data when testing him on tasks in this thesis.

Contrasted with these impairments, his language functions were largely intact (WAIS verbal IQ of 91) as was his short-term memory for both verbal (digit span = 6) and non-verbal tasks. He also had normal colour vision and good acuity with his right eye, although vision in his left eye was quite severely impaired (Snellen of 3/60): whether this is as a result of the accident or an untreated squint at the age of 8 months is unclear. His WAIS performance IQ was substantially lower (61) but the timed constructional tasks were harder for him due to his peripheral motor problems.

Thus for the purposes of this thesis he is tested as a prosopagnosic subject who is impaired compared to normals at matching both unfamiliar faces across views and matching facial expressions.

Because of the amputation of his right arm it should be noted that the experimental procedure was changed slightly for him as experiments **6.1**, **7.2**, **7.3** and **8.1** required a bimanual response. In his case the two response buttons were securely fixed to the desk in front of him and to the left of centre so that he could use different fingers of his left hand for the two different answers. This was not ideal and potentially led to longer reaction times overall. For experiment **4.1** he was just asked to press one button each time a stimulus appeared rather than both.

3.6.3 - Prosopagnosic Subject NR

NR is a 39-year old male who was the victim of a head-on motorcar collision in March 1982, at the age of 25. He suffered a severe closed head injury and also a number of other peripheral injuries, including broken ribs, multiple fractures to the left leg and hip, laceration of the face and a penetrating wound in the left eye. He was comatose for three weeks and when he was discharged two months after the accident he was described as disorientated. His peripheral injuries healed well but CT scans carried out in April and May 1982 showed a shallow extra-cerebral collection of blood and CSF over the **right** parietal lobe. A later scan the following year showed an infarct in the **left** parieto-temporal region of the brain.

He has been studied by de Haan and colleagues (de Haan et al 1992). His main neurological problems noted after the accident were severe memory problems, both anterograde and retrograde. Both his verbal and performance WAIS IQ's were low and his pre-morbid history suggested a reduction in IQ as a result of the accident. He had some difficulty with finding words and also reading comprehension although his oral comprehension was relatively intact. His verbal short-term memory was normal (digit span of 7) but he had slightly reduced non-verbal short-term memory and grossly impaired retention of prose, both immediate and delayed. His long-term spatial memory was very poor (½/36 on the Rey-Osterreith complex figure after a delay of 45 minutes).

He also had poor visuospatial perception (line orientation judgements and 3-D block building perception) and his visual perception of facial stimuli was very impaired. His performance on the Mooney faces was markedly worse than that of **PH**, scoring 9/40. Simultaneous, immediate and long-term matching of unfamiliar faces were all essentially at chance level, and facial expression matching was at the lower end of normal (14/18).

Identification of familiar faces was impossible whether by naming them or giving appropriate semantic information (0/40). He also performed at chance when he had to decide whether a presented face was familiar (19/32) but performed normally on a parallel test using names (30/32). Thus again he was likely to be impaired at the level of Bruce and Young's FRUs (1986), as are both of the other two prosopagnosic subjects.

He showed some visual object agnosia, scoring 13/36 on the Oldfield-Wingfield object naming test, performing worse than **PH**. He was also shown to have a category-specific impairment, naming 0/20 living items and 10/20 non-living items using the Snodgrass figures. He was also poor at discriminating between visually similar items in the same category, as shown with vegetables (4/20 correct) and flowers (0/26). Similarly to **SS** and **PH** there is a recognition deficit not just for faces but for other ambiguous multi-exemplar categories.

As with **PH**, **NR** was included in this thesis for his poor matching of faces and facial expressions.

Due to his lowered intellectual capacity and possibly frontal damage he finds it difficult to make decisions and also finds it harder to follow instructions than either of the other prosopagnosic subjects tested. Therefore the training periods were a little longer for him than for **SS** and **PH**.

3.7 - Subjects with Reversed Cerebral Asymmetry

Two subjects were used who were serendipitously discovered on the basis of PET scanning to have reversed cerebral asymmetry: specifically superior RH language processing. These subjects were not neurological patients and were normal in every way other than their cerebral dominance. They had participated in the PET studies as control subjects. They are included in the thesis as case

studies of subjects with reversed cerebral asymmetry on the basis of a linguistic PET studies. They were tested on a number of tasks, which were experiments **9.1** and **9.2**.

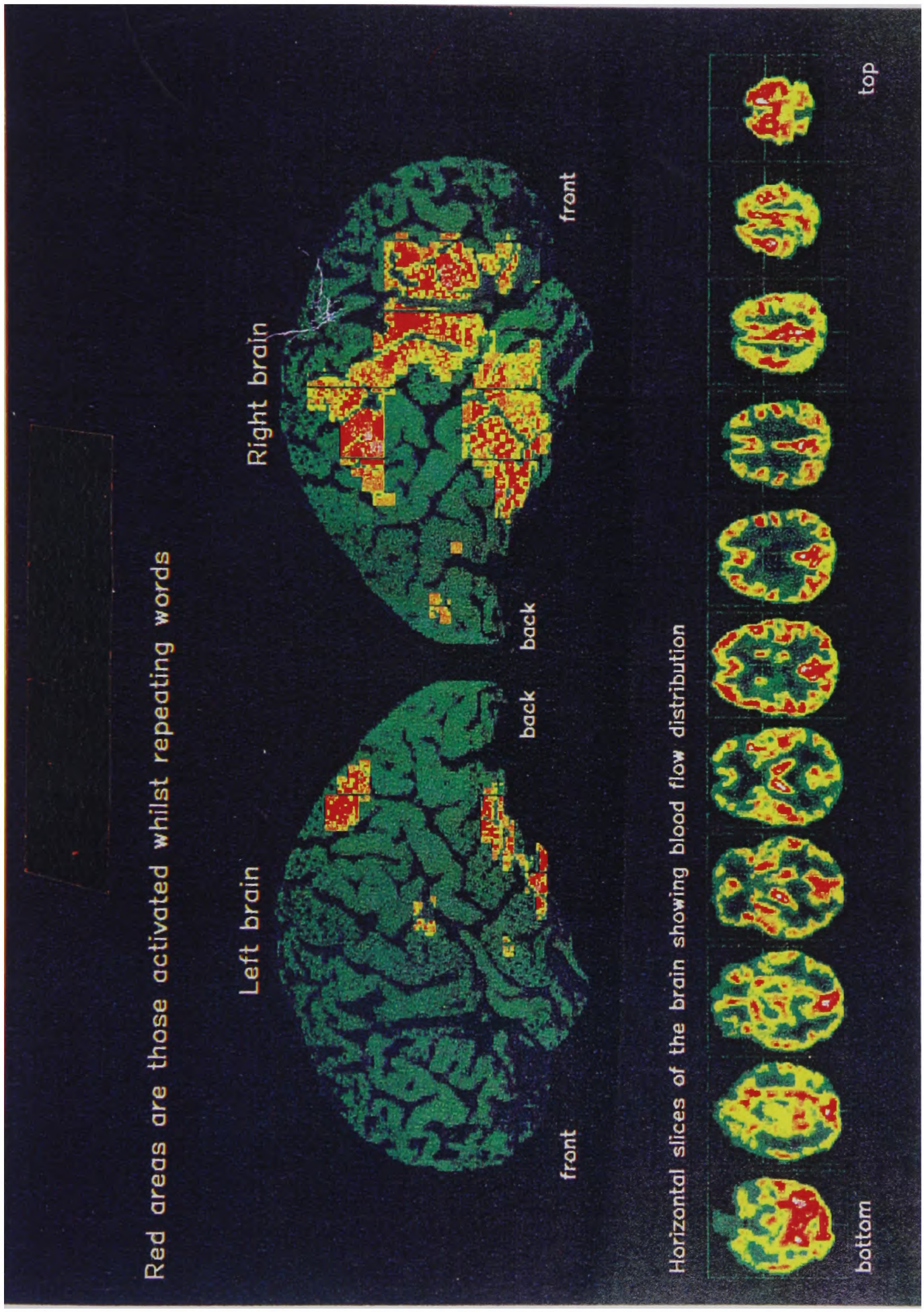
3.7.1 - Subject HJ

HJ is a 32-year old right-handed male. He has above average IQ and is a highly respected neurologist who had been a volunteer on a PET study concerning language processing (Paulesu et al 1993). The tasks that were run investigated the verbal component of working memory and involved firstly the subjects' monitoring for English letters, with Korean letters as the control, and secondly a rhyming task with English letters, with a visual similarity task for Korean letters as the control. **HJ** showed activity in the same areas as the other control subjects run, but unexpectedly in the right hemisphere rather than the left hemisphere. For this reason he was referred to me. Note that although right-handed he was forced to use his left hand for writing, etc. for 3-4 months at the age of 8 years due to breaking his right arm.

3.7.2 - Subject RL

RL is a 65-year old right-handed male. He is a qualified and highly experienced ballroom dance teacher and also a travel agent by profession. Like **HJ**, was a control subject on a language PET study, this one involving listening to auditorily presented words, compared to listening to reversed words (Experiment 3 in Price et al 1996), although his results were not in fact included in the paper which investigated the roles of Wernicke's and Broca's areas in such tasks. Although he now counts himself as right-handed he started out being left-handed but switched to using his right hand for writing whilst at school due to social pressure. He is now ambidextrous for writing and drawing, but opens boxes and uses scissors with his left hand and also is left-footed and left-eyed. Overall, then, he is probably left-handed to an extent, but not entirely. A copy of his PET scan can be seen in Figure 3.1.

Figure 3.1 - PET scan of RL repeating words



CHAPTER 4 - BASELINE REACTION TIME MEASUREMENTS

4.1 - Introduction

The majority of experiments in this thesis involve measuring reaction times during cognitive tasks. As has already been discussed in Chapter 3, reaction times are a good way of gauging the cognitive abilities of different subjects, and also of comparing the cognitive demands of different tasks. In order to be able to interpret the prosopagnosic subjects' reaction time data in the various face processing experiments it was decided to measure their baseline simple reaction times prior to the other experiments. This task and its results are presented in this chapter. It has already been noted in Chapter 3 that, for instance, prosopagnosic subject **PH** shows slow reaction times compared to normal subjects even on tasks on which he is accurate. Thus this task allows their baseline reaction times to be compared to those of the normal subjects so that a sensible interpretation of the results of the other experiments could be made.

4.2. - Method

4.2.1 - Materials

The same VDU and computer set-up were used as for all the other experiments. The responses were recorded using two response buttons, made by the electronics department and each consisting of a 35-mm film canister with a button on the end, which, when pressed, completed a circuit and sent a signal to the computer via the timer board mentioned above. Each response button gave a different numerical input to the computer, so that the program could determine which button or buttons (left, right or both) had been pressed. This was necessary as the two buttons were usually used to signify two different possible responses. However, in this case a simple response was required rather than a choice response, but the subject was still asked to press both buttons simultaneously in response to the stimulus, and the reaction time was taken as the time until the computer detected the pressing of the first button. Thus this measured the faster reaction time for

the two hands, assuming there was any difference, and is the method suggested by Bradshaw (1989, pg. 78). It should be noted that prosopagnosic subject **PH** responded by pressing only one button with his remaining left hand.

4.2.2 - Subjects

Eight normal subjects who had participated in one or more of the other experiments were tested. Their ages ranged from 19 to 49, with a mean of 31.1 years and a standard deviation of 9.2 years, and are thus comparable to the three prosopagnosic subjects, **SS**, **PH** and **NR**, who were also tested. Note that these control subjects were not used in all later experiments but are nevertheless considered to be representative of the population from whom all the control subjects in the thesis were taken.

4.2.3 - Procedure

The subject was seated centrally in front of the screen. In each trial a white circle (4 cm. in diameter) was presented in the centre of the screen and the subject was instructed to press both buttons (one in each hand) as quickly as possible. When one button was pressed the circle disappeared. The time until the next circle appeared, the interstimulus interval (ISI), was variable. Ten different ISIs were used: 0, 200, 400, 600, 800, 1000, 1200, 1400, 1600 and 1800 ms, and 24 trials were run for each ISI randomly ordered over 4 blocks each consisting of 60 trials. Note that in addition to the ISI there was an additional 35 ms time for drawing the stimulus. The subjects were instructed to respond as quickly as possible but not to anticipate - if they did so, a beep sounded to inform them to take more care. It was expected that the shorter the ISI, the longer the reaction time, due to a refractory period for the subject to ready his or herself for the next trial. Mean and median reaction times were calculated for all trials and also for all trials for ISIs of 800 ms or more. The value of 800 ms was chosen as from this ISI duration upwards there was no further decrease in reaction times, as can be seen from Graph **4.1** below.

4.3 - Results

Reaction times were measured and are shown in Table **4.1** for the controls and prosopagnosic subjects. Both mean and median reaction times are shown, firstly for all the trials put together, and then for all trials where the ISI was at least 800 ms, for the reason explained above.

Table 4.1 - Simple reaction times for Experiment 4.1

(in ms)	mean RT (all trials)	median RT (all trials)	mean RT (ISI ≥ 800 ms)	median RT (ISI ≥ 800 ms)
Controls (n=8)	257.0	226.6	223.3	213.3
S.D.	38.9	30.5	24.9	25.4
SS	313.7	286.5	275.7	266.0
PH	544.5**	516.0**	416.4**	353.0**
NR	314.3	285.5	287.9*	263.5

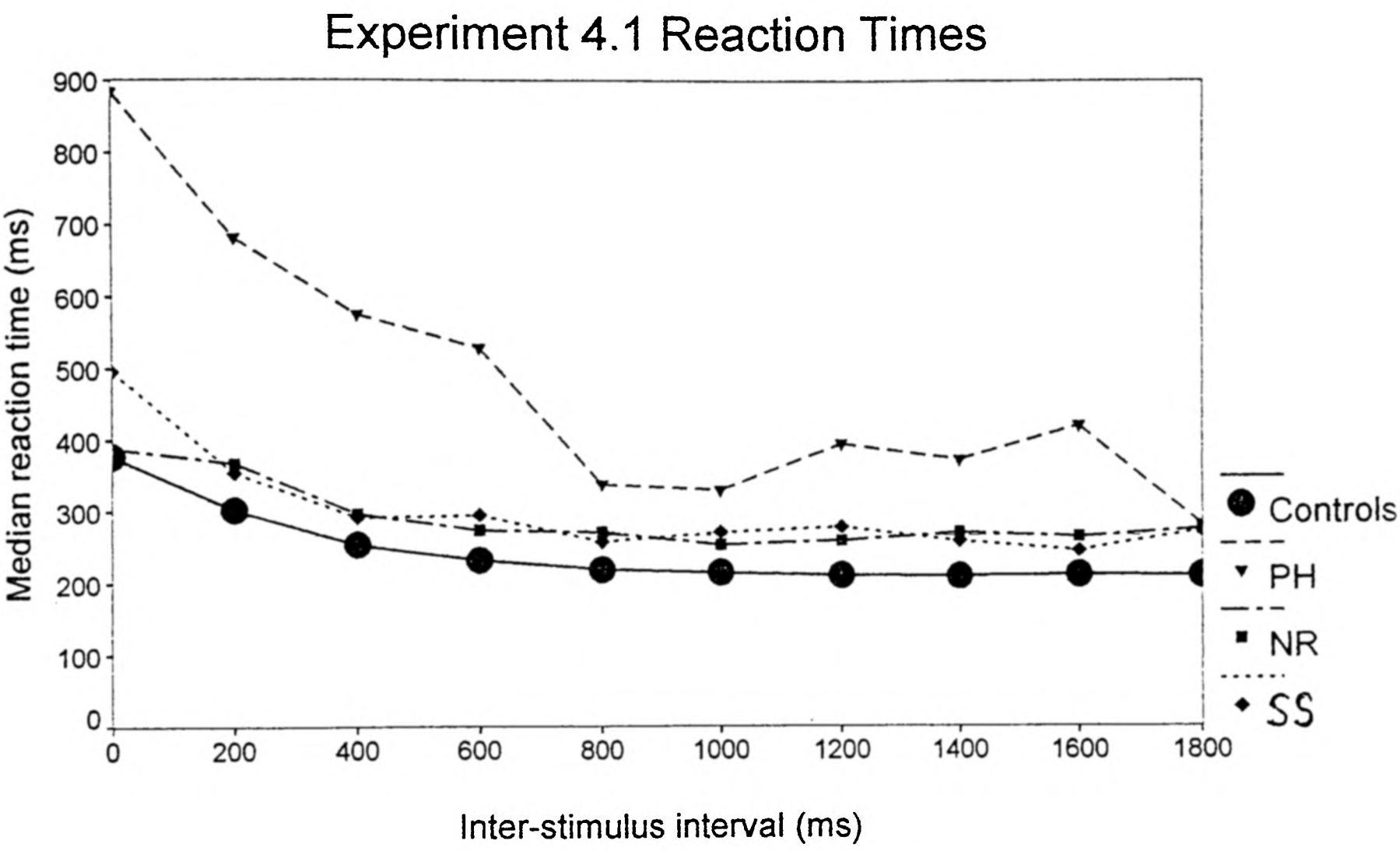
* Significant at the 5% level
** Significant at the 1% level

Several things can be seen from the table. Firstly, the difference between the figures in the two left hand columns from those in the two right hand columns shows that there are indeed longer RTs for those trials with shorter ISIs as the subject is not yet ready to make another response. This can also be seen from the greater difference between the mean and median RTs for the two left hand columns than for the two right hand ones: this reflects a greater positive skew towards longer RTs for trials with low ISIs.

Secondly the RT data for all three prosopagnosic subjects appears longer than for the control subjects, slightly in the cases of **SS** and **NR** but markedly so for **PH**. This reflects the findings of de Haan et al (1987) noted above. Statistical analysis of the RT data using two-tailed Dunnett's t tests with k = 4 (outlined in Chapter 3) shows that for all trials, only prosopagnosic subject **PH** shows significantly slower RTs for both mean reaction times (t_d = 7.38 - P < 0.01) and median reaction times (t_d = 9.48 - P < 0.01), whereas neither of the other two prosopagnosic subjects does so (**NR**: mean RT: t_d = 1.47 - n.s., median RT: t_d = 1.93 - n.s.; **SS**: mean RT: t_d = 1.46 - n.s.,

median RT: $t_d = 1.96$ - n.s.). However, when only those trials are included where the ISI is greater than or equal to 800 ms, so as to remove the effect of any refractory period, both **PH** and **NR** show significantly slower RTs on the basis of mean reaction times (**NR**: $t_d = 2.59$ - $P < 0.05$; **PH**: $t_d = 7.76$ - $P < 0.01$) than the control subjects. Also on the basis of mean reaction times, **SS** is certainly slower than the controls ($t_d = 2.10$ - n.s.), although **SS's** results just fail to reach significance on the basis of Dunnett's test (although it would have been significant on the basis of a normal t test). On the basis of the median reaction times, only **PH** is significantly slower than the controls ($t_d = 5.49$, $P < 0.01$) although both **NR** ($t_d = 1.97$) and **SS** ($t_d = 2.07$) are approaching significance (a t_d of 2.35 is significant at the 5% level for $k = 4$).

The median reaction time data for the individual inter-stimulus intervals for the controls and the prosopagnosic subjects are shown in Graph **4.1**. It is immediately obvious from this graph that reaction times decrease with increasing ISIs for all subjects, and also that **PH** is much slower than the controls, whereas **SS** and **NR** are consistently slower than controls, but not by enough to be significantly slower.



Graph 4.1 - Median reaction times for controls and prosopagnosic subjects on Experiment 4.1, the measurement of baseline reaction times

4.4 - Discussion

As expected, reaction times decreased for all subjects as the ISIs increased from 0 ms to almost 2 seconds. The raised reaction times for low ISIs are presumably due to the time the subject has to take in recovering from responding to the previous stimulus and preparing for the next one. As can be seen from Figure **4.1**, the reaction times flatten out at around 800 ms, which can therefore be taken as a measure of the refractory period below which the subject was not able to give 100% of his or her attention and cognitive processing to the task in hand. Above an ISI of 800 ms, there is little or no decrease in reaction times.

The purpose of the task was to investigate whether the prosopagnosic subjects had any increased level of simple reaction times due either to their cognitive impairments or the injuries that caused them (in the case of **PH** and **NR**). The results show that **PH** is indeed much slower than the control subjects, and this is not surprising, considering de Haan et al's (1987) finding that he had elevated reaction times on a number of tasks, which they suggest is due to a "general impairment due to closed head injury".

Both the other two prosopagnosic subjects, **SS** and **NR**, are on the whole slower than the controls, but only at levels approaching significance. **NR** is significantly slower than the controls for mean reaction times for those trials where the ISI was 800 ms or longer, but not for median reaction times. As Dunnett's t test, a more stringent test than the normal t test, was used to control for familywise error in repeated comparisons, some t values which would have been significant in a normal t test (such as **SS** having a $t = 2.10$ for mean RT for trials with an ISI of at least 800 ms) were not counted as significant. However, it cannot be disputed that **SS** is at the lower end of normal responding, as is **NR**.

The difference between the mean and median reaction times for the controls is higher when all the trials are included than when only those trials for an ISI of at least 800 ms are included in the calculation. This reflects the positive skew of the raw data, especially so because the shorter ISI trials lead to disproportionately increased reaction times due to the refractory period mentioned above.

When all the trials are included, the t values for the prosopagnosic subjects compared to the controls are higher for the median reaction times than they are for the mean reaction times. This reflects the decreased value of σ for the control median reaction time data. This is not the case when only those trials with an ISI of at least 800 ms are included. Here the values of σ for both the mean and median reaction times are similar. Again the median reaction times for all subjects for trials with an ISI of at least 800 ms are lower than their mean reaction times, as there are still longer reaction times causing a positive skew, as outlined in Chapter 3.

A comment should be made here about the difficulty in interpreting **PH**'s reaction time data throughout the thesis. He was the only subject who was found to have elevated simple reaction times, as shown by Experiment 4.1. This is not surprising, based on previous findings by de Haan and colleagues (de Haan et al 1987a) that his reaction times are slow even on tasks on which he is accurate, and as a result they suggest this "reflects a general impairment due to closed head injury and is not specific to tasks involving faces". Indeed, in all experiments in which he participated in this thesis, his reaction times were abnormally slow (see later chapters), whether or not he was as accurate as the control subjects. However, finding that his reaction times are elevated means that it is difficult to say whether elevated reaction times in face processing tasks are indicative of face processing deficits or due solely to the underlying increase in all reaction times. There are two possible ways of looking at this problem. The first is to say that **PH** was a certain amount slower and the second to say that he was a certain proportion slower. This raises the

question of whether mean or median reaction times should be used in this case (i.e. the data from Experiment 4.1) and also whether trials with an ISI of less than 800 ms should be included.

Table 4.2 - Simple reaction times for Experiment 4.1 showing how much slower PH is

(in ms)	mean RT (all trials)	median RT (all trials)	mean RT (ISI ≥ 800 ms)	median RT (ISI ≥ 800 ms)
Controls (n=8)	257.0	226.6	223.3	213.3
PH	544.5	516.0	416.4	353.0
amount slower	287.5	289.4	193.1	139.7
proportion slower	2.1	2.3	1.9	1.7

The above table, modified from Table 4.1, shows in ms how much slower than the control subjects **PH** is and the proportion slower he is (in other words, a value of 2 in the bottom row would mean he takes twice as long as the control subjects). Depending on which measure is taken he is between 140 and 290 ms slower than the controls, or takes between 1.7 and 2.3 times as long. As the other tasks in which he participated were choice reaction time tasks, none of which had an ISI of less than 800 ms, it is sensible to use figures from the right-hand side of the table. Also, in this case the mean reaction times were not calculated after the removal of outliers, in order to demonstrate the positive skew of reaction time data, whereas in all other experiments on which the prosopagnosic subjects participated, outliers were removed before the calculation of mean reaction times. Therefore, it is most sensible to use the furthest right column, and it can be assumed that **PH** was either 140 ms slower than the controls or took 1.7 times as long to respond. When both calculations are used to look at **PH**'s data in experiments 6.1 and 7.3, it is concluded that it is more sensible to treat **PH** as being an amount slower (e.g. 140 ms) than a proportion slower (1.7 times as slow). This is almost certainly an oversimplification, as the amount by which he is slower is likely to increase as tasks become harder, but by how much it is at present not possible to say.

In conclusion, then, when looking at the prosopagnosic subjects' data in the rest of the thesis, it should be borne in mind that **PH** is markedly slower at all cognitive tasks due to the closed head

injury he suffered, whereas **NR** and **SS** are at the slow end of the normal range. If **PH** is found to be significantly slower on any future task, then it is quite possible that he is not specifically impaired on that task, but his slow performance is explained as above, unless his slowness is even greater than indicated by measures of simple reaction time. If either of the other two prosopagnosic subjects are found to be significantly slower on future tasks than controls, it is harder to say for certain whether they are in fact disproportionately slower for that task, as they are right at the slow of end of normality. Therefore, for all three subjects, error data will be of great importance in determining the existence of any cognitive impairments.

CHAPTER 5 - AN INVESTIGATION OF HEMISPHERIC DIFFERENCES FOR MATCHING UPRIGHT FACES USING MAC-A-MUG PICTURES

5.1 - Introduction

There is much evidence to suggest that face processing has specialised mechanisms in the right hemisphere of neurologically normal adults. This evidence includes faster reaction times in tachistoscopic experiments when the stimulus for matching or recognition is presented to the left visual field (LVF) - i.e. the right hemisphere (RH) compared with when it is delivered to the right visual field (RVF) - i.e. the left hemisphere (LH). Also, although prosopagnosia (an inability to recognise faces and learn about new ones) is generally caused by bilateral occipitotemporal damage, and there is some contention whether bilateral damage is in fact necessary for prosopagnosia, RH damage seems to be more important and also to have a greater effect (De Renzi 1993, De Renzi et al 1994). Much of this evidence was detailed in the first two chapters of this thesis.

Some investigators have explored what it is about the mechanisms of face processing in the two hemispheres that might explain the RH superiority. For example, Tanaka and Farah (1993) and Hillger and Koenig (1991) have shown that face matching and recognition occur to a large degree holistically. In other words, the configurational properties of the arrangement of the facial features are used as opposed to the recognition of the individual features themselves. The RH has long been shown to process information more holistically than the LH, which is thought to act in a much more analytical, local and piecemeal way. Tachistoscopic studies have shown that faces presented to the LVF (RH) are matched faster than those presented to the RVF (LH) when the faces to be matched are upright and either identical or completely different; i.e. matching is global. However, when the face is inverted (Yin 1969) or only one feature differs (Hillger and Koenig 1991), a

piecemeal feature-by-feature analysis is necessary and either no hemispheric advantage or a LH advantage is found.

Some investigators have questioned exactly what configurational information is required, and have for instance removed or scrambled some features. The experiment described here investigates whether the internal features (eyes, eyebrows, nose and mouth), the external features (chin, ears, hair and head outline) or both are necessary for a RH advantage in matching faces.

Ellis and colleagues have investigated the relative importance of internal and external features in familiar and unfamiliar faces (Ellis et al 1979). They showed that there is an advantage in recognising familiar faces from internal features over external features, but that there was no difference in subjects' ability to recognise unfamiliar faces from either the internal or external features. As mentioned in Chapter 2, there are several possible reasons why the inner features are more memorable in known faces, including the role of the inner features in expression and lip-reading, and thus in a face whose identity is already known, the inside of the face is scanned more than the outside, leading to greater memorability. Also, the external features are easier to disguise, with hairstyles, facial hair and hats, than the internal features which are relatively stable. The faces in the experiments outlined in this chapter are all unfamiliar. However, it should be noted that when tests are designed for prosopagnosic patients investigating the relative saliency of internal and external features, familiarity (which would lead to increased saliency for internal features in normals) is lacking in such patients, and it might be expected that they show no difference between 'familiar' and 'unfamiliar' faces (i.e. those belonging to people they say that they are familiar with on hearing the person's name).

A set of pilot experiments is described in this chapter. In spite of the points made in Chapter 1 about ethological validity of facial stimuli, it was decided for these pilot experiments to use

artificial Mac-a-Mug faces (e.g. Hillger and Koenig 1991), and then to use photographs of real faces in later experiments. Mac-a-Mug is described in more detail in section 5.2. Experiments 5.1 - 5.3 investigated subjects' ability to match tachistoscopically presented Mac-a-Mug faces and were as such a partial replication of Hillger and Koenig (1991) - this being a major reason for using this particular stimulus type - but in addition investigated the role of external features as well as internal features. The other main reason for carrying out these tasks was to test whether the stimuli and experimental protocol and equipment used could replicate previously found results and therefore be suitable for later experiments in the course of the thesis.

The hypotheses of these 3 experiments were that tachistoscopically presented faces (whether full or only consisting of internal features) shown in the LVF would be matched with central faces significantly faster and more accurately than those shown in the RVF; it would be easier to detect changes in external features than in internal features; there would be a possible interaction between trial type and visual field in Experiment 5.2, in that differences in external features would be easier to detect when the second face was presented in the RVF, but differences in internal features would be easier to detect when in the LVF. Although Ellis et al (1979) showed that there was no difference between the external and internal features in recognising unfamiliar faces, this hypothesis is suggested as the Mac-a-Mug faces are more simple and distinctive than real faces, especially in terms of hairline.

It is known that the LH is superior for language processing, and therefore a control task was carried out which tested subjects' linguistic judgement as to whether words presented were nouns or verbs, the hypothesis being that words presented in the RVF would be classified more efficiently, thus showing a left hemisphere advantage. Unlike future experiments, both right-handed and left-handed subjects were used, the latter group originally being tested to look for evidence of reversed asymmetry. The right-handed subjects were split into male and female groups, and the left-handed

subjects were all male. However, data from all three subjects groups was in the end combined (please see section 5.2.1).

Thus there were four sets of tachistoscopic tasks carried out by each subject, as follows:-

Task 5.1

In each trial two faces were shown successively, the first in the centre of the screen and the second briefly in one visual hemifield (with central fixation). The faces were either identical or completely different, having no features in common, and the subject was asked to judge whether or not they were the same.

Task 5.2

This is similar to task 5.1, except the faces were either completely identical or partially different - either the external or the internal features were altered but not both. The subject again had to decide whether the faces were exactly the same or not. (This was similar to Hillger and Koenig's (1991) experiment 2, but where they had presented no difference or a difference in one feature, this task presented no difference or a difference in several features.)

Task 5.3

This is also similar to task 5.1, except that in this case only internal features were presented, which were either all the same or all different. Again the subject's task was to decide whether the faces were exactly the same or not. (This is very similar to Hillger and Koenig's (1991) experiment 1.)

Task 5.4

In each trial a word was displayed briefly in one visual field, the subject maintaining central fixation, and a judgement as to whether the word presented was a noun or a verb was required.

Two more tasks were carried out, also with Mac-a-Mug faces. These tasks investigated upright face matching as a function of ISI (interstimulus interval) between the presentations of the probe and target faces. They were carried out in order to test whether a longer delay would impair

matching performance. Task 5.5 investigated matching full faces (as task 5.1) and task 5.6 tested matching internal features only (as task 5.3). These two tasks were performed by sixteen right-handed normal subjects. It was originally hoped to test the prosopagnosic subjects on these two tasks to investigate the memoric aspects of their prosopagnosia, but due to time constraints on the patients this was not possible. After task 5.6 the subjects who had participated in tasks 5.5 and 5.6 were given a face recognition task, where they had to say whether faces presented to them had been presented during the course of the experiment or not. Note that this faces recognition task was more a test of long term memory for novel faces than a real recognition test for previously familiar faces, as such. The hypotheses of these two experiments were the same as for experiments 5.1 and 5.3, and additionally that as the ISI increased performance would worsen.

For all six tasks manual responses were made, and both reaction times and error rates were recorded.

5.2 - Method

The face stimuli were prepared with the Apple Macintosh program Mac-a-Mug, produced by Shaherazam in Milwaukee, USA. This program allowed the user to create faces from libraries of facial features stored on disc. The features available for manipulation were the head shape and hairstyle, eyebrows, eyes, ears, nose, mouth and chin, and the program also had libraries of eyeglasses, facial hair and miscellaneous paraphernalia. The face was not itself defined as male or female, but many of the features, especially hairstyle, eyes and lips, as well as the facial hair and miscellaneous categories dictated to a large extent whether the face looked male or female. The resulting faces were quite primitive, especially compared to photographs, but they were useful for the experiments. One good aspect of the program was that partial faces could be constructed, as it was possible to set a certain feature library to 'absent'. This allowed me to make faces composed

only of internal features, so that hairline was not an additional cue in the task of face matching, for instance. Further alteration and editing was carried out using Superpaint. Copies of some of the faces used are shown in Appendix A.1. Mac-a-Mug faces have been used in a number of papers, including those by Farah et al (1995a) and Hillger and Koenig (1991), and it was through the latter paper that I obtained them. The faces were then converted into PC-format image files using Adobe Photoshop.

There were two sets of face stimuli:

(i) Internal features only (eyes, eyebrows, nose, mouth),

(ii) Full face (as above, plus chin, hair and ears).

A procedure similar to that of Hillger and Koenig (1991) was used. Six sets of male features and hairstyles were used. For task 5.2 the internal and external features of four of these were combined to produce 16 different target stimuli. Each target face was paired with a probe face. For tasks 5.1, 5.3, 5.5 and 5.6 the probe face was identical to the target face in half the trials, and completely different in half. In task 5.2 a third of the trials showed two identical faces, a third differed in all 4 internal features and a third differed in all 3 external features. Tasks 5.1, 5.2 and 5.5 showed full faces, and in tasks 5.3 and 5.6 only internal features were presented. The subject was instructed to judge as quickly and accurately as possible whether the two faces were identical or not, whilst maintaining central fixation. Example face stimuli are shown in Appendix A.1.

The word lists for task 5.4 were prepared from *Word Frequencies in British and American English* (Hofland and Johansson 1982). Two sets of 18 words were used, where each pair was similar in that they began with the same initial letter and were usually the same length. This similarity between the lists was thought to necessitate actual reading and comprehension of the word during the experiment. The words used are listed in Appendix B.1.

5.2.1 - Subjects

For tasks 5.1 to 5.4, 18 normal subjects were used. Six were male right-handed subjects (mean age 41.8 years, SD 12.5 years), six female right-handed subjects (mean age 45.3 years, SD 2.16 years) and six were male left-handed subjects (mean age 31.8 years, SD 11.8 years). The age range was 23 to 60 years. Note that due to problems with one of the programs, only 16 of the 18 subjects completed task 5.3, matching internal facial features. It was originally planned to compare the different groups, but on account of the small number of subjects in each group, this was not done and data from all 18 subjects (16 subjects for task 5.3) were initially combined. For these tasks the results of the right-handed subjects were also analysed without the left-handed data, as combining left and right handed subjects was realised not to be a good idea in a laterality study, as left-handed subjects typically are less lateralised (and a greater proportion have bilateral language representation or reversed cerebral asymmetry).

For tasks 5.5 and 5.6 another group of subjects were used: they were 16 neurologically normal subjects, 6 male and 10 female (mean age 21.3 years, SD 3.7 years). All were right-handed. Their age range was 18 to 31 years.

5.2.2 - Procedure

Each subject was first asked to complete the Edinburgh Handedness Inventory so as to give an estimate of the extent of their right-handedness or left-handedness. A copy is shown in Appendix C.1. The subject then completed a practice block of 16 trials, the results of which were discarded, followed by two recorded blocks of 72 trials for each of the three face tasks (5.1, 5.2 and 5.3). The task order was counterbalanced between subjects. The word list was then given to the subject to be read aloud, in order to check his or her familiarity with the words, and a practice block of 16 trials followed by two blocks of 72 trials of the word experiment, task 5.4, were given.

5.2.2.1 - Tasks 5.1, 5.2 and 5.3

At the start of each face-matching trial, a central fixation cross was displayed for 1 s, followed by the target face presented centrally for 2 s. Following this, the fixation cross was again displayed for 300 ms. Then the probe face was displayed for 300 ms either to the left or to the right of the centre at a visual angle of three to four degrees. The subjects were asked to maintain central fixation and decide whether the two faces were the same or different. Two hand-held response buttons, described in Chapter 4, were used, one for 'same' responses and one for 'different' responses. The response hands were counterbalanced between subjects.

5.2.2.2 - Task 5.4

At the start of each word trial, a central fixation cross was displayed for 500 ms. The word was then displayed in one visual field for 150 ms, after which a grey mask covered the screen to prevent after-images. The response was one of two keys on the keyboard, one for verbs and one for nouns. The preferred hand was used for all responses, and different response fingers were used for the 'noun' and 'verb' responses, which were counterbalanaced between the subjects. There was an intertrial interval of 1.5 seconds.

5.2.2.3 - Tasks 5.5 and 5.6

Each subject was first shown each face to be used in the tasks. The subjects then performed a practice block of 12 trials to familiarise himself or herself with the procedure. Then 3 blocks of 48 trials of each of the two tasks (full face and internal features) were presented - the order was counterbalanced between subjects - making a total of 144 trials for full faces and 144 trials for internal features for each subjects. Finally there was a recognition task: 18 faces were shown successively to each subject, who had to say whether they had been seen before. Six of these

faces were the ones used originally, and the other 12 were made up of combinations of the features in the original 6 faces, and had not been seen already.

At the start of each trial, a central fixation cross was displayed for 1 second, followed by the target face for 2 seconds. Following this a fixation cross was shown for a variable time of 0.5, 2, 5 and 10 seconds and then the probe face was displayed for 300 ms either to the left of right of the centre, whilst the subjects maintained central fixation. The subjects were asked to decide whether the two faces were the same or different. Again, the two hand-held response buttons were used, one for 'same' responses and the other for 'different' responses. Response hand was counterbalanced between subjects.

5.3 - Results

For the six tasks reviewed in this chapter both reaction times and error rates were recorded and analysed. Raw error scores were analysed, rather than percentage errors as each trial type in all four tasks contained the same number of trials. Log transforms were not used for the error data on the basis that analyses with and without them had been carried out for other experiments (outlined in Chapter 8) and the results of such analyses had shown only a small difference. Therefore the assumption was made that the error data in the experiments described in this chapter were sufficiently normally distributed not to require a transform.

Both mean and median reaction times were calculated for each subject for each combination of trial type and visual hemifield. Both are included in this chapter to show the similarity between them. Mean reaction times were worked out after the removal of outliers (see Chapter 3 for an explanation of the method used) and the median reaction times were worked out prior to the removal of the outliers.

ANOVAs were carried out on the error data, the mean reaction time data and the median reaction time data. The ANOVAs for the first four tasks contained 2 factors - visual field (2 levels: left and right) and trial type. The trial type factor had 2 levels for tasks 5.1 and 5.3 (same and different), 2 levels for task 5.4 (noun and verb) and 3 levels for task 5.2 (same, different internal features and different external features). The ANOVAs for the tasks 5.5 and 5.6 each contained 3 factors - visual field (2 levels: left and right), trial type (2 levels: same and different) and delay (4 levels: 0.5, 2, 5 and 10 seconds). Where any analyses are significant at the 5% level their details will be given below.

5.3.1 - Edinburgh Handedness Inventory

In the Inventory Questionnaire, the subject is asked to indicate his or her hand preference for 20 activities, and whether it is a mild or strong preference, and also which eye and foot is used preferentially. The scores for right and left hands are used in calculating **H**, the laterality quotient. The formula used is:

$$H = \frac{R + L}{R - L} * 100$$

where **R** is the number of right-handed marks and **L** the number of left-handed marks.

This yields a number between +100 (completely right-handed) and -100 (completely left-handed).

The results were as follows:

Table 5.1 - Edinburgh Handedness Inventory Scores

Right-handed male		Right-handed female		Left-handed male	
Subject	**H**	**Subject**	**H**	**Subject**	**H**
ST	100	EP	48	RH	-68
NH	44	AO	83	OM	-8
CC	93	MG	81	MT	0
DH	75	SB	40	NL	-83
LG	49	WS	100	NLP	-43
JC	70	EB	100	JB	67
Mean	71.9	**Mean**	75.3	**Mean**	-22.5
SD	22.6	**SD**	25.7	**SD**	54.5

As can be seen from Table 5.1, the left-handed subjects, with one exception, showed a negative laterality quotient in comparison with the right-handed subjects. Subject **JB**, who has a typical right-handed laterality quotient, both writes and draws with his left hand, but carries out almost all other manual tasks with his right hand. The majority of the subjects (13) were right eyed, and only 2 subjects were left eyed, including only one left-handed subject. The right-handed subjects formed a homogeneous group on the basis of the inventory, but the left-handed subjects showed much broader values for **H** than either of the right-handed subject groups. This may suggest that there would be no significant effect of handedness throughout the experiment. Possibly a better measure of cerebral dominance should be found than handedness. See the discussion for more details.

The values for **H** for all the subjects were correlated with their results in the four tasks to see if the measured laterality quotient could explain any of the hemispheric differences. Analysis of the Pearson's Correlation Coefficients yielded no significant correlations for **H** with any other result obtained.

5.3.2 - Task 5.1 : Full Faces

Error Data

Table 5.2 - Error data for matching full faces (n = 18)

Number of Errors	Left visual field	Right visual field	Both fields
Different	54	42	96
Same	62	54	116
Both trial types	116	96	212

There were more errors made in the LVF than in the RVF out of a total of 1296 trials in each visual field, but on statistical analysis this difference was found not to be significant. Further analysis showed that trial type was also not significant, although there were more errors made for 'same' trials than for 'different' trials, nor was there a significant interaction. Thus, although more errors were made for trials where the target face was presented in the LVF, primarily accessing the RH, this was not a significant effect, possibly because of the percentage of errors was low in both visual fields (below 10%). The results of the ANOVA were unchanged when the 12 right-handed subjects were analysed.

Reaction Time Data

Table 5.3 - Reaction time data for matching full faces (n = 18)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Different	704 (683)	700 (687)	702 (685)
Same	685 (652)	693 (676)	689 (664)
Both trial types	694 (667)	696 (681)	695 (674)

RTs are mean (median)

Both mean and median reaction times were calculated for each subject. Only 11 of the 18 subjects showed a LVF advantage and there was no significant effect of field overall, nor was there an effect of trial type or a significant interaction. There does not appear to be any correlation between laterality quotient H and hemispheric advantage. However, when only the 12 right-handed subjects' data were analysed, on the basis of mean reaction times trial type became significant ($F = 4.95$, $DF = 1,11$, $P = .048$) in that same trials were responded too more quickly than different trials,

and also an almost significant interaction between field and trial type (F = 4.79, DF = 1,11, P = .051), where the LVF favoured 'same' trials but the RVF favoured 'different' trials. Note, however, that there visual field was still not significant.

5.3.3 - Task 5.2: Full Face, Partial Difference

Error Data

Table 5.4 - Error data for matching full faces, partial difference (n = 18)

Number of Errors	Left visual field	Right visual field	Both fields
Different external	47	47	94
Same	70	69	139
Different internal	124	99	223
All trial types	241	215	456

In this task there were three types of trial, data from 864 trials for each type being used. The two faces were either identical, differed in external features or differed in internal features. The error data showed slightly more errors for the LVF than for the RVF although not significantly so. However, there was a very highly significant effect of trial type (F = 10.34, DF = 2,34, P < .001). Most errors were made when there was a difference in internal features, fewer when the faces were the same and fewest errors were made when there was a difference in external features. See the Discussion for an interpretation. There was no significant interaction. These results were unchanged with only the 12 right-handed subjects.

Reaction Time Data

Table 5.5 - Reaction time data for matching full faces, partial difference (n = 18)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Different external	754 (719)	732 (696)	743 (708)
Same	825 (802)	861 (822)	843 (812)
Different internal	889 (891)	906 (920)	898 (906)
All trial types	823 (804)	833 (813)	828 (809)

RTs are mean (median)

Neither the mean reaction time data nor the median reaction time data showed a significant effect of visual field. There was again a highly significant effect of trial type on both the mean reaction time ($F = 24.76$, $DF = 2,34$, $P < .001$) and on the median reaction time ($F = 27.85$, $DF = 2,34$, $P < .001$). The subjects were slowest when there was a difference in the internal features and fastest when there was difference in the external features. There was also a significant interaction between visual field and trial type for the mean RT data ($F = 4.29$, $DF = 2,34$, $P = .022$) though not for the median RT data. [Tukey's HSD test did not show any significant differences at the 0.05 level.] This source of this interaction is explained in the Discussion section. These results were unchanged with only the 12 right-handed subjects.

5.3.4 - Task 5.3 : Internal Features

Error Data

Table 5.6 - Error data for matching internal features (n = 16)

Number of Errors	Left visual field	Right visual field	Both fields
Different	91	86	177
Same	69	84	153
Both trial types	160	170	330

In this task the faces only consisted of internal features, so hairline could not be used as a visual cue. There were no significant effects or interactions, although slightly fewer errors were made when the face was presented to the LVF, as opposed to the previous 2 tasks. These results were unchanged with only the 12 right-handed subjects.

Reaction Time Data

Table 5.7 - Reaction time data for matching internal features (n = 16)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Different	823 (803)	825 (805)	824 (804)
Same	807 (785)	836 (812)	822 (799)
Both trial types	815 (794)	831 (809)	823 (802)

RTs are mean (median)

There was a significant effect of visual field for the mean RT (F = 5.17, DF = 1,15, P = .038), the trials in the RVF taking longer than those in the LVF. The same trend was apparent in the median RT data, although this was not significant. There was no significant interaction. When only the 10 right-handed subjects were used in the analysis, visual field became just not significant (F = 4.73, DF = 1,9, P = .058) according to mean reaction times.

5.3.5 - Task 5.4 : Word Decision

Error Data

Table 5.8 - Error data for matching words (n = 18)

Number of Errors	Left visual field	Right visual field	Both fields
Noun	71	67	138
Verb	131	87	218
Both trial types	202	154	356

In this task the subjects had to decide as quickly as possible whether the word displayed was a noun or a verb, having already seen the lists of possible words. Although out of a total of 1296 trials in each visual field more errors were made for the trials in the LVF than for those in the RVF, as expected, this was not quite significant (F = 3.80, DF = 1,17, P = .068). There was, however, a significant effect of word type (F = 6.77, DF = 1,17, P = .019), in that the subjects made fewer errors for nouns than for verbs. There was no significant interaction. When only the data from the 12 right-handed subjects were analysed, word type became just not significant (F = 4.78. DF = 1,11, P = .051), but there was no change in the significance of other effects.

Reaction Time Data

Table 5.9 - Reaction time data for matching words (n = 18)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Noun	908 (872)	869 (842)	889 (857)
Verb	939 (904)	927 (898)	933 (901)
Both trial types	924 (888)	898 (870)	911 (879)

RTs are mean (median)

Again there was a significant effect of word type for mean reaction times (F = 5.70, DF = 1,17 P = .029) and an almost significant difference for median reaction times (F = 3.91, DF = 1,17, P = .064), in that the nouns were responded to faster than the verbs. There was no significant effect of visual field, although the subjects were marginally faster for trials in the RVF. There was no significant interaction. These results were unchanged with only the 12 right-handed subjects.

5.3.6 - Task 5.5: Full Face, Delayed Matching

Error Data

Table 5.10 - Error data for delayed matching of full faces (n = 16)

Number of Errors	Left visual field		Right visual field		Both fields
Delay (s)	**Same**	**Different**	**Same**	**Different**	
0.5	8	13	7	12	40
2.0	12	3	12	3	30
5.0	18	10	13	4	45
10.0	25	7	18	6	56
All delays	63	33	50	25	171

Significantly more errors were made when the second face was in the left visual field (F = 4.62, DF = 1,18, P = .048) than in the right visual field and also when the second face was the same as the first (F = 7.71, DF = 1,18, P = 0.14) - i.e. roughly twice as many matches were missed as were imagined. Delay itself was not quite a significant effect (F = 2.61, DF = 3,45, P = .063) although close to being significant - there was a consistent increase in the number of errors made as the delay increased from 2 to 10 seconds, although more errors were made at a delay of 0.5

seconds than at 2 seconds. There was also a significant interaction between trial type and delay ($F = 8.18$, $DF = 3,45$, $P < .001$). More 'same' errors (misses) were made than 'different' errors (false positives) for a delay of 0.5 second, but this pattern reversed for longer delays. This is more clearly illustrated in Figure 5.2. [Tukey's HSD test shows significant differences between 'same' trials at 10s delay and 'different' trials at all delays from 2s and upwards; also between 'same' 10s delay and 'same' 0.5s delay; finally 'same' 5s delay and ''different' 2s delay: all were significant at the 0.05 level.] This suggests that the subjects were more cautious for short delays, but that at longer delays they were more likely to accept the second face as being the same when it was not, possibly because they trusted their memory less as the delay increased.

Reaction Time Data

Table 5.11 - Reaction time data for delayed matching of full faces (n = 16)

Reaction time (ms)	**Left visual field**		**Right visual field**		**Both fields**
Delay (s)	**Same**	**Different**	**Same**	**Different**	
0.5	844 (812)	838 (819)	858 (832)	865 (829)	851(823)
2.0	817 (785)	883 (885)	867 (835)	883 (818)	862 (831)
5.0	880 (851)	882 (837)	887 (865)	873 (840)	880 (848)
10.0	895 (877)	920 (888)	892 (879)	909 (896)	904 (885)
All delays	859 (831)	881 (857)	876 (853)	883 (846)	874 (847)

RTs are mean (median)

When both mean and median reaction times were analysed, the only significant effect, in both cases, was delay (mean RT : $F = 5.75$, $DF = 3,45$, $P = .002$; median RT : $F = 5.45$, $DF = 3,45$, $P = .003$). Reaction time increased with increasing delay. The only interaction nearing significance was the complex three-way interaction of [*field* * *trial type* * *delay*] for mean reaction times only ($F = 2.30$, $DF = 3,45$, $P = .090$ [n.s.]). No explanation can be offered for this at the present time. Thus on the basis of reaction time data neither visual field nor trial type affect delayed full-face matching. This is contrary (or complementary) to the error data analysis.

5.3.7 - Task 5.6: Internal Features, Delayed Matching

Error Data

Table 5.12 - Error data for delayed matching of internal features (n = 16)

Number of Errors	Left visual field		Right visual field		Both fields
Delay (s)	Same	Different	Same	Different	
0.5	15	13	13	17	58
2.0	9	19	18	15	61
5.0	23	22	26	24	95
10.0	29	22	25	26	102
All delays	76	76	82	82	316

When only internal features were used for matching, neither visual field nor trial type were significant. Delay, however, was very highly significant ($F = 7.38$, $DF = 3,45$, $P < .001$), more errors being made as the delay increased. There were no significant interactions.

Reaction Time Data

Table 5.13 - Reaction time data for delayed matching of internal features (n = 16)

Reaction time (ms)	Left visual field		Right visual field		Both fields
Delay (s)	Same	Different	Same	Different	
0.5	886 (871)	986 (940)	963 (976)	975 (968)	953 (939)
2.0	921 (909)	922 (900)	969 (970)	962 (955)	944 (934)
5.0	1035 (1019)	985 (959)	1020 (1014)	1010 (1007)	1013 (1000)
10.0	1029 (1037)	1027 (1039)	1008 (1046)	1022 (1024)	1022 (1037)
All delays	968 (959)	980 (960)	990 (1002)	989 (989)	982 (978)

RTs are mean (median)

Both the mean and median reaction times yielded significant effects of delay, the reaction times in general becoming longer as the delay increased, although the RT for a delay of 0.5 s was generally slightly longer than for a delay of 2 s (mean RT: $F = 8.77$, $DF = 3,45$, $P < .001$; median RT: $F = 11.22$, $DF = 3,45$, $P < .001$). The median reaction times also showed a significant effect of visual field, the trials in the LVF being on average responded to almost 40 ms more quickly ($F = 4.84$, $DF = 1,15$, $P = 0.44$). Mean reaction times did not show a significant effect of visual field. Trial type was not significant, nor were there any significant interactions. Graphs of the mean reaction times as a function of delay, for both this and the previous experiment, are shown in Figure 5.1.

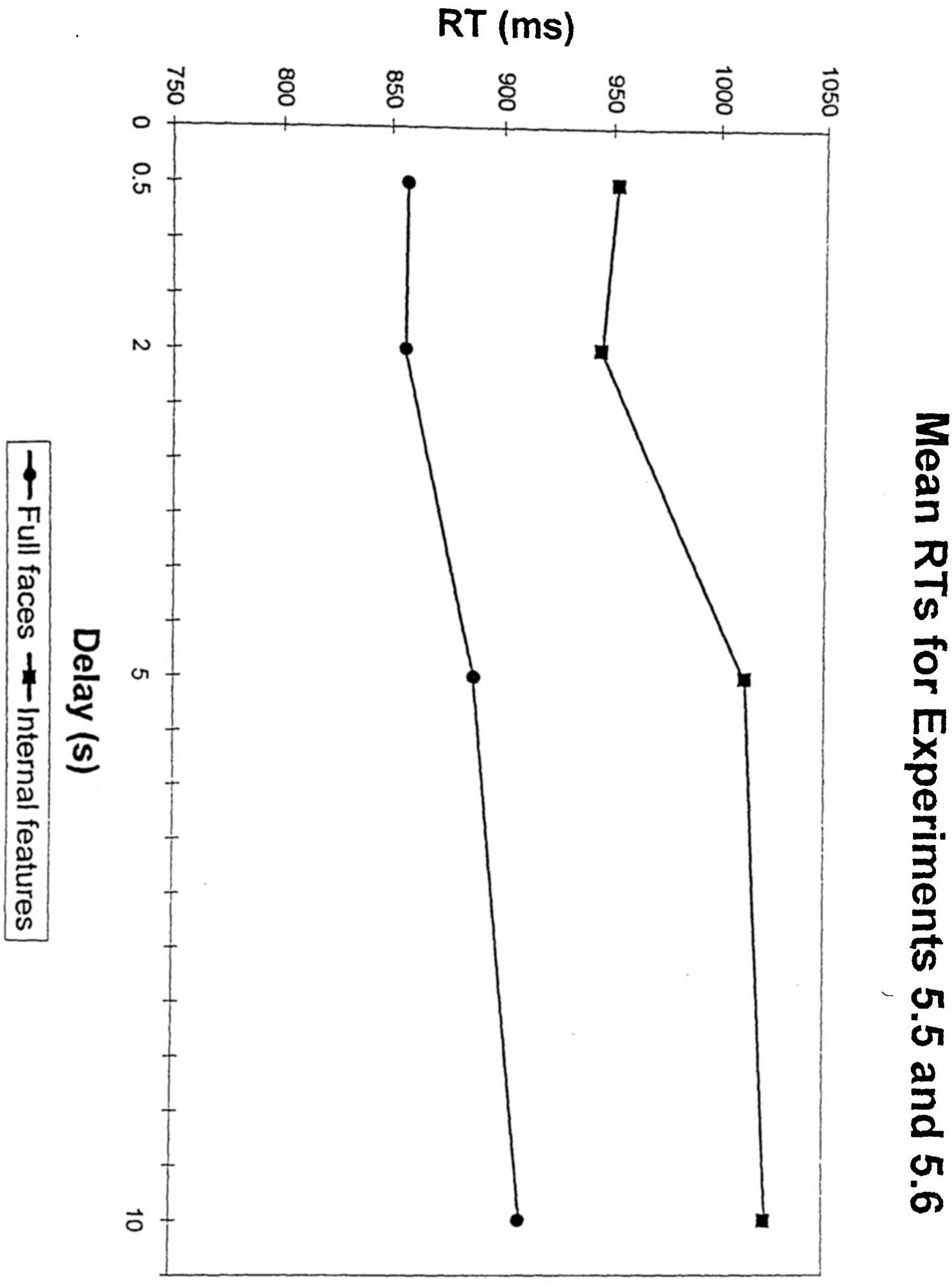


Figure 5.1 - Mean reaction times as a function of delay for Experiments 5.5 and 5.6

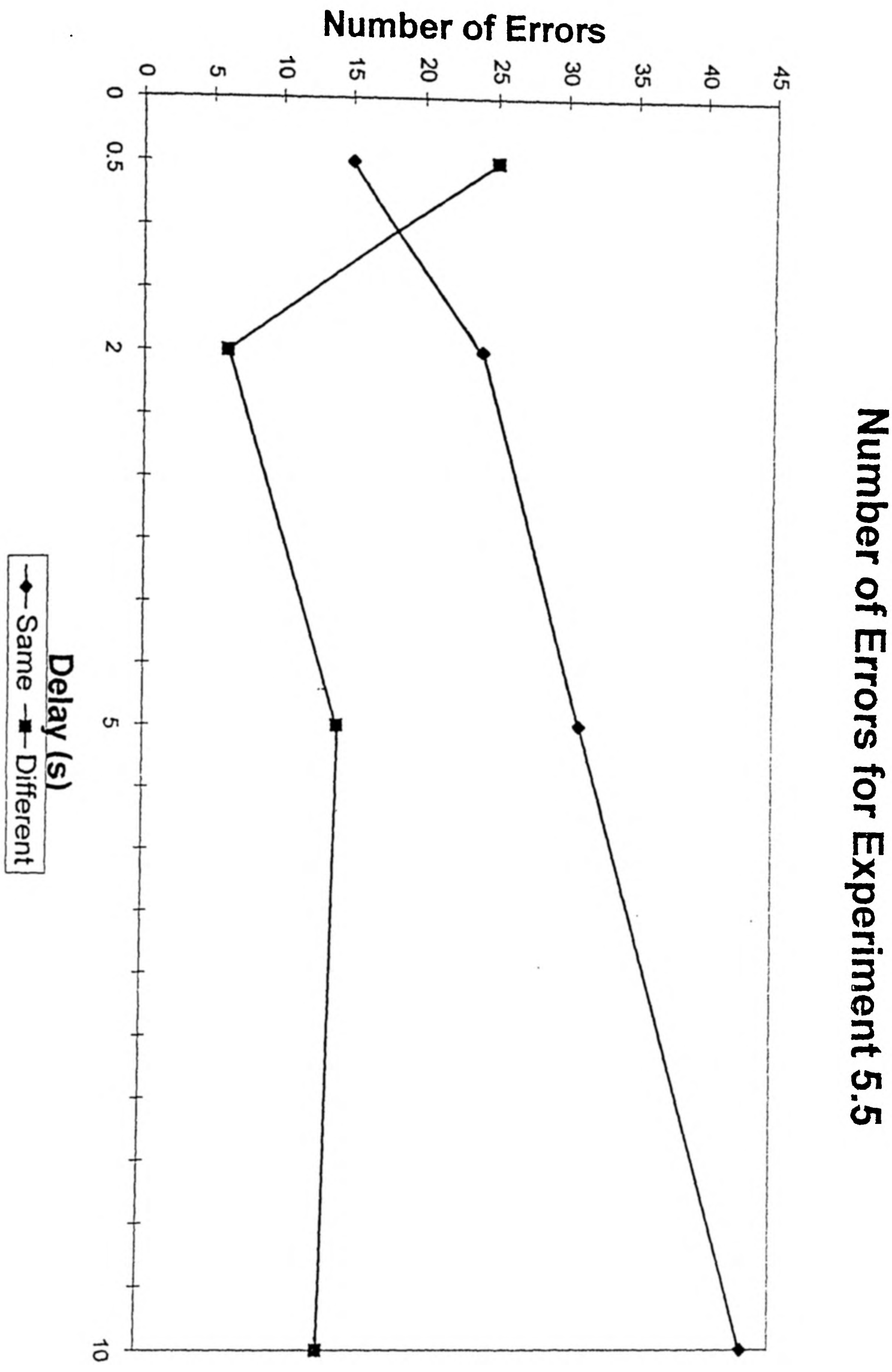


Figure 5.2 - Number of errors as a function of delay for Experiment 5.5

5.3.8 - Face Recognition Task

After completion of the face matching, the sixteen subjects who had participated in tasks 5.5 and 5.6 were shown 18 faces, 6 of which had been used in task 5.5 and 12 of which had not, being comprised of internal and external features from faces which were used in task 5.5, but combined in novel combinations. In total, the 16 subjects made 34 errors, making between 0 and 5 each (mean 2.1, SD 1.7). The same number of errors was made by those subjects whose last block was full faces (task 5.5) as those whose last block was internal features (task 5.6).

The pattern of errors is interesting: using a mixed design ANOVA, with error type as the within subject factor (2 levels: false positive and miss) and the last block done as the between subject factor (2 levels: full face and internal features), it was found that significantly more false positives were made (28) than misses (6) ($F = 17.83$, $DF = 1,14$, $P = .001$). The interaction between the types of errors made and the last block performed by the subject was not significant, although it was seen that more false positives were made when the last block contained internal features only than when it contained full faces, but more misses were made when the last block contained full faces than when it contained internal features only.

5.4 - Discussion

5.4.1 - Handedness

The Edinburgh Handedness Inventory is a crude measure, and this was exacerbated by the fact that some of the subjects did not fill in the form correctly. It is not thought that handedness necessarily reflects cerebral dominance, and this is borne out by the lack of any correlation between H and any of the empirical measures in the later tasks. It has been suggested that eye preference may be a better indicator of cerebral dominance than hand preference, although only after taking into account factors such as monocular amblyopia or astigmatism.

5.4.2 - Task 5.1 - Full Faces

Although more errors were made when the target face was presented in the LVF rather than the RVF, this was not significantly so, either for all 18 subjects or just the 12 right-handed subjects. However, there was a significant effect of trial type on the basis of mean reaction times when only the right-handed subjects were used in the analysis, in that matches were recognised faster than correct rejections. There was also an almost significant interaction between trial type and visual field, but again, only when the left-handed subjects were not included in the analysis. This implied that it was faster to recognise matches in the LVF (RH) but correct rejections in the RVF (LH). A similar interaction was found in Experiment 7.3 (see chapter 7), and in both cases it is hard to explain. One possible reason is that the two hemispheres have different internal criteria of accepting faces as pairs or not, but why this should be is unclear. The reaction time data, however, would imply that this set-up, using these stimuli, does not yield a RH advantage for face matching, where right-handed or mixed subjects are used.

5.4.3 - Task 5.2 - Full Faces, Partial Difference

On the basis of both the errors and the reaction times there was no difference in performance between the two visual fields, but there was a strong effect of trial type. The trials in which there was a difference in the external features were responded to most accurately and fastest, whereas most errors were made on the trials in which there was a difference in the internal features: these were also responded to the slowest. The explanation for this is that it was easier to detect a difference in the hairline, a gross feature, than in the internal features, which were much smaller, specifically in the distinctive Mac-a-Mug faces.

The mean reaction time data showed a significant interaction between visual field and trial type. Responses to trials in the RVF were faster when there were differences in the external features than

responses to those in the LVF, but this was not the case for the other two trial types, when trials were more quickly responded to in the LVF. This could reflect the different strategies which the different trial types may have required: matching external features could be done mainly on the basis of local features (the hairline) thus leading to a LH and RVF advantage, but internal feature matching might require more of a holistic configurational matching, which would favour the LVF and RH. There was no difference whether the data for all 18 or just the 12 right-handed subjects were analysed.

5.4.4 - Task 5.3 - Internal Features

The only significant statistic was the effect of visual field on the mean reaction times. Overall, the LVF (RH) trials were responded to more quickly than those in the RVF. This is as expected, suggesting a RH advantage in matching faces when intrusive hairstyles are removed as a possible cue. Note, however, that this effect became just not significant when only the right-handed subjects were used in the analysis. This is odd, as the main reason for reanalysing the results without the left-handed subjects was that a homogeneous group of right-handed subjects is more likely to yield a significant visual field effect, due to the generally accepted finding that left-handed subjects tend to be a more heterogeneous group in terms of their cerebral dominance and laterality of organisation. In this case, however, that does not appear to be the case. Note that it is still close to significance. In no other experiment in this chapter was the significance of any visual field effect altered by using only right-handed subjects in the analyses. There was no effect of trial type, nor a significant interaction. The presence of a field effect where one was absent for Task 5.1 suggests that the partial face stimuli used here are more suitable for investigating the hemispheric asymmetry for face processing, as the distinctive hairstyles were removed as possible cues in the matching task. Only mean reaction times showed this effect: neither median reaction times nor error rates showed a field effect, although marginally fewer errors were made for trials in the LVF,

agreeing with the reaction time data. This suggests that even with these stimuli and procedure the effect of field, though significant, is a small one.

5.4.5 - Task 5.4 - Word Decision

When a word was presented to one visual field and a grammatical decision required, the responses were generally more accurate and faster for words presented to the right visual field (left hemisphere) although visual field was not statistically significant. As it is well known that the left hemisphere is superior for linguistic tasks such as this one, the lack of a highly significant effect suggests that this experimental set-up is possibly not sensitive enough to measure the very small differences inherent in choice reaction time tasks of this type between the two hemispheres on any task. This could explain the difficulty in finding any strong field (and therefore hemispheric) differences in the earlier experiments concerned with face processing.

One significant effect, however, was that of word type: nouns were recognised more accurately and faster than verbs (significantly for errors and mean reaction times, and just not significant for median reaction times). This was wholly unexpected, and two possible explanations were put forward to explain the result. The words had been chosen so that pairs were physically fairly similar, but no attempt had been made to match the two lists for frequency of occurrence in general everyday language. When this was inspected, it was found that according to the source book used (Hofland and Johansson 1982), the nouns in the list occurred 70% more than the verbs chosen. This could explain the increased efficiency with which nouns were identified. The second possibility is that there really is a difference between the processing of nouns and verbs, be it qualitative or quantitative, which is independent of word frequency. This hypothesis is tested in a later experiment (10.1), when Task 5.4 is repeated several times, using word lists of different frequencies. Note that when only the right-handed subjects were used in the analysis, word type just ceased to be significant. One possible reason for this is that fewer subjects were used in the

analysis, and that handedness does not affect the subjects' ability to process nouns more efficiently than verbs in this experiment.

5.4.6 - The Effect of Delay

For both full-face matching and internal feature matching, an increased delay between the presentation of the central face and the lateral face resulted in poorer performance, measured either as longer reaction times or more errors or both. Delay was more significant for task 5.6, in which only internal features were presented, than in task 5.5, where full faces were presented. This suggests that there is a memory component to the task, and that this memory component is more important when the amount of information present in the stimulus is less, possibly due to the increased difficulty of the task (i.e. matching internal features is harder than matching full faces). The poorer performance at higher delays undoubtedly reflects the loss of the image of the central face from the short-term memory. It would have been interesting to have required the subjects to perform a secondary distracting task during the delay, such as counting or reciting the alphabet backwards out loud, to see if this increased processing load would further disrupt performance: this was not however tested.

When full faces were matched, there was a RVF advantage (significantly fewer errors than in the LVF). When only internal features were matched, however, there was now a LVF advantage (significantly faster median reaction times than in the RVF). This is similar to the findings from tasks 5.1 and 5.3, above, in which the internal features without any additional cue from the hair, ears and chin have to be matched more holistically and give rise to a significant RH superiority, seen as a LVF advantage. However, when the hair is included in the stimulus, the lack of the LVF advantage, or even the presence of a RVF advantage, as seen in task 5.5, can be explained by the nature of the task changing from holistic to local, where the matching relies much more on just the hairline.

For the full faces (task 5.5) there was an effect of trial type, in that more errors were made for 'same' faces than for different ones, but this pattern reversed at longer delays (giving rise to a significant interaction). This can be explained by the subjects' initially being cautious and not accepting faces as pairs unless they were sure, giving rise to more misses than false positives, but at longer delays the subjects were no longer sure of what they had seen and had to be less cautious, now making more false positives than misses. This was not found for matching internal features (task 5.6).

5.4.7 - Face Recognition

In the face recognition task carried out after tasks 5.5 and 5.6 on the subjects who participated in those 2 tasks, significantly more false positives were made than misses. As the novel faces were made by combining features which the subjects had seen during the experiment, the subjects were really being asked to remember the overall configuration of the faces, and not just the internal features (which were all present in the experiment) nor the external features (which also were all present in the experiment), but their specific combinations. The higher number of false positives than misses suggests that they were indeed being misled by their having previously seen all the stimuli, and were not matching fully on the basis of all the features. This is further evidence that much of the full-face matching using the Mac-a-Mug faces was on the basis of only some of the features, for instance, as has already been mentioned, the hairline. This does not disagree with the suggestion in section 5.4.3 that the internal features of the face may be processed holistically.

The fact that the number of errors made did not depend on the type of block performed lastly by the subjects (whether full face or internal feature matching) suggested that by the time they finished their penultimate block, they had had enough exposure to the faces, such that seeing

only the internal features for the last block before the recognition task would not further impair their recognition performance.

5.4.8 - Overall

A small non-significant advantage for the left hemisphere was found in task 5.1 and a small significant right hemisphere advantage was found in Task 5.3, (for right-handed and left-handed subjects combined) where partial faces were used. Tasks 5.5 and 5.6, which included trials with different ISIs, showed a small significant advantage for the left hemisphere for full-face matching and a significant advantage for the right hemisphere for internal feature matching. Task 5.2 did not show any overall hemispheric differences. However the effects shown in both tasks 5.1 and 5.3 were very small, and it is possible that this is due in part at least to the stimuli used. The drawings from Mac-a-Mug are not particularly lifelike (they resemble Identikit cartoons), and, in addition, the hairstyles were probably too distinctive a cue, drawing attention away from the other features of the face in the matching task. Examples are shown in Appendix A.1. The question to ask here is whether Mac-a-Mug faces are different enough from photographs of real faces in terms of the aspects of faces that generally yield a RH advantage to be unsuitable for such research; this cannot be answered at this stage, except to say in Mac-a-Mug's defence that the internal features at least have yielded significant RH advantages in other studies (e.g. Hillger & Koenig 1991).

One point of interest raised by these analyses is that the combination of right and left-handed subjects did not decrease any laterality effects. It is often argued that to uncover laterality effects it is necessary to use only right-handed male subjects: here is an example where the introduction of left-handed subjects does not remove any such effect (indeed the other way round in Experiment 5.3 for internal features). However, it should also be noted that no laterality effect was strong, if significant at all, and also that there are only a small number of subjects, and therefore quite

possible that all the left-handed subjects used do not have markedly decreased cerebral laterality in comparison to the right-handed subjects in the study.

For this reason and also the argument for ethological validity the tasks were repeated using photographs of real faces instead (Chapter 7). However, it is notable that the slight hemispheric advantages reversed between tasks 5.1 and 5.5 on the one hand, and 5.3 and 5.6 on the other, suggesting that the former two tasks may have been achieved using a more local, analytical strategy than the two latter tasks, where a more global, holistic strategy was needed. If this is the case, it is likely that it arises through the presence or absence of the hair: indeed some subjects complained in task 5.3 that it was harder exactly for this reason. Note, of course, that in everyday life, hairstyle may be an important cue assisting face recognition, but occasionally it could be a misleading cue, such as when someone is wearing a headscarf or hat, or has a new and different hairstyle. In such cases we can still usually recognise people. This suggests that although hairstyle may be an important cue in face recognition, it is by no means the only cue available. The findings on the recognition task suggest that the subjects may have been using the hairstyle as a cue to a greater extent than in everyday tasks, as there were many false positives where they will probably have been responding on the basis of the hairstyle. There was a strong effect of trial type in Task 5.2, where a change in external features including hairline was more readily noticed than a difference in the internal features. This is not in agreement with Ellis et al (1979) but may be due to the difference in task paradigms and also the artificiality, distinctiveness and simplicity of the Mac-a-Mug faces in comparison with the real photographs which Ellis used. Trial type was not a significant factor in Tasks 5.1 or 5.3, nor in 5.6, although in task 5.5, there was effect of trial type, in that the subjects were more cautious for short delays but less so for long delays.

A slight field difference was found in Task 5.4 for words - the left hemisphere was superior, as expected, but not significantly so. Unexpectedly, there was a difference in performance on judging

words as nouns or as verbs: this imbalance is investigated in a future experiment (9.1), using word frequency as a controlled variable.

Mean reaction times, median reaction times and error scores did not always yield the same significant effects, although the patterns of results were usually similar.

Therefore the findings of this chapter lead on to two more experiments which are presented later in the thesis:

- Repeat using photographs of faces with non distinctive hairlines. (Experiment 6.1)
- Repeat the word experiment, controlling word frequency. (Experiment 9.1)

CHAPTER 6 - THE INVERSION EFFECT FOR FACE MATCHING

6.1 - Introduction

As has been outlined in detail both in Chapters 1 and 2, and also in the Introduction to Chapter 5, there is much evidence to suggest that face processing has specialised mechanisms predominantly in the right hemisphere of neurologically normal adults. The evidence includes results from tachistoscopic experiments in normals and also the locus of damage in prosopagnosia, there being contention whether bilateral damage is in fact necessary for prosopagnosia, or whether RH damage, which seems to be more important and also to have a greater effect (De Renzi 1993, De Renzi et al 1994), is sufficient.

The previous chapter described a number of experiments that were carried out to investigate hemispheric asymmetry for face matching in normal subjects using Mac-a-Mug faces. The results of these experiments did not show a strong hemispheric asymmetry, although in experiments 5.3 and 5.6 a small RH advantage was found for matching internal features in the absence of external features. One possible reason put forward for the lack of any strong RH advantage was the artificiality of the face stimuli. Therefore experiments testing face matching in normal subjects, this time using photographs of real people as the stimuli, were carried out and are described in this chapter.

The experiments documented in this chapter used a set of face photographs of Israeli men which were obtained from Yael Moses (see Moses et al 1996, 1997). Matching for both upright and inverted (upside-down) faces was tested on both normal subjects and the prosopagnosic subjects.

As was discussed in Chapter 2, it is well known that inverted (i.e. upside down) faces are harder to recognise than upright faces. This was investigated by Yin (1969) who compared memory for faces with memory for other objects which are normally seen in only one orientation. The

objects he used were faces, houses, aeroplanes and stick-men in motion, and the subjects had to decide whether a visual stimulus was one they had seen before (in the same orientation). Results showed that upright faces were recognised better than other objects, but inverted faces worse than other inverted objects, showing that face recognition was disproportionately impaired by inversion. This effect has been replicated successfully (see Valentine 1988, for a review). One possible problem with this experiment is that the other classes of visual stimuli may not be equivalent to faces in terms of subject experience, complexity or within-category similarity of the exemplars. Diamond and Carey (1986) carried out a similar experiment by testing dog experts on recognition of upright and inverted dogs. Their results showed that naïve subjects showed a larger inversion effect for faces only, but the experts showed inversion effects for both faces and dogs. This could be taken to show that faces are not 'special' - processed in a qualitatively different way from other objects. However, it could also be taken as evidence that dogs (at least to dog experts) are a category equivalent to faces for all of us in terms of their complexity, subject experience and within-category similarity. Valentine and Bruce (1986, Experiment 1) used a category which was certainly equivalent to known faces in all aspects other than that of familiarity: own-race and other-race faces. If the disproportionate effect of inversion was due to increased familiarity in both of the above 2 experiments, then there ought to be an inversion effect for own-race faces, but not for other-race faces. This was not found - in fact the opposite interaction was obtained.

Yin (1970) also tested patients with right hemispheric posterior brain damage, and who were impaired at recognising upright faces, on an inversion task, and found that they performed normally at recognising inverted faces. This dissociation was not found with houses as visual stimuli. Bruyer and Velge (1981) used a matching task to study the effect of inversion on the perception of faces and other object categories on normals, RH damaged subjects and LH damaged subjects. They did not replicate Yin's findings for the RH damaged group, although

they used a matching task rather than a memory task, and this might have led to the different results. Overall there is a disconcerting lack of successful reported replications of Yin's study in the literature. However, there are replications; for instance, Farah and her colleagues (1995a) have shown that prosopagnosic patients who are impaired at upright face matching are no more impaired at inverted face matching, possibly even showing better performance for inverted faces than upright faces. This study used Mac-a-Mug faces rather than photographs of real faces. The present study tests the control subjects and the three prosopagnosic subjects described in Chapter 3 were tested on upright and inverted face matching in the hope of replicating Farah et al's (1995a) results, but with real faces.

Another interesting finding is that inversion sometimes removes the typical RH advantage seen for upright face recognition (e.g. Leehey et al 1978) in normal subjects. Although not invariably found, it is accepted that a RH superiority for recognition of unfamiliar faces is generally found. Leehey et al found a LVF (RH) advantage for upright faces but not inverted faces, and this finding has been replicated by others. However, this only shows a qualitative difference between face processing and the processing of other visual objects if inverting other complex visual stimuli alters the pattern of hemispheric superiority.

Levine et al (1988) investigated this using faces and houses as stimuli. Using two non-lateralised tasks (i.e. which over all subjects do not give a significant laterality) which were a chair matching task and a free-vision chimeric face task, they first split their subjects (all right-handed) into groups: those who showed a characteristic arousal asymmetry in favour of the RH; those who favoured the LH; and those who did not favour either hemisphere. They found that only those dextrals who had a characteristic arousal asymmetry in favour of the RH showed a LVF advantage for both upright faces and upright houses, but no visual field asymmetry for either stimulus class when they were inverted. As well as suggesting that faces may not be the

only class to show the inversion effect, two other conclusions can be drawn from this experiment. Firstly, some dextrals showed a RH advantage for the recognition of upright houses, suggesting that an orientation specific RH superiority is not specific to face recognition. Secondly, Valentine (1988) suggests in his description of Levine et al's results that the finding that LVF superiority for face recognition is limited to a subset of dextrals could account for the inconsistencies found in the literature as to whether face recognition leads to a LVF / RH advantage. It is noteworthy that there was exactly the same distribution of females and males in the two characteristic arousal asymmetry groups.

Thus Experiment 6.1 investigated face matching using photographs of real faces (cf. the Mac-a-Mug faces used is the previous chapter) across views, such that the task is face matching and not stimulus matching (Bruyer al 1987), both upright and inverted. A number of hypotheses were tested:

1. The control subjects would show a RH advantage for upright faces but this advantage would be abolished or even reversed by inversion of the faces.
2. The prosopagnosic subjects would show better matching of inverted faces than upright faces, as patient **LH** had done (Farah et al 1995a), but using photographs of real faces.
3. **HJ** and **RL**, the two subjects with reversed cerebral asymmetry, demonstrated by functional neuro-imaging and described in Chapter 3, would show a LH advantage for upright face matching.

6.2 - Method

6.2.1 - Subjects

Sixteen male control subjects participated in the experiment. Their ages ranged from 18 to 49, with a mean of 27.9 years and a SD of 8.4 years. Also the three prosopagnosic subjects and the two subjects with reversed cerebral asymmetry were tested (see Chapter 3 for details).

6.2.2 - Procedure

I was fortunate to contact a fellow researcher from the Weizmann Institute of Sciences in Israel who was working on facial recognition and who had a large database of male faces under different lighting and angle conditions which had been used in previous investigations by her (Moses et al 1997; Moses et al 1996). I obtained a number of these, which were converted to a raw data greyscale format which the Turbo Pascal program could use. Originally it was thought to use the faces as they were, together with the background of the photograph and a well defined hairline. However, this was thought to provide a greater cue in face matching, and therefore Adobe Photoshop was used to alter the images, colouring all the background black and hiding the edge of the hair in most cases, except where the hair was light coloured (most of the faces had dark hair). These were used in the actual experiment. The faces used were of 26 different models in each of two positions, looking straight at the camera and also at 17° to the right (i.e. to their left). The images were also copied and flipped to form a set of inverted (upside down) versions of the same faces.

The first face was presented in the centre of the screen for 2 seconds, and the screen was then cleared and a fixation cross presented for 750 ms. The second face was then presented for 100 ms in the centre of one of the two lateral halves of the visual display (at a visual angle of three to four degrees) and the screen was then cleared. On half the trials the second face was presented on the left side of the screen, and on the other half it was presented on the right side. The side

on which the second face appeared was randomised from trial to trial and therefore not predictable. There was an inter-trial interval of about 1700 ms. The subjects' response was bi-manual, using the response buttons already described in Chapter 4. Each subject was instructed to press one button if both faces were of the same person, and the other button if they were of different people. Each block comprised 80 trials with a break after 40 trials to allow the subject to have a rest, and each subject carried out two blocks for upright faces and two blocks for inverted faces. The order of these blocks was alternated, with their order counterbalanced so that some subjects matched a block of upright faces first, and some a block of inverted faces first. A practice block of 12 trials was given to familiarise each subject with the procedure and the nature of the stimuli, once containing upright faces before the first upright block, and once containing inverted faces before the first inverted block. The results of the practice trials were not recorded.

6.3 - Results

6.3.1 - Control Subjects

Reaction times and numbers of errors were recorded. The numbers of errors were converted to error percentages as these allowed for easier direct comparison with the prosopagnosic subjects, who each performed only one block and therefore half the number of trials of the controls. In this experiment just median reaction times were determined for each subject and these were used in the analyses, rather than the positively skewed mean reaction times (as explained in Chapter 3). Firstly the mean error percentages are presented:

Table 6.1 - Mean % errors for control subjects for Experiment 6.1

% errors	Upright		Inverted	
	LVF	RVF	LVF	RVF
Same	7.3	7.8	15.3	13.5
Different	15.3	11.5	18.8	17.8
Total	11.4	9.6	17.0	15.8
Total	10.5		16.3	

Looking at the above table certain things are immediately obvious. Firstly, the number of errors made on the inverted trials is much higher than on the upright trials. Second, there were more errors made when the second face was presented in the LVF than when it was presented in the RVF. Third, more errors were made on 'different' trials than on 'same' trials: in other words, the subjects were on the whole more likely to make false positives than misses. When these error data are analysed in a 3-way repeated measures ANOVA (factors: orientation [2 levels - upright, inverted]; visual field [2 levels - LVF, RVF]; trial type [2 levels - same, different]) significant main effects of orientation ($F = 18.91$, $DF = 1,15$, $P = .001$) and trial type ($F = 7.62$, $DF = 1,15$, $P = .015$) are found, and a nearly significant effect of visual field ($F = 3.81$, $DF = 1,15$, $P = .070$). None of the two way interactions nor the three way interaction was significant.

The median reaction times are as follows:

Table 6.2 - Median reaction times for control subjects for Experiment 6.1

Median RT	Upright		Inverted	
(ms)	LVF	RVF	LVF	RVF
Same	701	714	742	768
Different	770	759	772	817
Total	727	733	758	787
Total	729		772	

This table also illustrates certain findings. The median reaction times for the inverted trials are generally longer than those for the upright trials. There is little overall difference between the two visual fields, although the LVF appears faster except for upright different trials, but only slightly. Lastly, the subjects are quicker at making correct 'same' judgements than they are at making correct 'different' judgements. When these data are analysed in the same 3-way repeated measures ANOVA as used above for the error data, the same significant main effects are found as for the errors - for orientation ($F = 5.64$, $DF = 1,15$, $P = .031$) and trial type ($F = 12.58$, $DF = 1,15$, $P = .003$) - but not even approaching significance for visual field ($F = 1.67$, $DF = 1,15$, $P = .216$ [n.s.]). Again none of the interactions is significant.

It is worth noting that when the data for the upright trials and the data for the inverted trials are analysed separately, a 2-way repeated measures ANOVA for the inverted trials yields a significant effect of visual field ($F = 5.06$, DF - 15,1, $P = .040$) where the trials presented to the LVF are processed faster than those presented to the RVF.

It is true that these data do not show a significant effect of visual field, arguing against this being a good test for prosopagnosic subjects. However, the main reason for testing them was to investigate the effect of orientation on matching, more importantly than the effect of visual field. Therefore their data are still analysed as originally planned, including the visual field data for reasons of completeness.

6.3.2 - Prosopagnosic Subjects

The data for the three prosopagnosic subjects are compared with those of the normal subjects, with respect to the percentage of errors and the overall median reaction times. Dunnett's t tests are used for both the prosopagnosic subjects and the subjects with reversed cerebral asymmetry (therefore k = 6 - see Chapter 3 for more details).

Table 6.3 - % errors for control and prosopagnosic subjects for Experiment 6.1

% errors	Control (n=16)		NR	PH	SS
	μ	σ			
Upright faces	10.5	4.24	36.3*	28.8*	18.8
Inverted faces	16.3	4.67	45.0*	37.5*	23.8
Inverted-Upright	5.9	5.4	8.8	8.8	5.0

* Significant at the 1% level

The first two rows of data show that all three prosopagnosic subjects make more errors than the controls for both upright and inverted faces, but only **NR** (upright: $t_d = 6.09$, $P < 1\%$; inverted: $t_d = 6.14$, $P < 1\%$) and **PH** (upright: $t_d = 4.32$, $P < 1\%$; inverted: $t_d = 4.53$, $P < 1\%$) make significantly more. The bottom row of the table compares the prosopagnosic subjects with the controls for the difference in the proportion of errors made between the inverted and upright face

tasks: in other words, it is a measure of how much worse the subjects are at matching inverted faces than at matching upright faces. This shows that none of the prosopagnosic subjects is disproportionately worse than the controls at either task.

Table 6.4 - Median reaction times for control and prosopagnosic subjects for Experiment 6.1

Median RTs	Control (n=16)		NR	PH	SS
(ms)	μ	σ			
Upright faces	729	153	1239**	1571**	699
Inverted faces	772	167	1160	1275*	685
Inverted-Upright	42.2	67.6	-79	-296**	-14

* Significant at the 5% level
** Significant at the 1% level

What this table shows is that both **NR** and **PH** take far longer to perform the face matching than the controls for both upright and inverted faces. For inverted faces **NR** is slower than the controls, but not significantly ($t_d = 2.32$, [n.s.]). He is slower than the controls for upright faces ($t_d = 3.33$, $P < 1\%$), as is **PH** for both upright ($t_d = 5.50$, $P < 1\%$) and inverted ($t_d = 3.01$, $P < 5\%$) faces. **SS's** reaction times are easily within the normal range, in fact slightly faster than the mean for the controls.

Note however, that new figures can be calculated for **PH** in the above experiments using the calculations presented at the end of Chapter 4, in that he could be treated as being a certain amount slower or a certain proportion slower than the controls. For upright face matching **PH** took 1571 ms and the controls took 729 ms. When 140 ms is added to the controls' RT, **PH** is still significantly slower ($t_d = 4.59$), but when the controls' RT is multiplied by a factor of 1.7, he ceases to be significantly slower. However, looking at the data for inverted face matching, **PH** took 1275 ms and the controls took 772 ms. This was significant at the 5% level. When 140 ms was added to the controls' RT he was now found not to be significantly slower, but what was interesting was that when the controls' RT was multiplied by a factor of 1.7, they were now found to be slower than **PH**! This suggests that the addition of 140 ms is a more useful manipulation of the data, although it should be noted that it is possible that some prosopagnosic

subjects could be better than controls at inverted face matching, if they are generally fast at reaction time experiments and their impairment is very specifically restricted to upright faces - this is, however, most unlikely, as **PH** was poor at both car and flower naming, and also showed some object agnosia, suggesting his impairment is not restricted to upright faces. It makes more sense to add on an additional time rather than to assume all his cognitive processes are slower by a factor of 1.7 - the former explanation is more likely.

Thus it can be assumed that **PH**'s reaction times should be corrected by adding 140 ms to the controls' RT (identical to subtracting 140 ms from his RT) and he is therefore impaired at face identity matching on the basis of reaction times for upright faces, but not inverted faces.

In a similar way to the above table, the inverted and upright face matching reaction times are compared. The last row shows the median RT for the inverted trials minus the median RT for the upright trials. The controls were overall faster for the upright faces, but the three prosopagnosic subjects were all faster for the inverted faces, although only **PH** was significantly so, and in his case very highly significantly ($t_d = 5.00$, $P < 1\%$).

The following tables show the prosopagnosic subjects' data compared to the control data as a function of visual field.

Table 6.5 - Difference in % errors made between the LVF and RVF for both upright and inverted faces in Experiment 6.1

LVF - RVF % errors	Control		SS	NR	PH
	μ	σ			
Upright	1.7	4.76	12.5	2.5	12.5
Inverted	1.3	4.87	12.5	5.0	-10.0

What this table shows is that both **SS** and **PH** ($t_d = 2.27$, [n.s.]) made disproportionately more errors for trials in the LVF than the controls for upright trials, and that **SS** ($t_d = 2.30$, P[n.s.]) also made disproportionately more errors for trials in the LVF for inverted trials, but that these statistics

were just not significant (for a value of k=6, a t_d statistic of 2.51 is needed to be significant at the 5% level). However, **PH** (t_d = 2.32, [n.s.]) made disproportionately more errors in the RVF for inverted trials compared to the controls, but again just not significantly more. **NR** did not show any difference between the two tasks in terms of visual field differences and hence hemispheric asymmetry. None of these data are significant.

Table 6.6. - Difference in reaction times between the two visual fields in Experiment 6.1

LVF - RVF	Control		SS	NR	PH
Median RT (ms)	μ	σ			
Upright	-6	69	94	-204*	15
Inverted	-29	69	93	-183	111

* Significant at the 5% level

The reaction time data when viewed in this way appear to show a different pattern from the error data. One reason for this is the existence of a speed-accuracy trade-off, which is already discussed in more detail in section 1.3.1. However, the lack of significant data do not make comparison between error and reaction time data useful in terms of such an effect. **SS** is disproportionately slower in the LVF for both upright and inverted trials, but not significantly so. **PH** is not disproportionately slower in either visual field for upright trials, but for inverted trials is disproportionately, but again not significantly, slower in the LVF (t_d = 2.03, [n.s.]) than the controls, who do not show any significant difference in reaction times between the two visual fields (as covered earlier in this chapter). **NR**, on the other hand, is disproportionately slower for trials in the RVF, significantly so for upright trials ($t = 2.87$, $P < 5\%$) and just not significantly so for inverted trials (t_d = 2.23, [n.s.]). The existence of only one significant statistic does not allow detailed interpretation of the results.

6.3.3 - Reversed Asymmetry Subjects

The percentage errors and median reaction times for subjects **HJ** and **RL** are compared with the controls' data.

Table 6.7 - % errors for the control and reversed asymmetry subjects for Experiment 6.1

% errors	Upright		Inverted	
	LVF	RVF	LVF	RVF
Control μ	11.4	9.6	17.0	15.8
σ	4.44	5.26	5.16	5.36
HJ	0.0*	2.5	10.0	8.8
RL	11.3	16.3	21.3	27.5

* Significant at the 5% level

This table shows first that **HJ** is very accurate at this task, in fact making no errors at all for upright trials in the LVF, and this was significant ($t_d = 2.54$, $P < 5\%$). When all his upright face trials for both visual fields are compared with the controls he still makes fewer errors, but not significantly so ($t_d = 2.17$, [n.s.]).

RL, on the other hand, made either the same proportion of errors as the controls or more, almost significantly so for the inverted trials in the RVF ($t_d = 2.20$, [n.s.]).

Table 6.8 - Median RTs for control and reversed asymmetry subjects for Experiment 6.1

Median RT	Upright		Inverted	
(ms)	LVF	RVF	LVF	RVF
Control μ	727	733	758	787
σ	159	157	160	184
HJ	717	685	1059	1105
RL	737	655	964	1060

There were no significant differences in the reaction times between **HJ**, **RL** and the control subjects. However, it should be noted that even though the differences are not significant, for at least the inverted trials **HJ** was slower than the controls and also made fewer errors than the controls. One possible reason for this is that he might have been concentrating on accuracy at the expense of speed.

In a similar way to that used for the prosopagnosic subjects in the above section, the data for the difference between **HJ**'s and **RL**'s visual fields were compared with that of the controls .

Table 6.9 - % errors for LVF minus RVF for control and reversed asymmetry subjects for Experiment 6.1

LVF - RVF	Control		HJ	RL
% errors	μ	σ		
Upright	1.7	4.76	-2.5	-5.0
Inverted	1.3	4.87	1.2	-6.2

Unlike the prosopagnosic subjects, neither **HJ** nor **RL** show a significantly different pattern of errors data from the controls, although **RL** does make more errors in the RVF, unlike the average for the controls.

The following is a table for the LVF median RT minus the RVF median RT - i.e. the difference between them.

Table 6.10 - Median RT for LVF minus RVF for control and reversed asymmetry subjects for Experiment 6.1

LVF - RVF	Control		HJ	RL
RT (ms)	μ	σ		
Upright	-6	69	32	-46
Inverted	-29	69	82	-96

The table shows that **HJ** appears to have the opposite trend to the controls in that he is generally faster for trials in the RVF for both upright and inverted trials. The controls show no visual field advantage, and **RL** shows a slight LVF advantage: however, none of these results is significant.

6.4 - Discussion

6.4.1 - Control Data

Looking first at the control data by orientation, trial type and visual field, we see that the subjects are significantly faster and make significantly fewer errors for those trials where the faces are upright than those when they are inverted. The second point is that they are better at making 'same' judgements than they are at making 'different' judgements, making significantly fewer errors and responding significantly faster for the former trial type. The third point is that there was no overall significant difference between the two visual fields on the basis of either

reaction times or error rates. However, when the data for the two blocks were analysed separately, treating upright and inverted face matching as two different experiments, those faces in the LVF were matched significantly faster than those presented to the RVF for the inverted trials only; there was no such significant effect of visual field on the basis of the error data even when the upright and inverted trials were analysed separately. Thus there is evidence for a LVF advantage (in terms of reaction time) for inverted faces. This is contrary to the hypothesis, that there would be a LVF advantage for upright faces, and this would be removed or reversed for inverted faces. No explanation can be offered for this finding at the present time.

Regarding the orientation of the faces, it is not surprising that the subjects should be faster and make fewer errors for upright face matching that inverted face matching. This has been reported several times (Valentine 1988) and reflects the fact that we have far more experience of upright faces than of inverted faces, and can therefore match upright faces more easily.

As far as visual field is concerned, the hypothesis was that there is a right hemisphere superiority in face matching, and this should lead to a significant effect of visual field, at least for the upright faces. However, it has been claimed that the right hemisphere is superior for faces but not for inverted faces. Therefore it was also hypothesised that this LVF advantage would be removed in the inverted condition. However, this is not what was found. Overall there was no significant effect of visual field, and neither was there a significant effect of visual field for the upright face trials. There was however a significant effect of visual field (LVF faster) for inverted faces based on the reaction times (though not on the error data). This is contrary to what was expected and is difficult to explain in any convincing fashion.

On the basis of both reaction times and error rates, the control subjects were significantly better at responding correctly to 'same' trials than to 'different' trials. This suggests that the internal

criterion was set to be more likely to accept pairs of faces as similar and take longer to reject pairs of faces as different.

6.4.2 - Prosopagnosic Subject Data

When the three prosopagnosic subjects were compared with the controls for matching upright faces, it was found that **SS** was not significantly impaired, but both **NR** and **PH** were significantly slower and less accurate than the controls. All three prosopagnosic subjects made more errors on inverted trials than on upright trials, unlike patient **LH** (Farah et al 1995a) but like the control subjects. **NR** and **PH** made significantly more errors than the controls, but **SS** was not significantly worse. However, all three prosopagnosic subjects were faster at matching inverted faces than upright faces, significantly so in the case of **PH**. **NR** was significantly slower than the controls for upright faces only, but **PH** was slower for all trials. This is not surprising in light of his results in Chapter 4, showing that all his reaction times are elevated. These reaction time data are very interesting because they suggest that the prosopagnosic subjects may find it easier to match inverted faces than upright faces, and this would corroborate Farah's evidence for **LH**, although this effect was not replicated in the error data. The reaction time data suggest that **PH** might be disproportionately impaired at matching upright faces compared to other classes of stimuli, specifically inverted faces in this case. The same claim cannot at present be made for the other two prosopagnosic subjects, as their reaction time data, although suggestive of such a finding, are not significant.

When the visual field data for the prosopagnosic subjects are examined, at first glance the patterns of their results appear to be different for each of them. However, it is important to note that only one value (**NR**'s reaction time difference between the visual fields for matching upright faces) was significant - **NR** made a similar number of errors in each visual field, but he was much slower for faces in the RVF, significantly so for upright faces. This is surprising,

suggesting a RH advantage not expected in a prosopagnosic subject. This may be explained by his RH parietal damage but more extensive LH parieto-temporal damage. However, it should also be borne in mind that the control subjects did show a significant hemispheric advantage. This fact, together with the lack of significant data for field differences for the prosopagnosic subjects means that little conclusion can be drawn from the field data.

6.4.3 - Subjects with Reversed Asymmetry

Both **HJ** and **RL** were normal in their speed and accuracy, except that **HJ** performed at ceiling for upright trials, making no errors. Like the controls, both subjects with reversed hemispheric asymmetry made more errors when the faces were inverted, compared to when they were upright. Both were also quite a bit slower (though not significantly) for inverted trials, whereas the controls had only been slightly slower. When the data for the two visual fields are compared, neither subject was significantly different from the control subjects, although they both showed a trend opposite to that of the controls, making more errors in the RVF for upright trials, and **RL** also made more errors in the RVF for inverted trials. To uncover a LH superiority for face matching, they would have to show a significant RVF advantage and the controls would have to show a significant LVF advantage: this is certainly not what was found. Again there are no significant differences between the two visual fields in terms of reaction times, although **HJ** is slightly faster for trials in the RVF for both inverted and upright trials, and **RL** is slightly faster for trials in the LVF, again for both inverted and upright trials. Both subjects show a greater field asymmetry for inverted trials than for upright trials, but again not significantly so. An explanation for these findings is elusive, but, again, being non-significant statistics, not too much weight should be ascribed them. One likely reason for the lack of significant field data lies in the experimental set-up, which is still not sensitive enough to measure the subtle laterality effects being investigated.

6.4.4 - Overall

This experiment did not show a convincing RH advantage for face matching any more than the experiments outlined in the previous chapter did. One possible reason for this is the role that the hair may have played in the matching task: the hair was not hidden from view in the photographs, and may have acted as an important cue to identity, removing the necessity for using a holistic configural strategy, and thereby resulting in no hemispheric asymmetry. Another reason, as above, is that the experimental design and set-up are still not sensitive enough to detect subtle laterality differences. Both the control subjects and the subjects with reversed hemispheric asymmetry found it harder to match the inverted faces, performing either more slowly, less accurately, or both. The prosopagnosic subjects, on the other hand, were faster at matching the inverted faces (**PH** significantly so), although they too made more errors for the inverted faces. This decrease in reaction time as a result of inversion suggests that **PH** may have a disproportionate impairment in matching upright faces, which is the view put forward in much of the prosopagnosia literature, although this is not borne out by the error data. More data would be needed from the other two prosopagnosic subjects to investigate this possibility more fully, as their data were not significant.

These data suggest that the prosopagnosic patients may find inverted face matching easier than upright face matching, which is evidence for a specialised processing module for upright face matching (and recognition) which is disrupted in prosopagnosia. However, more investigation would be needed to tease apart the different trends in the reaction time and error data. The experiment failed to show a RH advantage in the controls, and also failed to show a LH advantage in the subjects with reversed asymmetry.

CHAPTER 7 - EXPRESSION MATCHING EXPERIMENTS

7.1 - Introduction

As well as ascribing identity to an individual due to the uniqueness of each face, faces portray a host of other information through the gestures they can produce. These gestures can be emotional of communicative. Emotional facial expressions tell us a great deal about the mood of a person and as such are very important for social communication. They are the visible aspect of our emotions and moods, and their recognition assists other people in assessing our moods and likely actions. Indeed, conversation with someone unable to make facial expressions, for instance as the result of facial muscular paralysis, can be more difficult than normal as the lack of expressions makes it hard to decipher the emotions behind possibly ambiguous speech. Patients with Parkinson's Disease, for example, often are unable to control their facial muscles and appear to have a flat, neutral expression all the time. This makes it very hard to tell what their mood is and also makes it difficult to communicate with them. In other primates, too, facial expression conveys information about the social hierarchy and mood of the monkeys. The ability to recognise facial expression forms an important aspect of the Theory of Mind. Communicative facial expressions communicate information not necessarily relevant to the mood of the person making the expression, and include for instance such information as whether a food tastes good or not, or the jerking of the head and raising of the eyebrows to one side to gesture 'over there'. This chapter concentrates on emotional facial expressions.

In normal everyday communication we have little problem in recognising others' facial expressions, and give the processing of such information little thought. The ability to recognise and also mimic facial expressions comes very early on in life - from about 6 weeks old a baby can smile in response to a smiling adult. Adults can generally distinguish emotional from non-

emotional (neutral) faces and reliably identify six basic categories of facial expression - happiness, sadness, surprise, disgust, fear and anger.

Some prosopagnosic subjects, in addition to being impaired on face identity recognition and matching, have been shown to have poor recognition, matching and naming of facial expressions compared to normal adults or others with right sided brain damage not leading to prosopagnosia, and this can sometimes be seen in their everyday lives as a failure to determine someone's mood as well as their identity until that person starts speaking. However, there is also evidence that some subjects may be prosopagnosic for facial identity but not for facial expression. Such a double dissociation lends support to expression and identity processing being separate processes, as suggested by Bruce and Young (1986)'s model. The exact loci of damage causing these deficits is not known, although it is generally agreed that right sided, and possibly bilateral, occipito-temporal damage is needed (De Renzi 1986, Ettlin et al 1992, De Renzi et al 1994).

When the superior temporal sulcus (STS) was lesioned (Heywood and Cowey 1992), the only deficit the monkeys showed was that of eye gaze direction detection, at which they were poor, but identity and expression processing were unaffected. Rolls suggested (in response to Heywood and Cowey's paper) that lesioning inferotemporal areas, which have been shown to contain face cells sensitive to identity (Rolls, 1992) might cause deficits in identity matching. However, as has been pointed out, monkeys with bilateral lesions of the inferotemporal area (IT) are impaired at a range of visual discrimination and identification tasks (e.g. Gross 1992, Eacott et al 1993) including identity and expression matching. Lesion data then does not yield a double dissociation between expression and identity processing, but neurophysiological data do: face cells which respond preferentially to faces have been found in various cortical areas (e.g. Perrett et al 1984, 1988, Rolls 1984) and Rolls and colleagues (Hasselmo et al 1989, Rolls 1992) have found different populations coding for identity in the IT gyrus and expression in the STS. This

lends support for expression and identity processing being separate.

An interesting question concerning the STS in monkeys is the identification of its anatomical and functional homologues in man. It has been suggested by Passingham (1997) that Wernicke's area in the LH of man may have an anatomical homologue in the left STS in monkeys. He says it is likely that it includes the upper bank of the STS and area Tpt, and possibly also the lower bank of the STS and area MTG. Heywood and Cowey (1992) have shown that monkeys with STS lesions are impaired at the detection of eye gaze direction. Desimone (1991) has also suggested that there may be a functional homology between the STS in monkeys and Wernicke's area in humans. A relevant finding that may suggest a possible functional homology between the two areas was shown by Dewson and colleagues (e.g. Cowey and Dewson 1972) who found that monkeys with STS lesions were not able to discriminate vowel sounds. This could be explained either by assuming that the STS and adjacent areas in monkeys have a role in the discrimination of auditory stimuli (with no relevance to 'language' whatsoever), or that these areas have a role in simple communication perception. Language is surely more than just auditory discrimination as the sound to referent mapping is generally abstract (i.e. the sound of a word usually gives no hint to its meaning). If the STS does have a role in generalised communication perception, and if language comprehension and eye gaze perception are both forms of communication processing, then it may follow that Wernicke's aphasics would show poor eye gaze detection. Facial expression is also a form of social communication and therefore it too may be poorly processed by Wernicke's aphasics. It was originally hoped that these hypotheses would be tested in these experiments, but unfortunately it was not possible to gain access to any Wernicke's aphasics to test them. This is an idea for future research (see Chapter 10).

Another intriguing aspect concerning facial expression perception is whether there is any

detectable hemispheric asymmetry in normal adults' ability to process expression information. It has been shown in previous experiments that there is sometimes a RH (LVF) advantage for face processing, in terms of faster reaction times and lower error rates for face matching. If this RH advantage is due to the special position that faces have in our visual perception abilities, and not just because faces are the most common and experienced multi-exemplar category with very similar exemplars, then there ought to be a RH advantage for matching expression in normals as well.

Another possible reason for expecting a LVF / RH advantage is that expression perception may require the registration of the holistic nature of the configurational properties of the features. One piece of evidence for this is that inversion impairs expression recognition (McKelvie 1995) for many expressions, and could be explained by the fact that someone showing two different expressions one after another will move his or her features, and their relative positions will change. However, it is also true that some expressions could be recognised on the basis of feature analysis. For instance, a surprised expression usually includes an open mouth, and possibly raised eyebrows, though here again this latter sign would be perceived as a configurational difference from other expression in that the distance between the eyes and eyebrows, and also between the eyes and hairline are increased. Again, McKelvie (1995) suggests that some expressions, whose recognition is not impaired by inversion, such as happy, may be represented componentially rather than configurally. Therefore it could be argued that expression perception relies on both local and global perception.

There have been a number of studies exploring hemispheric asymmetry in expression perception and expression learning (Schmitt et al 1997, Johnsen and Hugdahl 1991, and a review of earlier experiments in Ley and Strauss 1986) which used various paradigms, including forced-choice naming, autonomic conditioning to expression and same-different matching. Several of these

studies found a LVF advantage, although the task demands varied from experiment to experiment. In some cases this RH advantage was only found for certain expressions, for instance happy and sad, but not neutral, which gave rise to a RVF advantage (Buchtel et al 1978), and, in others, only for female subjects (Ladavas et al 1980). Overall, most of the studies show some LVF / RH advantage for both positive and negative facial expressions, although not all researchers have found the RH advantage for both: Reuter-Lorenz and her colleagues conclude that the RH advantage applies only to negative emotional expressions (e.g. Reuter-Lorenz and Davidson 1981), as do Schmitt and colleagues (1997) for fear and Hugdahl and colleagues (Johnsen and Hugdahl 1991, Hugdahl et al 1989) for anger.

The following set of three experiments is designed to investigate both how well prosopagnosic subjects can match facial expressions across faces and across view in comparison with normal control subjects, and secondly whether there is any hemispheric asymmetry of facial expression perception in the control subjects. When investigating the hemispheric asymmetry for expression matching, I am not analysing the positive emotional expressions separately from the neutral or negative ones - that is not being investigated in this thesis. However, these experiments specifically involve matching across views, which has not been investigated nearly as much as matching for the same view (e.g. Johnsen and Hugdahl 1991, Ladavas et al 1980, Reuter-Lorenz and Davidson 1981), and it more clearly necessitates an object-centred representation to be accessed and mentally rotated rather than the possibility of matching on the basis of the stimuli themselves without resorting to their 'meaning'. Matching on the basis of identity is also tested using exactly the same stimuli as the expression matching experiment so that those two tasks can be compared directly (cf. Young et al 1986). Note that Young et al (1986) did test matching across view, but not for prosopagnosic subjects, which the present experiments do investigate.

The first experiment (Experiment 7.1) tests the prosopagnosic subjects' and control subjects' ability to pick the one photograph from an array of 6 which shows the same facial expression as the probe, but not the same person, and a second photograph showing the same person but not the same expression. Only error rates and not reaction times were measured, and the subjects were allowed as long as they wished.

The aims of the second and third experiments (Experiments 7.2 and 7.3) are designed to investigate reaction times and error rates for matching both expressions and personal identity separately. The second experiment measures errors and reaction times for matching faces for expression, ignoring facial identity, and the third experiment measures errors and reaction times for matching facial identity, ignoring expression, for exactly the same stimuli as the second experiment. These two experiments also compare the processing of facial expressions and identity for the two cerebral hemispheres of the control subjects, using a similar tachistoscopic split-field paradigm to those used in previous experiments. This uses a similar method to Young et al (1986) except that they did not investigate hemispheric asymmetry, instead comparing familiar and unfamiliar faces. Previous facial identity matching experiments I have carried out (see Chapters 5 and 6) failed to give a large RH advantage, if at all, but this may have been due to inadequate visual stimuli, for instance a set of faces which varied in distinctiveness, or due to the strategy that the majority of subjects, when asked, confessed to - that of matching the faces on the basis of hairline alone - a local feature. This also assisted inverted face matching, and there was little hemispheric difference in that case compared to upright face matching, although a slight LVF advantage was found, contrary to expectations.

However, as mentioned earlier, perception of facial expression by its very nature could be thought to be global (McKelvie 1995) - in real spontaneous expression many features combine to produce the overall expression. Therefore, I would expect to obtain a RH (LVF) advantage for expression

matching. Note, however, that if I do not obtain such an asymmetry, this may be due to the stimuli portraying posed and unnatural expressions as opposed to spontaneous ones. The other hypothesis being tested is that all three prosopagnosic subjects will be impaired compared to the controls on both the expression matching and identity matching, as has been shown in previous research (de Haan and Campbell 1991, de Haan et al 1987, de Haan et al 1992).

7.2 - Method

7.2.1 - Stimuli - Photographic Images

For all three experiments, images of people's faces showing specified facial expressions were required. However, as one set would be shown as photographs and the other two experiments necessitated images on a computer monitor it was thought easiest to use two different cameras - a normal automatic one for the photographs, which could be developed in the usual way, and a special Canon Ion camera which saves images on a video floppy disc which can then be transferred to the computer as raw data images for the computer images.

Eight young adult males were asked to pose for each of 7 expressions. The expressions used were neutral, happy, sad, surprised, angry, disgusted and frightened. Photographs of each expression were taken with the models facing the camera and with them facing to the side of the camera, so that they were at about 20 degrees profile. This enabled matching across view to be investigated. They were asked to 'look' each expression, such as 'look sad' rather than 'be sad', but if they had problems making any expression, a simple scenario was suggested to them whereby they might feel the emotion leading to the expression required. This gave a total of 56 images looking in each of the two directions.

7.2.1.1 - Photographs for Experiment 7.1

Suitable lighting was arranged in the room so that flash photography was not needed. The pictures were taken using the background of a door behind the posing subjects. A total of 127 photographs were taken, on an automatic Olympus OM-30 SLR camera mounted on a tripod and processed into normal 6" x 4" photographs. Note that multiple pictures were taken of certain models making certain expressions, giving a total of more than 112. The 6" x 4" photographs were used for the task when the subject had to choose one of an array of possible target faces laid out in front of him or her. The photographs comprised the whole head including the hair, and also the top part of the body and arms. Clothing was therefore an additional cue to identity matching, though not to expression matching, which was they main task of interest. The photographs of each person were not necessarily taken all in the same session, and two of the models wore different clothes for different photographs. The effect of this on the results is noted later.

After all the pictures had been taken and developed into 6 x 4 inch prints, another set of 8 subjects were asked to label them all from the possible list of 7 expressions given above. Only those photographs which 6, 7 or 8 subjects labelled the same were kept for the experiment. This led to only 65 out of 127 original photographs being used for this experiment. Examples of the images used are shown in Appendix A.3.

7.2.1.2 - Images for Computer Presentation

The images needed for the two computer-controlled experiments (Experiments 7.2 and 7.3) were taken on a Canon Ion Still Video Camera model RC-260 which fed the images directly into a PC. This takes a smaller field and also the faces were closer to the camera, so in this case the models sat on a stool with a black curtain behind them and suitable lighting. They also had a head rest behind the back of their head to ensure their head was in the same position in each picture. These

images were then converted to a .PCX form and used in the TurboPascal programs, showing the images for a specified time on a computer monitor.

The eventual images had to be in the same format as for the previous experiments (see Chapter 7) so that they could be used by the Turbo Pascal programs. This was black and white 160 by 200 pixels, saved as raw data with no header: each was therefore 32 K in memory size. The Canon Ion camera saved the images in full colour with a very much larger memory demand, so firstly the Ion program was used to convert all the images to mono (i.e. grey scale, dividing the memory required by a factor or 3), then all the images were transferred to Adobe Photoshop on the Apple Macintosh, which converted them to the right size and raw black and white data. Small amounts of graphic editing were also carried out at this stage, for instance hiding the corners of the head rest which protruded from the sides of the head on some frontal pictures. Also the faces were centred in the images, which they had not all been when the pictures were taken. Only the faces and hair and possibly the top of the shoulders were shown, and most clothing and collars were edited out of the images. Any clothing left in the pictures was generally dark and nondescript, giving no additional cues to identity, and certainly not to expression, of course. Then 8 subjects were asked to label them in the same way as those above, and only those images were used which were labelled correctly by 6, 7 or 8 people. This led to 72 out of 126 images being used.

7.2.2 - Procedure

7.2.2.1 - Experiment 7.1

Subjects

Six control subjects were tested. Four were male and 2 female. Their ages ranged from 21 to 31 years, with a mean of 26 years and a standard deviation of 3.4 years. The three prosopagnosic subjects described in Chapter 3 were also tested.

Procedure

In this experiment, the photographs were used. An array of 6 photographs was laid out on the table. Then the probe photograph was shown to the subject, who was asked to point to or pick the photograph in the array which showed the same expression as the probe and the one which showed the same identity as the probe. The six photographs in the array were each of different people and different expressions, one of which showed another person making the same expression as the probe, and one of which showed the same person as the probe, making a different expression. The fact that certain pairs of expressions are more easily confused with each other (e.g. surprise / fear) than other pairs (e.g. happy / sad) was not taken into account in this task, and therefore the exact photographs used in each trial, although the same for all the subjects, were in fact essentially random.

Each subject was given 14 trials matching for both identity and expression. Error scores were noted, but there was no measure of reaction times in this task: indeed the probe was left in the subject's view for as long as they wished.

7.2.2.2 - Experiments 7.2 and 7.3

Subjects

Initially 21 subjects were tested. Three were left-handed and the other 18 were right-handed. Their ages ranged from 18 to 29 with a mean of 20.2 years and a standard deviation of 3.1 years. However, on analysis of the data it was discovered that there had been an error in the program and that no visual field data had been recorded. Therefore the experiment was run for a second time to provide the visual field data needed to investigate the hemispheric asymmetry of the task.

This second group consisted of 17 subjects (1 left-handed and the remainder right-handed). Six were male and 11 were female, and their ages ranged from 18 to 28 with a mean of 20.8 years and

a standard deviation of 2.7 years. However, the data for the earlier experiment with the 21 subjects are included in this chapter and the ensuing analyses where visual field was not an issue, specifically where comparison of the prosopagnosic subjects with a control group was necessary. For this reason the reader should note whether any table says 'n=17' or 'n=38' at the top, to determine whether only the second or both sets of control subjects were included in that particular analysis. The program was exactly the same for both groups except that the first version did not save the visual field data. For this reason, the two groups are treated as one with respect to overall reaction times and error rates.

For those tasks where all 38 subjects are included in the analyses their ages range from 18 to 29, with a mean of 20.5 years and a standard deviation of 2.9 years.

Also the three prosopagnosic subjects **SS**, **PH** and **NR** were tested. They are described in detail in Chapter 3.

Procedure

The procedure followed was similar to that of previous experiments (see Chapters 6 and 7). The subject sat facing the computer screen and a fixation cross was shown in the centre of the screen for 750 ms. The first face was then displayed for 2 seconds in the centre of the screen. A second fixation cross was then presented, again in the centre of the screen for 750 ms and then the second face was presented briefly, for 150 ms, in the centre of one side of the display. The subject was instructed not to move his or her eyes to the second face but keep their gaze directed towards the centre of the screen. The brevity of the presentation helped decrease the probability of looking at the second face, as did the factors already mentioned in Section 3.4. Reaction times taken to make the judgement required were measured.

There were three types of trials. The two faces showed either the same expression but different people, the same person but different facial expressions, or both different identities and different expressions. In Experiment 7.2 the subject was instructed to decide whether the faces showed the same expression and ignore the identity, and in Experiment 7.3 the subject was told to ignore expression and decide whether the faces were of the same person or not. A manual response was used, one button being pressed for 'same expression' and the other button for 'different expression' in Experiment 7.2 and 'same identity' and 'different identity' in Experiment 7.3. (Note that the prosopagnosic subject **PH** pressed both buttons with different fingers of his left hand - see Chapter 3 for details.)

In each experiment the 'same' category - i.e. same expression for Experiment 7.2 and same identity for Experiment 7.3 - comprised half the trials with the other two trial types comprising a quarter of the total number of trials each. Thus for any block the subject would press each response button an equal number of times, assuming they performed at a level of 100% correct.

The other difference between the two faces presented in any one trial was the view. In each trial the two faces differed in the direction in which they were facing: one was directly facing the camera and the other was looking about 20 degrees over the subject's right shoulder. Which of the two faces was full-face and which was in profile varied randomly from trial to trial, but overall half of the trials presented the central first face full-face and half presented the second tachistoscopic face full-face. Thus there is the additional factor of a different angle of view as well as possibly different identity, expression or both to increase the difficulty of the task.

To familiarise themselves with the task, each subject first performed one practice block of 12 trials, the results of which were not recorded. They then performed three blocks matching identity, and three matching expression, and these were alternated, such that no two adjacent blocks were of the

same type, except for the practice block, which was of the same type as the first real block. The first block given was counterbalanced across subjects, as was response hand for 'same' responses. Each block contained 48 trials. After 24 trials in each block the subjects were given a break to rest their eyes and renew their concentration. Due to time constraints of access to the prosopagnosic subjects, **NR** and **PH** only sat 2 blocks for each experiment, giving them overall two thirds the number of trials which **SS** and all the controls carried out. However, their data were analysed in precisely the same way as for the other subjects.

7.3 - Results

7.3.1 - Experiment 7.1

The results for the six control subjects and the three prosopagnosic subjects were as follows:

Table 7.1 - Number of errors made in Experiment 7.1

No. of errors	Controls (n=6)		NR	PH	SS
	μ	σ			
Expression	0.5	0.55	6*	1	1
Identity	0	0	5*	2*	2*

* Significant at the 1% level

As can be seen from Table 7.1, **NR** was much worse than either the other two prosopagnosic subjects or the controls at this task. Some of the pairs of pictures of the same person showed them wearing different clothes and all three prosopagnosic subjects were caught out by this - twice for **SS** and **PH**, and three times for **NR**. **NR** did not seem to notice the clothes explicitly, and matched one pair incorrectly as he said he was trying to go by the shape of the nose, rather than the clothes, which were clearly visible. The subjects were allowed unlimited time, and time was not explicitly measured, but it was noticed that both **PH** and **NR** were extremely slow to make a decision. The control subjects made no errors on the identity matching, although some of them found the first trial, where the probe and target pictures were of the same person wearing different clothes , harder than the subsequent trials, commenting on this. The three control subjects who each made one error on expression matching made the error on the same trial, confusing the expressions of anger

and disgust. Analysis shows that **NR** was significantly worse than the controls as both expression and identity matching, and both **SS** and **PH** were significantly worse than the controls at identity matching, although it should be noted that the controls found the task extremely easy and scored 100%. Given this ceiling effect we can conclude that the prosopagnosic subjects are impaired compared to the controls, but it is difficult to say whether it is a qualitative or quantitative impairment.

7.3.2 - Experiment 7.2

This experiment investigated the subjects' ability to match across views on the basis of facial expressions whilst ignoring identity. Firstly the controls' error and reaction time data by trial type and visual field will be presented, and then the overall prosopagnosic subject data in comparison to the controls will be presented.

7.3.2.1 - Error data

As there were a different number of trials carried out for each condition, the percentage of errors was calculated as being the most useful piece of error information. The following table shows the percentages of errors made by the control subjects (n=17) as a function of both visual field and trial type.

Table 7.2 - Percentage of errors made by the controls when matching expressions (n = 17)

% errors	Left visual field	Right visual field	Overall
Different	13.7	15.7	14.7
Same expression	25.2	20.4	22.8
Same identity	15.0	18.3	16.7
Total	19.8	18.7	19.2

The above table shows that there was little difference in the percentage of errors made between the visual fields, but that more errors were made on trials where the expressions were the same, suggesting that it is particularly difficult to be confident of similarity of expression when the two faces differ in other ways, such as identity or viewpoint. This bias appeared stronger for faces in

the left visual field. To investigate these data statistically a repeated measures ANOVA was carried out for the above data. There were two factors, visual field (two levels) and trial type (three levels). As was expected from the table, there was a significant effect of trial type ($F = 4.91$, $DF = 2,32$, $P = .014$) but not a significant effect of visual field ($F = 0.01$, $DF = 1,16$, $P = .913$ [n.s.]). The interaction between visual field and trial type was also not significant ($F = 1.70$, $DF = 2,32$, $P = .199$ [n.s.]).

When the percentage error data were first transformed with a log transform to make the distribution more normal, the results of the ANOVA were still a significant effect of trial type ($F = 5.37$, $DF = 2,32$, $P = .010$) but not of visual field ($F = 1.99$, $DF = 1,16$, $P = .178$ [n.s.]), nor was the interaction significant ($F = 2.45$, $DF = 2,32$, $P = .102$ [n.s.]). Thus, whether or not the transform is used on this particular data set the results of the ANOVA are the same. Note that as there are values of 0, it was decided to use ln(errors percent + 1). This is explained in more detail in Chapter 3.

When the control data were compared with those of the prosopagnosic subjects, the overall error percentages were as shown in the table below:

Table 7.3 - Percentage error data for controls and prosopagnosics on expression matching

	Control		NR	PH	SS
	μ	σ			
% errors (n=17)	19.2	6.53	38.5*	25.0	25.7
% errors (n=38)	17.5	4.98	38.5*	25.0	25.7

* Significant at the 1% level

When these data are investigated by trial type and then visual field the following results emerge:

Table 7.4 - Percentage error data for prosopagnosics and controls on expression matching

% errors	Control (n=17)		NR	PH	SS
	μ	σ			
Different trials	14.7	7.07	41.7**	16.7	13.9
Same expression	22.8	8.38	33.3	35.4	34.7
Same identity	16.7	11.24	45.8*	12.5	19.4
Left visual field	19.8	6.51	35.4*	22.9	29.2
Right visual field	18.7	7.86	41.7**	27.1	22.2

* Significant at the 5% level
** Significant at the 1% level

Tables **7.3** and **7.4** show several things. All three prosopagnosic subjects made more errors than the controls at matching for expression, especially **NR**. The other two prosopagnosic subjects, however, could be described as being at the higher end of the normal range. Where the trials were of two different people with the same expression, all three prosopagnosic subjects were consistently poorer at detecting the matched expressions, although both **PH** and **SS** were better at detecting when the expressions were different (whether identity was the same or not). This was however not the case for **NR**, who performed close to chance. Both **NR** and **PH** made more errors for faces presented to their RVF, whereas **SS** made more errors for faces presented to the LVF.

When Dunnett's t tests (k = 4) are applied to the error data (as explained in Chapter 3), only **NR** matches expression significantly worse than the controls both overall (for 17 controls, $t_d = 2.96$ - $P < 0.01$; for 38 controls, $t_d = 4.22$ - $P < 0.01$) and for different trials ($t_d = 3.81$ - $P < 0.01$) and same identity trials ($t_d = 2.59$ - $P < 0.05$). He was not, however, significantly worse for same expression trials nor were either of the other two prosopagnosic subjects significantly worse for any condition (**PH** overall $t_d = 0.88$ - n.s.; **SS** overall $t_d = 0.99$ - n.s.). On the basis of the visual field data only **NR** is significantly worse than the controls, and for both visual fields (LVF: $t_d = 2.40$ - $P < 0.05$; RVF: $t_d = 2.93$ - $P < 0.01$). Neither of the other two prosopagnosic subjects are significantly worse than the controls - indeed, they are at the slower end of the normal range.

7.3.2.2 - Reaction time data

Mean reaction times with outliers removed were calculated but there was no difference between the analyses for mean and median reaction times. Therefore it was decided to include only median reaction time data here. However, for the sake of completeness the reader is invited to see Appendix D.2 for an explicit comparison of the mean and median data. The following table contains the median reaction times for all controls:

Table 7.5 - Median reaction time data for controls on expression matching (n=17)

Median RT (ms)	Left visual field	Right visual field	Total
Different	869	858	864
Same expression	898	888	890
Same identity	847	870	859
Total	875	882	876

The above table shows no main effect of either visual field or trial type. This is borne out by the results of the ANOVA carried out as for the error data: visual field ($F = 0.01$, $DF = 1,16$, $P = .941$ [n.s.]) and trial type ($F = 0.87$, $DF = 2,32$, $P = .428$ [n.s.]) are both clearly not significant, and neither is their interaction ($F = 0.66$, $DF = 2,32$, $P = .522$ [n.s.]).

When the prosopagnosic subjects' data for overall reaction time are compared to the control data, the following results appear:

Table 7.6 - Reaction time data for prosopagnosics and controls on expression matching

Median RT	Control		NR	PH	SS
	μ	σ			
(ms) (n=17)	876	176	1210	1689*	803
(ms) (n=38)	887	203	1210	1689*	803

* Significant at the 1% level

The above table shows immediately that **PH** is much slower than the controls and that **NR** appears to be somewhat slower, but **SS** has normal reaction time data. On the basis of t tests only **PH** is significantly slower (for 17 subjects, $t_d = 4.62$ - $P < 0.01$; for 38 subjects, $t_d = 3.95$ - $P < 0.01$); **NR** is just not significantly slower than the controls, although near the slowest end of normal reaction times ($t_d = 1.90$ - n.s.) for the 17 controls, but when compared with the 38 controls, he is

further from being significantly slower (t_d = 1.59 - n.s.). **SS** is certainly not different from the controls in either table (for both tables, t_d = 0.41 - n.s.). It should however be noted that this is reflected in the results from Experiment 4.1 (Chapter 4) showing that **PH** has a slower baseline reaction time than the other two prosopagnosic subjects.

7.3.3 - Experiment 7.3

This experiment investigated the subjects' ability to match identity from faces whilst ignoring facial expressions using the same stimuli as the previous experiment.

7.3.3.1 - Error data

Again percentage error data were calculated. Overall this led to error percentages for the controls as shown in the table below:

Table 7.7 - Percentage of errors made by the controls matching identity (n = 17)

% errors	Left visual field	Right visual field	Overall
Different	13.1	11.4	12.3
Same expression	22.2	19.6	20.9
Same identity	18.3	18.0	18.1
Total	18.0	16.6	17.4

This table shows that more errors were made for the faces in the left visual field and more errors made when for both visual fields when the faces had something in common, either identity or expression. To investigate these data statistically the same ANOVA as described above for Experiment 7.2 in this chapter was carried out (visual field - 2 levels; trial type - 3 levels). This analysis yielded a significant effect of visual field (F = 9.75, DF = 1,16, P = .007) but not a significant effect of trial type (F = 0.46, DF = 2,32, P = .637 [n.s.]). However, there was also a significant interaction of the two factors (F = 5.25, DF = 2,32, P = .011). Post-hoc Tukey test shows that this interaction arises from a significant different (P < 0.02) between the two visual fields for 'different' trials only. The visual field effect is explained by fewer errors for trials in the right visual field than in the left visual field.

When log transformed data were analysed in the same ANOVA the following results were obtained: a significant effect of visual field ($F = 9.78$, $DF = 1,16$, $P = .006$) but not of trial type ($F = 1.87$, $DF = 2,32$, $P = .170$ [n.s.]). However, unlike the untransformed data, the interaction was now not quite significant at the 5% level ($F = 2.88$, $DF = 2,32$, $P = .071$ [n.s.]). Thus the source of the significant interaction in the raw data is likely to be an outlying data point, the power of which is decreased when the transform is carried out, making the error data distribution more normal. However, the significance is close to 5%, so should not be completely ignored and will be mentioned in the discussion. Again the log transform used ln(error percent + 1).

The following table shows the control data compared to the prosopagnosic subject data.

Table 7.8 - Percentage error data for controls and prosopagnosics on facial identity matching

	Control		NR	PH	SS
	μ	σ			
% errors (n=17)	17.4	4.27	43.8*	34.4*	40.3*
% errors (n=38)	14.2	5.71	43.8*	34.4*	40.3*

* Significant at the 1% level

When these data are investigated by trial type and then visual field the following results emerge:

Table 7.9 - Percentage error data for prosopagnosics and controls on facial identity matching

% errors	Control (n=17)		NR	PH	SS
	μ	σ			
Different trials	12.3	7.86	50.0**	45.8**	44.4**
Same expression	20.9	7.99	41.7*	20.8	34.7
Same identity	18.1	6.88	41.7**	50.0**	47.2**
Left visual field	18.0	4.24	47.9**	33.3**	34.7**
Right visual field	16.8	5.48	40.0**	47.9**	45.8**

* Significant at the 5% level
** Significant at the 1% level

The above two tables show several things. Again, as for experiment 7.2 above, all three prosopagnosic subjects appear to be worse than the controls at judging whether the identities are the same or different. In fact they are all worse at this experiment than the preceding one where

they had to match on the basis of facial expression, and on the basis of t tests all three prosopagnosic subjects are highly significantly worse at matching on the basis of identity than the controls in both tables (**NR** overall for 17 controls, $t_d = 6.18$ - $P < 0.01$; for 38 controls, $t_d = 5.18$ - $P < 0.01$; **PH** overall for 17 controls, $t_d = 3.99$ - $P < 0.01$; for 38 controls, $t_d = 3.53$, $P < 0.01$; **SS** overall for 17 controls, $t_d = 5.30$ - $P < 0.01$; for 38 controls, $t_d = 4.57$ - $P < 0.01$). All three prosopagnosic subjects were highly significantly worse at matching different trials (**NR**: $t_d = 4.80$ - $P < 0.01$; **PH**: $t_d = 4.27$ - $P < 0.01$; **SS**: $t_d = 4.10$ - $P < 0.01$) and same identity trials ((**NR**: $t_d = 3.42$ - $P < 0.01$; **PH**: $t_d = 4.63$ - $P < 0.01$; **SS**: $t_d = 4.23$ - $P < 0.01$). However only **NR** was significantly worse at matching same expression trials ($t_d = 2.60$ - $P < 0.05$) whereas the other two prosopagnosic subjects were not significantly impaired (**PH**: $t_d = 0.01$ - n.s.; **SS**: $t_d = 1.73$ - n.s). On the basis of visual field all three prosopagnosic subjects are significantly worse than the controls for trials in both visual fields (**NR** LVF: $t_d = 7.05$ - $P < 0.01$; RVF: $t_d = 4.23$ - $P < 0.01$; **PH** LVF: $t_d = 3.60$ - $P < 0.01$; RVF: $t_d = 5.68$ - $P < 0.01$; **SS** LVF: $t_d = 3.94$ - $P < 0.01$; RVF: $t_d = 5.29$ - $P < 0.01$).

7.3.3.2 - Reaction time data

The controls' median reaction times for all correct trials as a function of both visual field and trial type are shown below.

Table 7.10 - Median reaction time data for controls on facial identity matching (n=17)

Median RT (ms)	Left visual field	Right visual field	Total
Different	762	797	768
Same expression	756	816	788
Same identity	785	799	792
Total	772	796	786

To investigate these median reaction time data statistically the same ANOVA as described for Experiment 7.2 was carried out. This yielded a significant main effect of visual field ($F = 8.05$, $DF = 1,16$, $P = .012$) but not of trial type ($F = 0.24$, $DF = 2,32$, $P = .791$ [n.s.]), nor was the interaction significant ($F = 1.11$, $DF = 2,32$, $P = .343$ [n.s.]). As can be seen from Table 7.10

this visual field effect is due to the subjects' being faster when the second face is displayed in their left visual field than when it is displayed in the right visual field.

When the prosopagnosic subjects' data for overall median reaction times are compared to the control data, the following results appear:

Table 7.11 - Reaction time data for prosopagnosics and controls on facial identity matching

Median RT	**Control**		**NR**	**PH**	**SS**
	μ	σ			
(ms) (n=17)	786	125	1090*	1403**	804
(ms) (n=38)	784	158	1090	1403**	804

* Significant at the 5% level
** Significant at the1% level

As in experiment 7.2, **PH** again appears much slower, **NR** somewhat slower and **SS** has normal reaction times. On the basis of t tests, **PH** is significantly slower in both tables (for 17 controls, $t_d = 4.94$ - $P < 0.01$; for 38 controls, $t_d = 3.92$ - $P < 0.01$) and **NR** is significantly slower for the first table, but not significant for the second table (for 17 controls, $t_d = 2.43$ - $P < 0.05$; for 38 controls, $t_d = 1.94$ - n.s.). Even with 38 controls, **NR** is still at the slow end of the normal range of reaction times. **SS** is not slower than the controls (for 17 controls, $t_d = 0.14$ - n.s.; for 38 controls, $t_d = 0.13$ - n.s.).

Again a note should be made about **PH**. As already explained in Chapter 4, **PH** can be considered to be either an amount or a proportion slower than the controls. In a similar way as in Chapter 6, the calculation described in Chapter 4 will be carried out on the data for the present experiment. **PH** took 1403 ms and the controls took 785 ms. If 140 ms is added to the controls' RT, **PH** remains significantly slower, whereas if the controls' RT is multiplied by a factor of 1.7, **PH** is now hardly slower than the controls, again suggesting that **PH**'s reaction times should be corrected in the first instance by adding 140 ms to the controls' reaction times, rather than multiplying them by a factor of 1.7.

7.4 - Discussion

Three experiments are reviewed in this section of the thesis, concerned either with facial expression or identity perception. The first experiment (Experiment 7.1) investigated prosopagnosic subjects' ability to match real photographs for both identity and expression concurrently. They were allowed as much time as they wished and only errors were recorded.

The second and third experiments measured both reaction times and error rates for matching either on the basis of facial expression or on the basis of facial identity across views. For these experiments the prosopagnosic subjects were compared overall with controls, but in addition the control data were analysed by the visual field in which the second tachistoscopic face was presented and also by the type of trial. Thus both hemispheric asymmetry in normals and abilities in prosopagnosic subjects were investigated.

In experiment 7.3, when the subjects' task was to match on the basis of identity ignoring expression, the stimuli used were exactly the same as in Experiment 7.2, and it thus was investigated whether this added dimension of expression could create confusion in identity matching.

Firstly the control data will be discussed in relation to visual field and trial type for Experiments 7.2 and 7.3. Then the prosopagnosic subject data for all three experiments will be discussed.

7.4.1 - Control Data and Hemispheric Asymmetry

Looking first at expression matching across view (Experiment 7.2), there was no significant difference between the processing of the faces in the two visual fields in terms of either median reaction times or the proportion of errors made. Thus the original hypothesis, that the faces

presented to the LVF would be more efficiently processed, measurable either as reduced reaction times or as a reduced number of errors, was not supported.

There are several possible reasons for this. The first concerns the number of subjects and amount of data collected. With all such tasks, if an effect is present, then the larger the sample the more robust any effect will be and the more likely it is that it will be detected. However, it was thought that 17 subjects would provide enough data to be statistically robust and also the two P values (P = .913 for percentage errors and P = .941 for median reaction times) are not approaching significance (although when the errors are log transformed, we find that P = .178, somewhat closer to being significant), so it can be concluded that with a larger sample it is likely there would still be no measurable hemispheric asymmetry.

A further possible problem concerns the stimuli which were used. The expressions in the photographs were produced by (for the most part) students who were not actors and therefore not used to producing expressions on demand in the absence of the underlying emotion, and therefore might differ from spontaneously produced expressions. Even suggesting a scenario to them did not always produce the required expression. The photographs and computer images which were used were checked by a panel of 8 people, and to be included in the experiments they had to be identically labelled by 6 or more of those panel. Possibly only those pictures identically labelled by all 8 should have been included but this left very few usable photographs, with some expressions having only one or two examples in total. Therefore a compromise was made and those labelled by most of the panel (6 or more) were accepted. The task involved tachistoscopic stimuli, so the subjects did not have very long to form a clear picture of the second face, but this has not been a problem in previous tachistoscopic studies, on which there is a large literature (see Chapter 2). The stimulus duration in experiments throughout this thesis is generally accepted to be long enough for satisfactory visual processing to occur, as demonstrated in these experiments by

the relatively low error rates for the controls. Therefore the short duration cannot explain the lack of a visual field asymmetry.

A further explanation could be that previous research suggests that the perception of only some facial expressions leads to a RH advantage (e.g. Buchtel et al 1978, Schmitt et al 1997). However, Experiment 7.2 did not investigate the controls' performance as a function of the individual expressions, combining data for all expression. This may have masked any hemispheric asymmetry if it were only present for certain expression. The final possibility as to why there was no field advantage found is that expression matching, using the precise set-up and stimuli that I did, is not processed preferentially by either hemisphere, specifically the RH (but see later for discussion on the identity matching in this chapter).

The results for Experiment 7.3 (identity matching across views) are more confusing than those for the previous experiment. The comparison of the two visual fields yields somewhat conflicting results: there were significantly fewer errors in the right visual field than the left, but the overall median reaction time was faster in the left visual field. If indeed hemispheric superiority can be measured as an increased efficiency of processing, seen either as a reduction in errors or decreased reaction time for visual stimuli delivered preferentially to that hemisphere from the contralateral visual field, then both hemispheres appear superior, depending on which measurement is made. Thus it is difficult to say whether the hypothesis that there would be a RH advantage for identity matching has been upheld.

In reaction time experiments there is often a trade-off between reaction time and error rate, inasmuch as subjects told to perform as fast as possible tend to produce more errors, and subjects told to perform as accurately as possible tend to be slower. In the present experiment it is almost as if there has been a speed accuracy trade-off between the two hemispheres, the right hemisphere

performing more quickly and the left hemisphere performing more accurately, though why this should be is difficult to say. One possible reason, for which I have no direct evidence, is as follows: the first face was placed centrally, and the subjects probably spent longer looking at the left half (i.e. the side on the left as they looked at it) of the face than the right (Burt and Perrett 1997, Campbell 1978). If the second face were in the LVF, then it would first access the RH, which would process it more quickly due to the assumed RH's superiority in face processing; whereas if the second face were in the RVF, then the left side of the face, which had been scanned more heavily originally, would be closer to fixation and therefore there would be fewer errors than when the face was in the LVF. However, firstly, the subjects' instructions did not favour either a speed or an accuracy approach, as they were told to respond as fast and accurately as possible; and secondly, if such an explanation were true, then it would be a major blow to much of the remainder of the face laterality literature, which claims a RH advantage on the basis of both reaction times and error rates. Note also that this was the only experiment out of several in this thesis which found such a pattern of results, suggesting an anomaly.

In fact, none of the experiments in Chapters 5 or 6, which also investigated face matching, yielded RH advantages for full faces, using either stimulus matching of Mac-a-Mug faces or face matching across views of photographs of real faces. Matching of internal features in isolation, with no external features, did however show a RH advantage. Thus none of the experiments carried out in this thesis investigating full face matching in normal subjects has found a reliable RH advantage.

Note that in the above discussion I have referred to median reaction times. Mean reaction times with the outliers removed as discussed in Chapter 3 were also calculated and analysed by similar ANOVAs: these yielded the same results as median reaction times, showing that the two methods are equivalent. These are included in Appendix D.2 for the sake of completeness.

7.4.2 - Control Data and Trial Type

There were three trial types in each block:

- different - in both expression and identity
- same expression - but different identity
- same identity - but different expression

In Experiment 7.2, the second type listed comprised half the trials and was the only type to which the 'same' response was expected. In Experiment 7.3, the third type listed comprised half the trials and was the only type to which the 'same' response was expected. The two trial types to which the 'different' response was expected each comprised a quarter of the total number of trials in each block. Note that in all cases the pairs of faces presented on any one trial differed in view (the direction in which the face was looking).

Looking first at Experiment 7.2 (expression matching) there is a significant effect of trial type for the error data, but no effect for the reaction time data. Looking at Table **7.2** this is explained by the larger proportion of errors made for the 'same expression' trials than for the other two trial types. In other words, more misses were made, when the subjects rejected matched expressions, than there were false positives, when the subjects accepted unmatched expressions as the same. Thus overall the internal criterion of the controls was set so as to be more likely to reject pairs of faces as having the same expression if the subjects were unsure.

Turning now to Experiment 7.3 (identity matching), normal observers showed no significant difference between performance on the three trial types in terms of either errors or reaction times. This suggests that a different internal criterion was used for the acceptance or rejection of facial

identity matches to that used for expression matching: if they were unsure, the subjects were more likely to accept identity pairs than expression pairs.

However, ANOVAs showed a significant interaction at the 2% level between visual field and trial type for the error data and a value approaching significance for the mean reaction time data (although not for the median reaction time data). Note however, that this interaction ceased to be significant, but only just, when the error data were transformed with a log transform to make the distribution more normal. Even though, it is almost significant (P = .071), and will therefore be discussed. Interactions are always difficult to explain, especially either when there are more than two factors or, as in this case, one of the factors has more than two levels. Post-hoc tests (Tukey's HSD) showed that the source of the interaction is that there were more errors for the 'different' trials (i.e. the false positives - where the subjects thought two different people were in fact the same person) in the left visual field than the right, yielding the greater overall error rate for the left visual field. This suggests a different internal criterion or perceptual strategy for the two visual fields, but why this should be is hard to explain. The differences in the mean reaction times (with the outliers removed in the method outlined in Chapter 3) are of a similar pattern, although the other way round - as has already been stated, the reaction time were shorter for the trials in the left visual field than the right (the analysis of the mean reaction times is included in Appendix D.2). However, the least difference was still in the same identity trials whereas the largest reaction time difference between the visual fields was in the same expression trials, where the left visual field was on average over 50 ms faster. This could be explained if the right hemisphere were superior for determining that two faces are <u>not</u> of the same person, but not for determining that they <u>are</u>. However, this is unlikely to be the case especially in the light of the error data. Why there should be more hemispheric differences (visual field differences) for 'different' trials than for 'same' trials remains a mystery. Note however, that the main interaction of trial type and visual field is not approaching significance for the median reaction times, which are used more widely in this thesis,

and the above discussion is included only for reasons of completeness, and should not be ascribed too much weight.

Overall, then, it is difficult to say that these experiments show a right hemisphere superiority for either identity matching or expression matching in the controls tested, and any effects either of trial type or interactions between trial type and visual field can be explained in terms of the internal response criterion of the subjects.

7.4.3 - Prosopagnosic Subject Data

These experiments demonstrate that the three prosopagnosic subjects differ in their abilities to match faces across view on the basis of expression and identity. Overall **SS** shows normal reaction times, **NR** is at the slow end of the normal range, and **PH** is significantly much slower, taking on average twice as long as controls to make the decision. This is the case for both experiments 7.2 and 7.3, although both the latter two prosopagnosic subjects were faster to match for identity than expression. Note that Chapter 4 shows that **PH** is much slower than both the other two prosopagnosic subjects at simple reaction time tasks, so it not surprising that he is the slowest of the three at these matching experiments.

On the basis of the number of errors made, **NR** was the most impaired at both expression matching and identity matching, performing close to chance on identity matching and showing an almost 40% error rate at expression matching. Both **SS** and **PH** made about 25% errors in expression matching, compared to a control rate of below 20%, showing a mild but not significant impairment. For identity matching, all three prosopagnosic subjects were significantly worse than the controls: **PH** was overall the least impaired, making almost 35% errors, followed by **SS** who showed an error rate of about 40%. These error rates are borne out by the data from Experiment 7.1, where unlimited time was allowed. **NR** made many more errors than either of the other two

prosopagnosic subjects, both of whom made more errors on identity matching than expression matching. However, an added source of confusion is that in the first experiment the clothes were visible, but some of the models wore different clothes for different photographs. This confusion is described in the results section, but showed that at least for some of the photographs the prosopagnosic subjects were matching explicitly on the basis of clothing, although in at least one trial **NR** ignored the clothes, saying he preferred to match on the basis of nose shape, which, being especially difficult between different views, led to an incorrect response. One problem was that the control subjects performed at ceiling for the identity matching, and it might have been better to have carried out the experiment with all the subjects either wearing the same clothes or where the photographs had ended at the level of the collar.

What is interesting is the pattern of the prosopagnosic subjects' errors. Looking once again at the data from the expression matching experiment (7.2), it can be seen that all the subjects showed a bias one way or the other towards 'same' or 'different' expression trials. The control subjects and both **SS** and **PH** made more errors on the 'same expression' trials, suggesting that they were more likely to reject than to accept 'same' decisions if they were at all unsure. However, **NR** made fewer errors for 'same expression' trials than 'different expression' trials - he seemed happier to accept them if he was not sure, suggesting he had a different criterion for acceptance.

In the identity matching trials (Experiment 7.3) all three prosopagnosic subjects were poor at matching on the basis of identity when the expressions in the two faces were different (i.e. 'different' and 'same identity' trials) but both **PH** and **SS** made fewer errors for the 'same expression' trials. In other words, where the expression was the same, they somehow found it easier to work out that the identity must be different. The subjects were not told in advance that there would be no trials on which both faces would be of the same identity and expression, only that they were to decide if the two faces were of the same person, and ignore expression. Could it

be possible that the same expression on two different faces acts as a cue that their identities are different? Perhaps the prosopagnosic subjects could detect that something was different (other than the view) and that if they could see that the expression was the same, then the identity must have been the source of the difference. This only appears possible in the case of **PH** (and **SS** to a lesser extent) however. **NR** showed no such pattern.

To summarise the prosopagnosic subject findings, then, **SS** shows normal reaction times and fairly reasonable expression matching, but poor identity matching of unfamiliar faces when clothes are not a cue. **NR** is slower at matching and also very poor at both expression matching and identity matching, even when clothes are an additional cue. **PH** is the slowest, needing a lot more time than normal to reach any decision. However, on the basis of his error data, he is reasonable at matching expressions and less impaired than the other two prosopagnosic subjects at matching unfamiliar faces on the basis of identity, although still greatly impaired in comparison to the control subjects. Note that his increased reaction times are in part due to the procedure he used, pressing both buttons with the same hand, and these reaction time data should be interpreted in the light of his baseline simple reaction time, which is measured and discussed in Chapter 4.

7.5 - Conclusions

Overall, then, these experiments do not support the hypothesis that the RH is more efficient in normal subjects at processing facial expression or even facial identity across different views. Possible reasons for these are set out in section 7.4.1. The three prosopagnosic subjects are all impaired at identity matching, but on the basis of error data only **NR** is poor at expression matching, shown both in the photographic array test and the tachistoscopic matching task. Neither **SS** nor **PH** are impaired at expression matching on the basis of error data, although **PH** is significantly slower than controls at this task: this could be due however not to an impairment in facial expression processing but more to an overall elevated baseline reaction time and the fact that

he was forced to make both responses with one hand. These dissociations confirm that several different computations are involved in "face processing", which is probably much more complicated than we commonly assume, as most face processing appears to be effortless, as far as we are concerned. However, the unavailability or crudity of any anatomical brain images for these three subjects makes it impossible to relate their differences to different cortical pathologies.

CHAPTER 8 - EXPERIMENTS INVESTIGATING THE PERCEPTION OF EYE GAZE

8.1 - Introduction

The perception of eye gaze direction - that is, whether someone is looking directly at you or not, and if the latter, where they are looking - is important in social communication (Walsh and Perrett 1994, Perrett et al 1992). It is hard not to notice people's eyes, especially when they are pointed at us. The ability to tell whether one is being looked at, or indeed tell where someone is looking seems to involve more than just the perceptual abilities of acuity and resolution, but also the ability to calculate where that person is looking from the relative areas of visible iris. Primates use a stare as a threat from a higher to a lower animal in the social hierarchy, and this would not be possible if the animal being looked at cannot detect this. In humans too, eye contact during conversation is an important social cue to one's interest in that conversation, and eye contact is also important in determining whether another person is a potential mate. Another use of eye gaze perception is in assisting understanding of the subject of a conversation, for instance, when the speaker looks at the object being discussed for added clarification. This ability to perceive where someone else is looking has been described by Baron-Cohen as the eye-direction detector (EDD) and the shared attention mechanism (SAM), and he has suggested that the latter may be lacking in certain types of autism (Baron-Cohen 1993, 1994).

Some prosopagnosic subjects, such as **SS** (Campbell et al 1990), have been shown to have poor perception of eye gaze without any other problems of acuity compared to normal adults or others with right sided brain damage not leading to prosopagnosia. However, there is also evidence for some subjects prosopagnosic for facial identity but not for eye gaze perception, such as **KD** (Heywood and Cowey 1992). The exact loci of damage causing these deficits is not known, although it is generally agreed that right sided, and possibly bilateral, occipito-temporal damage

is needed.

Perrett and others have done a great deal of research on the properties of cortical cells in areas of the occipital and temporal lobes of monkeys (Perrett et al 1982, 1984, 1988, 1992, Harries and Perrett 1991, Hasselmo et al 1989, Rolls 1992, Walsh and Perrett 1994). Different populations of face cells encoding different attributes, including those responsive to eye gaze in area STPa, just near the STS.

It has been shown that monkeys with IT lesions are impaired on virtually all visual discrimination tasks, not just those concerned with face processing (Gross 1992, Gaffan et al 1986, Eacott et al 1993). Heywood and Cowey (1992) found, however, that when the superior temporal sulcus (STS) was lesioned, the only deficit the monkeys showed was that of eye gaze direction detection, at which they were poor, similarly to the prosopagnosic subject **SS** (Campbell et al 1990), but that they were not impaired at face perception and identification tasks. However, Eacott et al (1993) interpret this as part of a general problem with pattern discrimination after STS lesions. Thus it possible that area STS has a role in eye gaze perception and other pattern perception whereas IT has a wider role in object and face recognition, but the absence of a double dissociation leaves the data inconclusive.

It has been suggested by Passingham (1997) that Wernicke's area in the LH of man may have an anatomical homologue in the left STS in monkeys, as mentioned in Chapter 8. If there is also a functional homology and the STS is responsible for a range of social communication processes, and if language comprehension and eye gaze perception are both forms of communication processing, then it may follow that Wernicke's aphasics would show poor eye gaze detection. I hoped to test this but unfortunately was not able to gain access to any Wernicke's aphasics to test. This is a possible subject for future research, and will be mentioned in Chapter 10.

Two experiments are described in this chapter which investigate the perception of eye gaze direction in normals and the three prosopagnosic subjects outlined in Chapter 3. In Experiment **8.1** the models directly face the camera and the images only show them having moved their eyes, not their heads. The subjects' ability to perceptive eye gaze direction is measured both in terms of their error rates and also their reaction times. Little data have been gained from prosopagnosic subjects on reaction times, only on their error rates (e.g. **SS** in Campbell et al 1990). For this reason, **SS** is being included in this task, which necessitates the formation of a dyadic representation of the subject and the model on the screen, as described by Baron-Cohen's EDD.

The second experiment (**8.2**) involves looking at photographs of a person who is looking at one of five objects also in the photograph, and the subject's task is to decide which object is being looked at. This is similar to Baron-Cohen's idea of the SAM, and necessitates the formation of a triadic representation of the subject, the person in the photograph and the object being viewed.

A number of hypotheses are being tested. Firstly it is hypothesised that all the subjects (both control subjects and prosopagnosic subjects) will find it easier to do the task the further to the side the model is looking, seen as both a reduction in the numbers of errors made and a reduction in reaction times. It is hypothesised that **SS** will be impaired on both experiments compared to the controls, based on previous studies. It is also hypothesised that, like **SS** and unlike **KD**, both **PH** and **NR** will also show poor perception of eye gaze direction. In the second experiment, it is hypothesised that the prosopagnosic subjects will be impaired at forming a triadic representation based on eye gaze direction.

8.2 - Experiment 8.1

8.2.1 - Method

8.2.1.1 - Stimuli

Eleven pictures of each of two people were taken using the Canon Ion camera already described in Chapter 7. One model was male, the other female. They were instructed to look directly at the lens of the camera, or to a certain distance to its right of left, still in the horizontal plane. Marks were made on the wall behind the camera such that the angles which their direction of gaze made with straight ahead were ± 5°, ± 10°, ± 15°, ± 25° and ± 40°. In this experiment only lateral eccentricities of gaze were investigated in order to keep the paradigm and analysis fairly simple. Further experiments could investigate the perception of gaze deviations in vertical and other radial directions. The models were instructed not to move their heads from straight forward. This yielded 11 images for each of the two models, making 22 in total. These images were then converted into raw data .IMG images which the Turbo Pascal program running the experiment could display.

8.2.1.2 - Subjects

There were 21 control subjects used, all students, 9 male and 12 female. Their ages ranged from 18 to 29 with mean of 20.2 years and a standard deviation of 3.14 years. Three were left-handed and the remainder right-handed. Then the three prosopagnosic subjects outlined in Chapter 3 were run on the task.

8.2.1.3 - Procedure

The subject sat in front of the computer monitor, directly in line with the centre, and in each trial one face was displayed in the centre of the screen. Each block contained 50 trials, the first 5 being practice trials the results of which were not recorded. The subject was told that each face would either be looking directly at them, or past them to one side. The subject was also warned that the ±

5° faces (though they were not told the angle) may seem to be looking at the side of their face, though not past them, but that these should be responded to as not looking directly at them. The responses made were manual, using the response buttons as described in Chapter 4: one button for 'looking directly at you' and the other for 'looking past you or not directly at you'. The faces did not disappear from the screen until one of the response buttons was pressed, so this was not a tachistoscopic task. Of the 45 actual trials in each block, 15 displayed faces looking straight at the subject, and 3 were looking in each of the other 10 directions. Thus a third of the faces were looking directly at the subject, and the subject was told this in advance. Four blocks were run for each subject, giving a total of 180 trials. It should be noted that prosopagnosic subject **NR** had some difficulty understanding the task required of him and as a result the first block was scrapped. For this reason (and time constraints) he only participated in 3 blocks, giving a total of 135 trials.

8.2.2 - Results

A data handling program was written in Turbo Pascal to run basic analysis on the data, yielding the number of errors and the median reaction time for each angle of gaze.

8.2.2.1 - Error Data

A table of the overall percentage error data is shown below. For the purposes of this table and analysis I have ignored whether the face was looking to the subject's right or left, and combined the data for the two sides for each angle of regard. This is also done later in the section on reaction times.

Table 8.1 - Percentage errors

% errors	0°	±5°	±10°	±15°	±25°	±40°
Controls	21.2	69.4	24.8	2.4	0.8	0.6
S.D.	12.67	10.49	17.45	3.38	2.13	1.49
SS	33.3	83.3	25.0	16.7**	0.0	0.0
NR	4.4	66.7	55.6	44.4**	5.6	5.6**
PH	1.7	95.8*	91.7**	66.7**	37.5**	12.5**

* significant at the 5% level
** significant at the 1% level

Certain findings are immediately obvious from the above table of percentage errors as a function of the angle of gaze direction. The main one is that the number of errors increase as the direction of gaze becomes closer to straight ahead. This is not surprising, as the further to the front the face is looking, the greater the difficulty in discriminating between the face seen and a forward looking face. However, when the face is looking far to one side very few errors, if any, were made. Those errors for a gaze angle of 0° are where the face actually is looking straight at the subject but they decide that it is not, and those errors for a gaze angle of ± 5° and greater angles are where the subject thinks the face is looking straight ahead, but in actuality it is not.

The difference in the pattern of data in terms of the percentage errors for 0° and 5° gaze angle are due to the range of discrimination biases that different subjects used. In other words, some subjects responded that the face was looking at them only if they were sure and hence made many errors for 0°, but very few errors for ± 5° gaze angle, for instance control subject **BB**, whereas some responded that the face was looking at them if there was the slightest chance it could be looking straight forwards, such as control subject **OD**, and also prosopagnosic subject **PH**, who made few errors for 0°, but many errors for ± 5° gaze angle, as shown in the following table. (Note that 'looking left' means over the subject's left shoulder - i.e. the model in the photograph is looking to his or her right, and vice versa.)

Table 8.2 - Percentage errors made by 3 subjects for different gaze angles

% errors	-5°: looking left	0	+5°: looking right
BB (control)	33.3	53.3	66.7
OD (control)	66.7	3.3	91.7
PH (patient)	100	1.7	91.7

Thus some subjects made few false positives for ± 5° but as a result many misses for straight ahead trials, and other subjects made many false positives for ± 5° and few misses for straight ahead trials.

Concerning the data for the prosopagnosic subjects, **NR** (who completed fewer trials than the other two prosopagnosic subjects or the controls) showed less impairment at small angles (≤ 5°) than the other prosopagnosic subjects, and indeed apparently normal error rates. However, at greater angles from straight ahead he performed worse than controls. Prosopagnosic subject **SS** performed worse than controls for small gaze angles (≤ 5°) but showed fairly normal performance at greater angles, making no errors for the two positions furthest from straight ahead (25° and 40°). **PH** is much more impaired at this task than either of the other two prosopagnosic subjects. As mentioned above, his internal bias was such that he was much more likely to accept that a face was looking at him if he was not sure, and therefore there were very few errors for 0° (as was the case with **NR** as well). This illustrated itself as a very high number of errors (over 95% for 5° gaze angle) for all trials where the face was not looking directly at him, although again there was a reduction in the number of errors as the angle of gaze increased, but less than for the controls and other two prosopagnosic subjects.

When these error data are analysed using Dunnett's t-test (k = 4), **PH** is significantly worse at ±5° at the 5% level ($t_d = 2.51$, $P < 0.05$) and at the 1% level for all larger angles ($t_d > 2.92$, $P < 0.01$); **NR** is worse at the 1% level for ±15° ($t_d = 12.43$, $P < 0.01$) and ±40° ($t_d = 3.36$, $P < 0.01$); **SS** is just worse for ±15°t the 1% level ($t_d = 4.23$, $P < 0.01$).

When the two sides are compared to each other the following data are the result. (Note again that left regard in the following table is from the point of view of the subject doing the task and therefore means that the person in the photograph is looking to his or her right and thus over the subject's left shoulder, and vice versa.)

Table 8.3 - Percentage errors by side of gaze

Side of Regard	Left	Centre	Right	Left minus Right
Controls	18.6	21.2	20.6	-2.1
SD	7.62	12.67	6.31	9.66
SS	16.7	33.3	33.3	-16.6
NR	37.8	4.4	33.3	4.5
PH	50.0	1.7	71.7	-21.7

What this table shows is that there is no difference in the proportion of errors controls make for those trials looking to their left and those looking to their right. Both **SS** and **PH** make more errors when the face is looking over their right shoulder, but on the basis of Dunnett's t-tests this is not a significant effect.

8.2.2.2 - Reaction Time Data

A table of the median reaction times for correct trials as a function of the direction of eye gaze is shown below. Again median reaction times were used as there was a highly positive skew with many especially long reaction times.

Table 8.4 - Median reaction times (ms)

Angle	0°	±5°	±10°	±15°	±25°	±40°
Controls	814	1122	932	722	652	622
SD	227	320	269	144	117	110
SS	968	1785	1284	962	904	904*
NR	1262	2130**	2317**	1132*	1293**	1206**
PH	1174	2530**	2738**	3573**	2371**	2061**

* significant at the 5% level
** significant at the 1% level

As with the error data, there is an improvement in performance (i.e. a decrease in reaction times) as the angle from straight ahead increases, although both the controls and the prosopagnosic subjects are quicker at deciding that a forward looking face is looking straight at them, than they are when they decide that a ± 5° face is not looking at them. **PH** shows less of a decrease in reaction times at higher gaze angles than the other prosopagnosic subjects or controls.

All three prosopagnosic subjects are slower than the controls, especially **PH** who is extremely slow even when the face is looking as far away from straight ahead as 40°. It should be remembered that these reaction times are for only the correct trials (as explained in Chapter 3), and that in the case of **PH**, for instance, there are very few correct trials to use in the calculation of the median reaction times, and therefore these may not be very reliable. In this task, too, unlike most of the other reaction time tasks, the faces were not displayed tachistoscopically, but remained on the screen in the subject's view until he or she pressed one of the response buttons.

PH also had a problem where at one point he forgot what task he was meant to do during the course of one of the blocks and thought he was meant to be looking at facial expression - this increased his reaction times. This could be due to the fact that he had been matching faces on the basis of expression earlier in the session and he had perseverated, becoming confused.

When the above reaction time data were analysed using Dunnett's t test (k = 4) **SS** was significantly slower only for the largest gaze angle, ±40° ($t_d = 2.56$, $P < 0.05$), but both **NR** and **PH** were slower for all angles of gaze at the 1% level ($t_d > 2.92$, $P < 0.01$).

When the two sides are compared to each other the result is as follows. Again note that the side refers to the subject's shoulder over which the person on the screen appears to be looking.

Table 8.5 - Median reaction times (ms)

Side of Regard	Left	Centre	Right	Left minus Right
Controls	692	814	719	-27
SD	143	227	153	75
SS	812	968	1144	-305*
NR	1361	1262	1456	-68
PH	2750	1174	1882	895*

* significant at the 1% level

This table shows that the controls were hardly faster when the face was looking to one side of them compared to when it was looking to their other, but they were slower to decide that the face was looking straight at them than that it was not. However, **PH** to a large extent and **NR** to a lesser were both faster at deciding that the face was looking at them than that it was not (for correct trials). Why this should be is not clear. **SS** did not appear to show a marked difference either way, although reaction times were in fact significantly faster for judging faces looking to the left than those looking to the right ($t_d = 3.71$, $P < 0.01$). **NR** was not significantly faster on either side. **PH** on the other hand was significantly faster for those faces looking to his right ($t_d = 12.29$, $P < 0.01$), but it must again be remembered that he scored well below chance (50%) for those faces looking to his right, so these reaction time comparisons cannot be taken too seriously. It is however undeniable that he is much slower than any of the other subjects.

8.3 - Experiment 8.2

8.3.1 - Method

8.3.1.1 - Stimuli

This experiment used actual 6″ x 4″ photographs and was not computer driven. It involved deciding what object the person in the photograph was looking at. Again the same two models were used. As actual photographs were needed the Olympus camera (see Chapter 7) was used. Five objects were arranged on a table in front of the model and the camera placed on the other side of the table so that the model and all five objects were in the field of view. The centre object was placed directly in front of the model and two objects were placed on either side at equal distances from one another, so that there was an array of five objects in front of the model, who had to look to the left for two of them, to the right for two, and straight ahead for the remaining one. The objects that were used were a rubber toy dinosaur, a pocket thesaurus, a coffee mug, a small (half a litre) bottle of squash and a can of soft drink. The order in which the objects were placed on the table was varied from photograph to photograph.

Twenty pictures were taken in all, 10 for each model. Firstly one was taken for each model looking at each of the five positions (at whichever object was there). Then the camera was moved along the table to the left a few feet. The objects and model stayed in the same place and five more photographs were taken. Now the model was not facing the camera, although he or she was facing the central object. Examples of two of the photographs are shown in Appendix A.4.

8.3.1.2 - Subjects

Ten control subjects participated in this experiment. Their ages ranges from 20 to 38 years, with a mean of 28.2 years and a standard deviation of 6.23 years. Six were male and 4 female. The three prosopagnosic subjects described in Chapter 3 were also tested.

8.3.1.3 - Procedure

The task was explained to the subjects and then they were shown each photograph in turn in a random order and asked to say which object the person in the photograph was looking at. They were allowed as much time as they needed, and reaction times were not measured.

8.3.2 - Results

The number of errors made was measured and is shown in the table below.

Table 8.6 - Total number of errors in Experiment 8.2

Subject	Number of errors (out of 20)
Controls - mean	1.6
S.D.	0.84
SS	7**
NR	7**
PH	4*

* Significant at the 5% level
** Significant at the 1% level

Using Dunnett's t_d statistic both **SS** and **NR** are significant at the 1% level ($t_d = 6.43$, $P < 0.01$) and **PH** at the 5% level ($t_d = 2.86$, $P < 0.05$). When these data are investigated as a function of the individual viewpoints of the models in the photographs, the following is seen:

Table 8.7 - Pictures where the model is facing the camera

Mean errors	Far left	Near left	Ahead	Near right	Far right
controls		0.5		0.2	
(n=10)					
SS		2			1
NR		2		1	
PH		1		1	

Table 8.8 - Pictures where the model is not facing the camera

Mean errors	Far left	Near left	Ahead	Near right	Far right
controls		0.7		0.2	
(n=10)					
SS	1	2	1		
NR			1	2	1
PH	1			1	

These two tables show several things. Firstly, slightly more errors were made by the controls and two of the prosopagnosic subjects for the picture where the model was not facing the camera than when the model was facing the camera. Secondly, all the control errors were made for the near right and near left object positions, where in each case the subject thought that the model was looking at the far right or far left positions respectively. Lastly, the prosopagnosic subjects' errors were not restricted to these two positions, especially when the model was not facing the camera.

8.4 - Discussion

8.4.1 - Experiment 8.1

This experiment investigated the subjects' abilities to perceive whether they were being looked at or not. On the basis of both the error data (Table **8.1**) and the reaction time data (Table **8.4**), all subjects made fewer errors and responded more quickly for greater gaze angles. This is not surprising, as the further to the side the model is looking, the clearer the subjects' judgement will become. Note however that **PH**'s reaction times did not decrease clearly as gaze angle increased, but the possible explanation for this is that reaction times are based only on the correct trials (as explained in Chapter 3), and he made so many errors, that for some gaze angles the median reaction times are calculated only on the basis of one (gaze angle of ±5°) or two (gaze angle of ±10°) trials, leading to potentially unreliable data. Remember also that **PH** has generally elevated reaction times, partly due to his general impairment due to closed head injury (de Haan et al 1987a) but also due to his having to make both responses with the same hand.

SS made slightly more errors and was slightly slower than the controls, but generally this was not significantly so, except for error data for ±15° and reaction time data for ±40°. **NR** made more errors than the controls or SS and was significantly poorer than the controls at gaze angles of ±15° and ±40°. He was however, significantly slower than the controls at all gaze angles other than straight ahead. **PH** was significantly impaired at this task, making significantly more errors and

being significantly slower than the controls for all angles of gaze other than straight ahead. For gaze angles of ±5° and ±10° he made over 90% errors.

This leads on to the topic of the subjects' internal criterion. Table **8.2** shows the proportion of errors made for faces looking straight ahead and those looking 5° to the side for a few subjects. This is most likely explained as being due to different subjects setting different internal criteria for responding, either only accepting that the face was looking straight at them if they were sure, or only accepting that the face was not looking at them if they were sure. These two strategies would yield the two different patterns of results seen, for instance by control subject **BB** and prosopagnosic subject **PH** respectively. This difference in internal criterion or strategy is by no means a dichotomy, but a continuum across the subjects, and Table **8.2** draws attention only to the most marked cases.

Tables **8.3** and **8.5** compare the subjects' data for those trials where the faces are gazing to the subjects' left and those to the subjects' right. There are no statistically significant differences between the two sides for the error data, but **SS** and **PH** show a significant difference in reaction times, which are faster for faces looking over **SS**'s left shoulder and **PH**'s right shoulder. One possible reason might be that these two prosopagnosic subjects (**SS** and **PH**) look consistently at one or other eye. As the two eyes were focusing on the camera when the pictures were taken, they are pointing in slightly different directions, so that their gazes converge on the camera, and therefore one eye will have a slightly greater eccentricity of gaze than the other. However, if this were the reason for the different reaction time data on either side (clearer judgements being made more quickly) then this would be expected to result in a similar trend for errors, which was not the case. No information was gathered as to which eye the subjects looked at and whether one was looked at consistently more often than the other. Further experimentation would be needed to test this hypothesis and elucidate the reason for these findings.

Combining the error and reaction time data for this experiment, it can be seen that the first hypothesis is supported, in that it becomes easier for all subjects to perform the task as the gaze angle increases, as both the number of errors and the median reaction times decrease with increasing gaze angle, although this was less marked for **PH**'s reaction time data. The second hypothesis, that all three prosopagnosic subjects would be markedly impaired at this task compared to the controls, was only weakly supported. Both **PH** and **NR** show greatly impaired eye gaze direction perception on the basis of reaction times (more reliably for **NR**) and error rates (more reliably for **PH**). **SS**, however, who has already been found to be impaired on such tasks, especially at small gaze angles (Campbell et al 1990), fared much better than the other two prosopagnosic subjects, and was only marginally impaired on this task, making significantly more errors only for a gaze angle of ±15° and being significantly slower only for a gaze angle of ±40°. On the basis of reaction time data, **SS** was certainly towards the lower end of the normal range, but a similar pattern of results to Campbell et al (1990) was not seen. However, there is obviously some level of impairment present. **SS** also seems to show more problem for faces looking to the right than those looking to the left. Why this should be remains a mystery, and warrants further investigation.

8.4.2 - Experiment 8.2

This experiment investigated the ability of the subjects tested to determine what third object a person in a photograph was looking at. As can be seen from Table **8.6**, all three prosopagnosic subjects made significantly more errors on Experiment **8.2** than the controls. Tables **8.7** and **8.8** show also that their pattern of errors was not the same as the control subjects. The control subjects' errors were all for the near right and near left object positions, and all consisted of overestimating the gaze angle in the photograph. The prosopagnosic subjects, on the other hand, made errors both of underestimation and overestimation.

In general, more errors were made for the photographs where the model was not facing the camera than when the model was facing the camera; in the latter case the head faced forward, and the eyes were both easier to see in the photographs than in the former case.

8.4.3 - General Conclusions

As described in Chapter 1 and in the introduction of this chapter, Baron-Cohen (1993, 1994) has proposed a model to explain how babies can 'read minds', and specifically how we (and other animals) can perceive eye gaze. He puts forward two possible mechanisms, the eye direction detector (EDD) which is used in detecting whether we are being looked at or not, building a dyadic representation of the self and the other person, and the shared attention mechanism (SAM) which is used in determining which third object another person is looking at, building a triadic representation of the self, the other person and the object.

He suggests that the SAM, though not the EDD, may be lacking in certain types of autistic children. The results of the two experiments in this chapter suggest that the prosopagnosic subjects tested may show problems in both the EDD and SAM. However, Baron-Cohen discusses the SAM in terms of shared mentalistic states and an inability in the autistic children to understand the concepts of desire and goal - rather than asking which object the person in the drawing (called 'Charlie') was looking at, the question asked was "Which one does Charlie want?" (Baron-Cohen et al 1995). It is unlikely that the prosopagnosics have a problem in understanding such concepts in the manner proposed for the autistic children and it is more likely that there is a problem with their ability to perceive the actual direction of gaze due to the variety of face processing impairments they have.

To conclude, then, the three prosopagnosic subjects tested show impairments in forming both dyadic and triadic representations of eye gaze. This may or may not be problematic in all prosopagnosics. It is likely that prosopagnosics who show no problems with building the dyadic representations, such as **KD** (Campbell et al 1990) would show no problems in building the triadic representations, tested in the second experiment in this chapter. Further research is needed to test this. For example, the range of gaze direction used thus far is narrow. The tasks could be made much more demanding by using deviations in many radial directions and also by introducing a variety of relevant and irrelevant head orientations.

CHAPTER 9 - EXPERIMENTS CONCERNED WITH LANGUAGE PROCESSING

9.1 - Introduction

As has already been covered in some detail in Chapter 2, the left cerebral hemisphere in the majority of people is more specialised for language processing that the right cerebral hemisphere. Evidence for this comes from a number of sources: dichotic listening tasks (e.g. Kimura 1967) and tachistoscopic visual tasks (e.g. Mishkin and Forgays 1952) in neurologically normal adults; patients with lateralised lesions suffering from aphasias (e.g. Iaccino 1993 pp. 61-63) and commisurotomy patients (Sperry and Gazzaniga 1967); electrical stimulation during brain surgery (Penfield and Roberts 1959, Ojemann and Mateer 1979); the results of unilateral carotid sodium amytal administration (Rasmussen and Milner 1977); and more recently, brain imaging methods (e.g. Paulesu et al 1993, Price et al 1996).

However, although the majority show LH language dominance, it has also been noted that some adults appear to have RH language dominance, evidence again coming from a number of sources, including WADA tests (Rasmussen and Milner 1977), dichotic listening tasks (Kimura 1961) and brain imaging tasks (e.g. subjects **HJ** and **RL**). One thing of interest is the convergence of evidence from different sources for the reversal of asymmetry in some subjects. Thus the two experiments described in this chapter attempt to use tachistoscopic visual methods to corroborate the functional imaging data which had been previously obtained.

A second question investigated by the experiments in this chapter is whether there is any interaction between hemispheric asymmetry and certain attributes of words. It is known that overall the LH processes words more efficiently than the RH, but does this increase in efficiency differ for different word types, for instance nouns and verbs, or rare and common words? There was no significant interaction between word type (noun or verb) and visual field in experiment

5.4, but it is possible that the LH advantage could hypothetically be different for common words and rare words. Also, familiarity and typographic uniqueness of words are investigated as a function of visual field.

This chapter describes two experiments that investigated various aspects of word processing and hemispheric asymmetry. Both experiments were performed by neurologically normal subjects and also by the two subjects outlined in Chapter 3 who have reversed cerebral dominance.

The first experiment, 9.1, follows on from the findings of Experiment 5.4, described in Chapter 5. Experiment 5.4 investigated hemispheric differences in subjects' abilities to judge whether visually presented words were nouns or verbs. A slight RVF advantage was found, although not as large as expected and not significant, but it was unexpectedly found that the nouns were responded to significantly more accurately and faster than the verbs. The experiment described here investigates one possible source of this effect, namely that increased word frequency increased the efficiency with which words are recognised, and that in Experiment 5.4, the nouns were more familiar and commonly used than the verbs in the word lists. Therefore the experiment was repeated using four different combinations of two lists of verbs and two lists of nouns. One list for each word type contained high frequency, common words, and the other list for each word type contained low frequency, rare words. Also, only right-handed subjects were used, unlike in experiment 5.4: this was a likely reason for the absence of a significant LH advantage.

The second experiment, 9.2, was carried out for a different reason, not specifically to follow up the results of any previous experiment, but more to take advantage of my serendipitous acquisition of two neurologically normal subjects shown on the basis of PET imaging tasks to have reversed cerebral dominance, and therefore RH language processing. I wished to test them

both on a number of face-processing tasks in order to investigate whether they showed any LH face-processing superiority, and therefore thought it a good idea also to test them on a linguistic task, to see whether I could show a RVF advantage using a simple and non-invasive procedure that would corroborate the PET findings. Thus Experiment 9.2 was performed by these two subjects, together with a number of control subjects, who were assumed for the purposes of this experiment not to have reversed asymmetry - unfortunately there was no way of in fact testing this, as I did not have access to a PET scanner, but it is a fairly safe assumption to make as they were all right-handed, and it has been shown that 96% or more of right-handers have their language processing mainly in their left hemispheres (Rasmussen and Milner 1977 - see also Chapter 2). The task that was used in the end was not one requiring a manual response to a linguistic judgement, such as was used in Experiments 5.4 and 9.1, but rather a verbal response to the word itself - the subject was required to read the word out loud. Reaction times and errors were recorded, and various aspects of the task were investigated, including hemispheric asymmetry and the effects of word familiarity, frequency, typographic uniqueness and length. (Note **HJ** and **RL** were also tested on Experiment 9.1.)

9.2 - Experiment 9.1: Word Judgements as a Function of Word Frequency

9.2.1 - Introduction

It is now well documented that the left hemisphere of the majority of neurologically normal right-handed adults is specialised for language processing,. This can be demonstrated in a number of ways, as described above.

In my previous experiments, which were concerned with face matching (5.1, 5.2 and 5.3), primarily a right hemisphere task, a linguistic task was used as a control procedure (Experiment 5.4) to check that hemispheric advantages in terms of reaction times and error rates could be demonstrated using the equipment. The task used was a judgement whether a word presented

briefly in one visual field was a noun or a verb. A small left hemisphere advantage was shown both in terms of reaction times and error rates, but this was not significant. However, an unexpected significant advantage for nouns compared with verbs was found, demonstrated by reduced error rates and faster reaction times for nouns. Whether this was an effect of the word types themselves or merely a result of different word frequencies for the two word types was unclear. Therefore it was decided to repeat the word task using lists of both high and low frequency nouns and verbs to see if altering word frequency affected reaction times and error rates for judging word type.

It was also decided to test subjects **HJ** and **RL** on this task in the hope of showing reversed findings to the control subjects, the hypothesis being that they would be faster and make fewer errors for words displayed in their LVFs. Their data were not included in the investigation of word frequency, however.

Thus the hypotheses being tested were that common words would lead to fewer errors and faster grammatical classification than rare words; there would be interaction between word type and visual field; **HJ** and **RL** would show a RH advantage and the controls a LH advantage.

9.2.2 - Method

Four lists of words were prepared from *Word Frequencies in British and American English* (Hofland and Johansson 1982), two containing high frequency words and two containing low frequency words. The words used, together with their number of occurrences per million words according to Hofland and Johansson, are given in Appendix B.2. Many of the words used in the previous experiment were used. There were eighteen words in each list, and the words were chosen so that they could only be a noun or a verb but not both. Each set of 4 words began with the same letter, and as far as possible contained the same number of letters as each other, and

had several letters in common. For instance, eat, ear, err and eel were one set. Also there were certain words which were similar, such as laze and raze, although haze was not in the list. This similarity of form between the words on the different lists was judged to increase the necessity of reading the whole word before a grammatical decision could be made.

9.2.2.1 - Subjects

Seventeen right-handed subjects were used, all students. Their ages ranged from 18 to 28, with a mean of 20.4 years and a SD of 2.3 years. Ten were female and 7 were male. The two subjects with reversed cerebral asymmetry, **HJ** and **RL**, were also tested. They are detailed in Chapter 3. [Note that in light of the literature on individual differences in laterality, and specifically the view of some researchers that females tend to be less lateralised than male subjects, it would have been preferable to have used only male subjects, although there are a number of papers in the laterality literature which do use students of both genders.]

9.2.2.2 - Procedure

Each subject was given the list of 72 words and asked to read them aloud, checking that they were familiar with and understood all of them. They then completed one practice block to familiarise themselves with the procedure, and then completed a further 8 blocks, 2 for each of the four combinations of pairs of lists. The order of blocks was counterbalanced between subjects. The subjects responded by pressing one of two keyboard keys on the number pad. Each subject used only one hand, different fingers being used for the different responses. Response hand and also response finger were counterbalanced between the subjects. **HJ** and **RL** completed fewer trials than the other subjects due to time constraints and their error scores are scaled up in the results section for direct comparison with the other subjects' performance.

At the start of each trial, a central fixation cross was displayed for 500 ms. The word was then displayed in one visual field for 150 ms, after which a grey mask covered the screen to prevent after-images. The response was one of two keys on the keyboard, one for verbs and one for nouns. There was then an intertrial interval of 1.5 s.

At the end of the experiment, 9 of the 17 subjects (not **HJ** or **RL**) were asked to recall as many words as possible from all of the lists in a free recall test. They were not warned of this beforehand, and had as much time as they wanted. The reason for this was to see if there was any difference in the subjects' ability to recall rare or common words, and nouns or verbs. The hypothesis was that they would recall common words more easily than rare words, but there would be no difference between noun and verb recall.

9.2.3 - Results

Number of errors and mean and median reaction times were calculated for each subject and also for all subjects combined for each pair of word lists. The four experiments were as follows:

A Common verbs and common nouns.

B Common verbs and rare nouns.

C Rare verbs and common nouns.

D Rare verbs and rare nouns.

9.2.3.1 - Experiment A - common nouns and verbs

Table 9.1 - Error data for noun verb judgements (n = 17)

Number of Errors	Left visual field	Right visual field	Both fields
Noun	86	96	182
Verb	84	69	153
Both trial types	170	165	335

Table 9.2 - Reaction time data for noun verb judgements (n = 17)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Noun	754(703)	733 (685)	744 (695)
Verb	733 (698)	710 (677)	721 (689)
Both trial types	744 (699)	721 (680)	732 (692)

RTs are mean (median)

The right visual field was significantly faster for both mean reaction times (F = 8.76, DF = 1,16, P = .009) and median reaction times (F = 6.84, DF = 1,16, P = .019), although there was no significant difference in error rates (F = .12, P = .731). There was no significant difference between nouns and verbs, although verbs yielded generally faster reaction times and fewer errors: based on mean reaction times, F = 4.43, P = .052, which was very close to being significant. Median reaction times and error rates respectively yielded F values of 1.80 (P = .198) and 1.43 (P = .250). There were no significant interactions between word type and field. Thus the right visual field and therefore the left hemisphere is definitely processing the words faster, although there is no difference in the number of errors made by the two hemispheres. It is likely that in this experiment verbs were processed more effectively than nouns, but this was probably reflected in their different frequencies (see section 9.2.3.6).

9.2.3.2 - Experiment B - common verbs and rare nouns

Table 9.3 - Error data for noun verb judgements (n = 17)

Number of Errors	Left visual field	Right visual field	Both fields
Noun	111	93	204
Verb	79	79	158
Both trial types	190	172	362

Table 9.4 - Reaction time data for noun verb judgements (n = 17)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Noun	765 (728)	724 (705)	744 (717)
Verb	715 (694)	695 (660)	705 (693)
Both trial types	739 (710)	709 (680)	724 (697)

RTs are mean (median)

Again performance in the right visual field was significantly faster than the left for both mean reaction times (F = 16.71, DF = 1,16, P = .001) and median reaction times (F = 10.85, DF = 1,16, P = .005), although there was no significant difference in the number of errors made in the two fields (F = 1.01, P = .330). In this experiment, verbs were responded to significantly faster - mean reaction time (F = 11.47, DF = 1,16, P = .004) and median reaction time (F = 11.37, DF = 1,16, P = .004) - and also significantly more accurately - error rates (F = 12.57, DF = 1,16, P = .003) - than the nouns. There were no significant interactions between field and word type. Again the left hemisphere is superior, and also verbs, the word group with the higher frequency, are processed and recognised more efficiently than nouns.

9.2.3.3 - Experiment C - rare verbs and common nouns

Table 9.5 - Error data for noun verb judgements (n = 17)

Number of Errors	Left visual field	Right visual field	Both fields
Noun	100	90	190
Verb	109	104	213
Both trial types	209	194	403

Table 9.6 - Reaction time data for noun verb judgements (n = 17)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Noun	722 (695)	720 (695)	721 (695)
Verb	760 (789)	744 (735)	752 (762)
Both trial types	741 (742)	732 (715)	736 (728)

RTs are mean (median)

Again the right visual field is faster for both mean (F = 6.48, DF = 1,16, P = .022) and median reaction times (F = 5.18, DF = 1,16, P = .037), but there was no significant difference in error rates (F = .34, P = .569). In this experiment, nouns were responded to significantly faster as shown both by mean (F = 6.85, DF = 1,16, P = 0.19) and median reaction times (F = 8.64, DF = 1,16, P = .010), although there was no significant difference in error rates (F = .84, P = .374) unlike the previous experiment. There was a significant interaction between visual field and word type on the basis of the median reaction times (F = 6.66, DF = 1,16, P = .020), although

there was no significant interaction for either mean reaction times or errors. The interaction in median reaction times appears to lie in the fact that the increase in time to identify verbs over nouns in the LVF (96 ms) was longer than in the RVF (40 ms), but this was not significant for mean reaction times (38 ms cf. 24 ms). A possible source of this interaction will be explained in the discussion. Again the left hemisphere is superior, and also nouns, the word group with the higher frequency, are processed and recognised more efficiently than verbs.

9.2.3.4 - Experiment D - rare nouns and verbs

Table 9.7 - Error data for noun verb judgements (n = 17)

Number of Errors	Left visual field	Right visual field	Both fields
Noun	96	102	198
Verb	122	78	200
Both trial types	218	180	398

Table 9.8 - Reaction time data for noun verb judgements (n = 17)

Reaction time (ms)	Left visual field	Right visual field	Both fields
Noun	800 (756)	774 (727)	787 (743)
Verb	789 (743)	790 (734)	790 (737)
Both trial types	795 (751)	782 (732)	788 (739)

RTs are mean (median)

Results by field show significantly faster reaction times for the right visual field for means (F = 6.26, DF = 1,16, P = .024) and almost significant for medians (F = 3.95, DF = 1,16, P = .064). Again the error rates are not significantly different although there is more difference than in the previous experiments (F = 2.95, P = .105), there being fewer errors in the RVF. There is no difference between noun trials and verb trials in terms of mean (F = .17, P = .686) or median reaction times (F = .23, P = .641) or error rates (F = .00, P = .950). There is no significant interaction between reaction times and word type for either mean or median reaction times, but there is a significant interaction for error rates (F = 7.04, DF = 1,16, P = .017). This is because there are fewer errors made for verb trials in the LVF but fewer errors made for noun trials in the RVF. Why this should be is unclear, especially as this pattern is not reflected in the reaction

times. Again there is a left hemisphere advantage, and now no difference between nouns and verbs, explained by the similarity of frequency between the verbs and the nouns.

9.2.3.5 - Visual Field

Table 9.9 - Error data for noun verb judgements for all four experiments (n = 17)

No. Errors per subject	Left visual field	Right visual field	Both fields
Noun	23.1	22.3	45.4
Verb	23.1	19.6	42.7
Both trial types	46.2	41.9	88.1

In summary, all four experiments show faster reaction times, both mean and median, in the RVF and thus a left hemisphere advantage (in Experiment D, the median RTs are just not significant). Although fewer errors were made in the RVF in each experiment and overall, this was not found to be significant. This was also a consistent finding across the majority of subjects. The reaction time data do show a difference in the extent of this advantage for different experiments. Using both mean and median reaction times for all subjects' data combined, there is a greater left hemisphere advantage (although not significant) for experiment B than for experiment C, possibly suggesting that rare nouns and common verbs exercise more linguistic processing than rare verbs and common nouns. Why this should be is uncertain. This trend was not evident from the error data.

9.2.3.6 - Word Frequency

Both errors and mean reaction times as a function of word frequency showed similar results for the four experiments. Median reaction time results showed the same trends, although they were slightly less similar. In general, when the nouns or verbs used were of low frequency, more errors were made and the reaction times were longer. The exception to this was Experiment A, when both sets of words were of high frequency. In this case there were fewer errors and faster response times for verbs than for nouns. This is contrary to what was found in the previous

experiment (5.4), when there were fewer errors for nouns than for verbs. Note, however, that in Experiment 5.4, the nouns and verbs were not matched for frequency, the nouns being more common than the verbs used. The reaction times were longer and the error rates higher for Experiment D compared with Experiment A. What these results suggest is that the performance on this task is highly affected by word frequency, and that in Experiment A the verbs are in general more common than the nouns, whereas in the previous experiment the nouns were more common than the verbs in general. To test this it is necessary to look at the word lists (Appendix B.2).

As can be seen from the totals at the base of the table in the Appendix, the lists of nouns and verbs were matched for frequency of occurrence of the actual word being tested. But according to Hofland and Johansson, when the frequencies of occurrence of the words plus their derivatives and related words were used, the common verbs were significantly (P = .0167) more common than the common nouns, on the basis of a one-way ANOVA. (An example is the word *choose* which gives the related words and derivatives *choosing, choice, choices, chosen* and *chose* - note that the related words and derivatives can come from any part of speech.). The same procedure was carried out for the words used in the previous experiment (5.4), again using one-way ANOVAs. The results of these showed that, in spite of the fact that nouns were responded to more accurately than verbs in Experiment 5.4, the verbs including their derivatives were almost twice as common as the nouns plus their derivatives. However, this difference was not statistically significant (F = 2.67, DF = 33,11,33, P = .112). It is odd, however, that nouns were responded to more accurately in Experiment 5.4 whereas the verbs were actually more common when their derivatives are taken into account. An explanation for this is that where one word type is much more common than the other, as in Experiment 5.4, there will be an advantage in responding to that word type. However, if the two word types are matched for frequency, as is the case in Experiment A here, it is only then that the importance of the

frequency of the derivatives of the words in the lists comes into play: in Experiment A the two word types are matched for frequency, but when the derivatives are taken into account, the verbs were significantly more common, leading to an almost significant advantage for verbs over nouns.

Two significant interactions were found during analysis. In Experiment C (rare verbs and common nouns) median reaction times were much faster for nouns than verbs in the LVF, but the difference was a lot smaller in the RVF. One possible explanation for this is that the RH is more poorly equipped for recognising and grammatically classifying rare words than common words. It is known that the linguistic abilities of the RH tend to be based more on simple concrete nouns than verbs so that it is also possible that this interaction can be explained by the RH's being better at recognising nouns. If a similar interaction were present in Experiment B (common verbs and rare nouns) this would suggest that the RH is better at recognising nouns than verbs, and if the opposite interaction were found, it would suggest that the RH is better at recognising common words than rare words. There was in fact no significant interaction found in Experiment B, but the trend in the reaction times suggested that the increased difficulty in recognising nouns over verbs was marginally greater in the LVF than in the RVF; this tends to favour the explanation that the RH is better at recognising common words than rare words to a greater extent than the LH.

The other significant interaction was found in the error data for Experiment D (rare verbs and rare nouns). This was due to fewer errors being made for verbs in the LVF but fewer errors for nouns in the RVF. This pattern was not reflected in the reaction time data, and a possible reason is that, again, the RH is better at recognising nouns than verbs. Why verbs are better recognised than nouns in the LH is difficult to explain at present.

9.2.3.7 - Subjects with Reversed Cerebral Asymmetry

Subjects **HJ** and **RL** were also tested on this experiment. Their results were not analysed with respect to word frequency or word type, as the only aspect of interest was their hemispheric asymmetry in terms of making the linguistic judgement as to whether words were nouns or verbs. They were tested on all four tasks, but their data were collapsed over the 4 conditions and are presented in the tables below.

Table 9.10 - Error data for noun verb judgements for subjects with reversed asymmetry for all four experiments

Number of Errors	Left visual field	Right visual field	LVF - RVF
Controls (n = 17)	46	42	4
HJ	32	24.5	7.5
RL	39	49	-10

Table 9.11 - Reaction time data for noun verb judgements for subjects with reversed asymmetry for all four experiments

Reaction Time	Left visual field	Right visual field	LVF - RVF
Controls (n = 17)	755 (716)	736 (696)	19 (20)
HJ	762 (734)	771 (752)	-9 (-19)
RL	1091 (968)	1175 (1099)	-84* (-131)*

RTs are mean (median)
* Significant at the 1% level

The above tables show that **HJ** was marginally faster for words in the LVF although he made fewer errors in the RVF, as did the controls. Thus overall it cannot be said that he shows a LVF advantage. However, he does not show a RVF advantage either, which was what was found in the controls. When his data were compared with the other control subjects by carrying out a Dunnett's t test (k=3) on the differences in errors between the right and left visual fields, he was not significantly different from them: neither was he significantly different from the controls in terms of hemispheric asymmetry for either mean or median reaction times.

RL, on the other hand, showed very much faster reaction times for trials in the LVF on the basis of both mean RTs (84 ms faster) and median RTs (131 ms faster). He also made fewer errors in the LVF. These data suggest that he shows a strong LVF advantage, unlike **HJ**. On the basis of his error data, comparison with the controls shows that he is not significantly different from them ($t_d = 1.12$). When the difference between the mean reaction times (with outliers removed according to the method described in Chapter 3) for the two visual fields are compared with those of the controls, he is highly significantly different from them ($t_d = 5.26$, $P < .01$): the mean differences for the controls was 19 ms faster in the RVF. When a similar analysis was carried out for median reaction times (before the removal of outliers) he is still significantly different from the controls ($t_d = 5.70$, $P < .01$), who were 20 ms faster in the RVF.

9.2.3.8 - Word Recall Experiment

After they had completed the experiment, the last 9 of the 17 subjects tested were asked to recall as many words as possible which they had encountered during the course of the experiment. They had not been warned in advance that they would be asked to do this, and therefore had not set out in advance to commit as many of the words to memory as possible.

When the number of words recalled were analysed in an ANOVA (2 factors, each with 2 levels - frequency and word type) neither factor yielded a significant effect, nor was there a significant interaction, although this was closer to significance ($F = 3.77$, $P = .088$ [n.s.]). Thus the hypothesis was not correct that common words would be remembered better than rare words.

Table 9.12 - Number of words recalled after Experiment 9.1

Words recalled	Verbs	Nouns	Total
Common	40	62	102
Rare	64	51	115
Total	104	113	217

This almost significant interaction can be explained by the fact that more common nouns were recalled than rare nouns, but more rare verbs were recalled than common verbs. Why this should be the case is unknown.

However, one factor that was significant was that of recency. When the words recalled were analysed with respect to how recently the subject had seen them, it was found on the basis of a one way ANOVA that significantly more words (130) were recalled which had been presented in the last block on which the subject had been tested, than were those (87) which had not been presented in the last block (F - 6.79, P = .0192). This is not surprising and is well documented as the **recency effect**, in that items more recently perceived are more easily recalled (e.g. Glanzer and Cunitz 1966).

It is also notable that in addition to the 217 words recalled (out of a possible total of 648, comprising 4 lists of 18 words for each of the 9 subjects), 8 false positives were made, i.e. words recalled which had not been in the original lists. These false positives were only made by 3 of the 9 subjects tested. They are listed in the following table together with possible reasons:

Table 9.13 - false positives on the word recall task

Word 'recalled'	Possible reason
believe	*belief* in noun list
see (by 2 people)	*sea* in noun list
gnat	*gnaw* in verb list
haze	*laze* and *raze* in verb list
peril	incorrectly recalled as a verb and not a noun, though in list
wife	*woman* and *wafer*(?) in noun lists
idea	??

9.2.3.9 - Summary

For the control subjects all the above experiments show a right visual field and hence a left hemisphere advantage for the linguistic decision of noun vs. verb - this is what was expected. A significant correlation between word frequency and reaction time was also found - the higher the

frequency, the faster the response. The results from Experiment A show also that it may be the frequency of a word plus its derivatives that influence our familiarity rather than the frequency of the word itself. The interaction found in Experiment C suggests that the RH may be disproportionately worse at recognising rare words than common words compared to the LH.

RL was found to show significantly reversed results compared with the control subjects on the basis of both reaction times and errors. **HJ** was not significantly different from the controls, although he was less asymmetric in his results than many of the control subjects. From this it can be concluded either that this task is not very sensitive to hemispheric asymmetry, or that **HJ** and **RL** differ in the extent to which they are lateralised in favour of the RH for language tasks, a finding which would not be surprising considering the fact that no two brains are identical.

9.2.4 - Discussion

In each experiment for the control subjects a significant RVF and LH advantage was found for RT data, with a non-significant trend for errors, demonstrated as both faster and more accurate responses to words displayed in the RVF. Experiments B and C showed a significant advantage for common words (verbs in the case of Experiment B and nouns in the case of Experiment C) over rare words in terms of reaction times for both experiments and error rates for Experiment B. This shows that our ability to recognise words alters as a function of word frequency, in that we are better able to recognise words when they are common than when they are rare.

These results can help to explain the findings of Experiment 5.4, where nouns were responded to more accurately and faster than verbs. Further investigation showed that the nouns used in Experiment 5.4 were 70% more common than the verbs used. The present experiment is evidence that this difference in frequency was the cause of the difference in performance between nouns and verbs.

A further aspect of word frequency is the difference between the frequency of the word itself and the word together with its derivatives. Frequencies for both cases are shown in the Appendix listing the words used in this experiment, and as is explained in the results section, in Experiment A, the verbs were significantly more common than the nouns when the frequency of their derivatives were taken into account, explaining the finding that the verbs were responded to faster (almost significantly so) than the nouns.

The significant interaction found in Experiment C also suggests that the RH is disproportionately better at processing common words than rare words compared to the LH. This could be because there are processing mechanisms in the RH for more often used and more common words, or because due to their increased frequency they cause a higher activation and are passed interhemispherically more efficiently.

HJ and **RL** were tested on exactly the same tasks as the control subjects, and the only difference was that they had been shown to have right hemisphere dominance for two linguistic tasks tested by PET scanning, a phonological loop task for **HJ** and a word repeating experiment for **RL**, whereas it was assumed that the control subjects would show a left hemisphere advantage for such tasks, as upwards of about 96% of right-handed people do, as far as we know, show left hemispheric advantages for language tasks (Rasmussen and Milner 1977). However, it was found that **HJ**'s and **RL**'s results differed from one another in that the latter showed significant reversed asymmetry in this task, but the former did not. This may reflect underlying differences between the two of them in terms of their reversed asymmetry, or possibly suggest that the task was not as sensitive as the next one (9.2 - see below) in detecting reversed cerebral dominance for language. As **HJ** and **RL** were tested on different PET studies (described in more detail in Chapter 3), in which they were asked to do different tasks, it is impossible to compare them

directly in terms of their neuro-imaging data. Therefore the possibility that the difference between their performances is due to underlying differences in the extent to which their brains are lateralised cannot be ruled out.

The recall test conducted on the last 9 subjects did not show that either type of word was recalled better than the other, nor that common words were recalled better than rare words, which might have been expected. What was found, however, was that words which had been more recently presented to the subject were recalled significantly better than words which had been presented to the subject a longer time in advance. This is the recency effect, and was expected. A small number of false positives were recorded, words incorrectly recalled, as they had not been presented during the course of the experiment. With the exception of one word, *idea*, plausible explanations can be proposed for why they had been included in the lists of recalled words, usually that they were nouns corresponding to verbs in the lists (or vice versa), or that they were very similar in structure or pronunciation to words in the lists.

Thus Experiment 9.1 shows that words presented to the RVF are classified grammatically into nouns and verbs significantly more efficiently than words presented to the LVF, reflecting the language superiority of the RH. The experiment also shows an effect of word frequency, in that more common words are classified into nouns and verbs more efficiently than rare words. Finally it shows that **RL**, but not **HJ**, has reversed cerebral asymmetry in terms of language processing.

9.3 - Experiment 9.2: Reading Laterally Presented Words Out Loud

9.3.1 - Introduction

It is well documented and uncontested that the left hemisphere is superior for language related tasks in almost all right-handed adults and the majority of left-handed ones. This has been shown in a number of ways, the most notable of which are the effects of left vs. right brain damage, dichotic listening tasks and tachistoscopic split field visual studies. Both of these last two areas of study show faster and more accurate processing of words presented to either the right ear or the right visual field. These two paradigms work because of the crossed nature of the visual (complete crossing) and auditory (partial crossing) pathways: stimuli presented to the left ear or visual hemifield reach first and are preferentially processed by the right hemisphere and vice versa. Much of this is covered in more detail in Chapter 2 and the introduction to this chapter.

However, it is not the case that all right-handed people have their language processing primarily in the left hemisphere (e.g. Kolb and Whishaw, pg.359). In the case of patients who are suffering from intractable epilepsy that can only be eased by brain surgery, it can be vital to the surgeon to know in which hemisphere the language processing is located so that language comprehension and production, processes which are of great importance to general survival and communication with other people, can be spared during the surgery. Previous data collected from patients during the WADA test (Kolb and Whishaw pg.358-9), in which sodium amytal, an anaesthetic, is injected into the internal carotid artery on one side and then (if necessary) the other in order to anaesthetise and inactivate the ipsilateral cerebral hemisphere, have suggested that the following are representative proportions, for a sample studied by Rasmussen and Milner (1977).

Table 9.14 - Hemispheric language dominance for epileptic subjects

People	Number of Cases	Hemisphere		
		Left	Both	Right
Right-handed	140	96%	0%	4%
Left-handed	122	70%	15%	15%

As mentioned earlier, this test is used to determine which is the dominant hemisphere, at least in terms of language, prior to any epilepsy surgery. The test involves injecting sodium amytal, which is an anaesthetic, into one of the carotid arteries, each of which delivers blood primarily to one half of the brain. It is worth noting that there is a pattern of blood vessels at the base of the brain, called the Circle of Willis, which allows shunting of blood between the two cerebral hemispheres. There may sometimes be odd effects on language whichever side is injected, not due to bilateral language processing but rather due to increased shunting of the blood and therefore of the sodium amytal from one hemisphere to the other. For this reason, the WADA test may not be 100% accurate. Before and after the injection the patient lies on his or her back, holds both arms in the air and counts backwards. After injection, the arm contralateral to the injection will fall, and if the injection is on the side of Broca's and Wernicke's areas, the patient will stop counting for a few minutes, as a temporary aphasia ensues.

In two previous experiments (5.4 and 9.1), I investigated the speed and accuracy with which normal adult subjects could decide whether words briefly presented to one visual hemifield were nouns or verbs. The results showed that although the speed and accuracy depended on the frequency with which the words occurred in everyday use, there was a significant effect of visual field for the latter experiment, and a non-significant trend in experiment 5.4: the words presented to the right visual field were classified as nouns or verbs faster and with fewer errors than those presented to the left visual field. This was interpreted as the left hemisphere's being more efficient at processing verbal material. A likely reason for the absence of a significant LH advantage in Experiment 5.4 was the inclusion of both right and left handed subjects.

These two experiments, outlined above, used visually presented words and manual responses. The responses were made using one of two keys on the computer keyboard, one for 'noun' and one for 'verb', both of which were pressed using different fingers of the same hand. Both

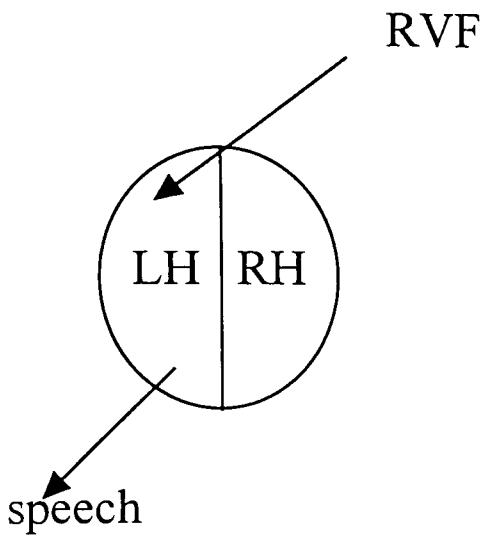
response hand and response finger were counterbalanced between subjects to control for differences in handedness (although the preferred hand was used in Experiment 5.4 in which both right-handed and left-handed subjects participated). All the subjects who participated in Experiment 9.1 were right-handed on the basis of their own description, but, unlike in this experiment, a detailed profile of their handedness for various tasks was not collected.

Experiment 9.2, described below, investigated a different, and hopefully better, method of testing hemispheric dominance for language tasks. An important use of this test, should it be shown to be sensitive enough, would be to investigate the quantitative correlation between different methods of measuring laterality, viz. this tachistoscopic test and the results of brain imaging (PET, MRI). If the test described below could be developed to a high degree of accuracy, it could possibly be used alongside the sodium amytal test on some occasions, potentially to increase the accuracy of language dominance prediction when the results of the WADA test are inconclusive (due to the shunting of blood in the Circle of Willis). It could never replace the WADA test, of course, and it should be noted that in some cases at least surgeons carry out a more detailed investigation of functional localisation using methods such as microelectrode recording (e.g. Penfield and Rasmussen 1950, Ojemann et al 1992).

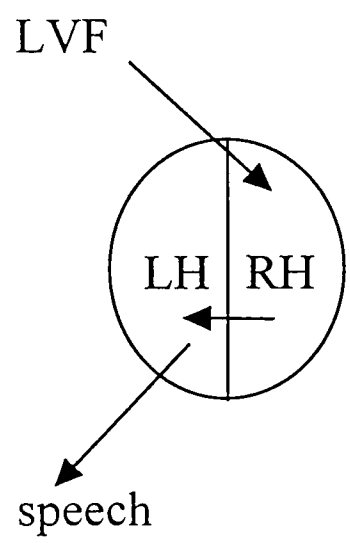
The main difference between this experiment and the two cited above was the response mode used: the present experiment used a verbal response rather than the manual response used previously. As the question under investigation concerned finding the optimum way of determining a person's dominant hemisphere without having to resort to sodium amytal, a verbal response was thought likely to give a more efficient prediction of cerebral dominance than a manual response, as both the word-processing and output (i.e. saying the word) stages would be mediated by the same hemisphere. This is easier shown in diagram 9.1, which should be compared with diagram 2.1 in Chapter 2, showing the pathways for information in a manual

task. It can be seen by comparing the two diagrams that the number of information-processing 'steps' is a maximum of 3 rather than 4 - in other words only one interhemispheric transfer of information is needed at most when a verbal response is needed, as opposed to a possible two when the response is manual. Also, the number of information-processing 'steps' now varies as a function of visual field only, and not response hand, and therefore not as a function of trial type (verb / noun). Having only one response type (read the word orally) removes the possibly confounding variable of which hemisphere is responsible for the response.

LH language superiority

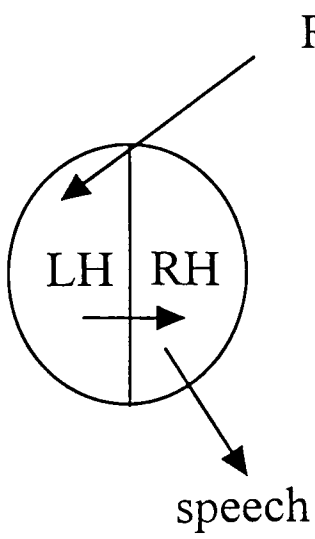


9.1a - 2 steps

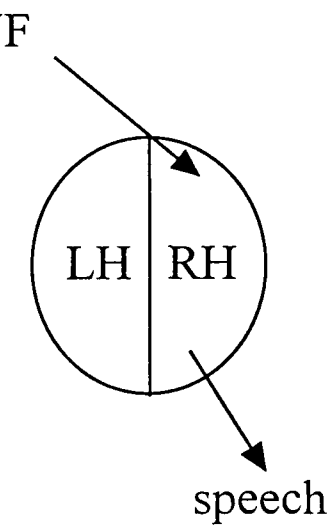


9.1b - 3 steps

RH language superiority



9.1c - 3 steps



9.1d - 2 steps

Figure 9.1 - The pathways for information in a hypothetical linguistic task with both LH and RH superiority requiring a verbal response

The plan was to test several normal right-handed adults, all assumed to have left hemisphere language dominance (on the basis of the proportions noted above) and also subjects **HJ** and **RL**, the former being a right-handed adult, and the latter probably originally a left-handed adult who now writes with his right hand, but both of whom have been shown on the basis of PET functional neuro-imaging data to have mainly right hemispheric activity during a linguistic task, and are thus both unusual and ideal subjects for this experiment.

As a verbal response was used throughout, it was thought better for the subject to read the word out loud and the reaction time to do so to be recorded, than to say whether the word presented was a noun or a verb. A 'voice key' was used, which links a microphone to the computer and can therefore measure the reaction time between the start of visual word presentation and the onset of speech. This is explained in Chapter 3. Because different phonemes have different volumes and different voice onset times, it was not feasible merely to compare the reaction time to vocalise two different words. Therefore each word appeared twice, once in each visual field, and the difference in reaction times between each of the two presentations was one of the measures recorded for analysis. However, this in turn led to another potential problem, that of priming.

Priming occurs when the presentation of one stimulus, the prime, whether it is effective subconsciously or consciously, results in increased efficiency in processing a subsequent stimulus, the target. This increase in efficiency is measured as an increased level of recognition or a decreased reaction time, and has been shown to occur in a variety of tasks concerned with memory and visual recognition, whether the prime is semantically related to the target (e.g. Nebes et al 1989) or identical to the target (e.g. Tulving et al 1982).

My concern in this experiment was that, due to priming, any word could be read more quickly the second time it occurred than it was on its first presentation. If this were the case, the results would be unclear, as the primary interest was in the difference in reaction times between the two presentations as a result of hemispheric differences, and not as a result of any other effect, such as priming. In the worst case scenario, a word is presented twice, once in one visual field and then in the other field on the immediately following trial. The second time the word appears it will probably be read significantly more quickly, whichever field it is in. This is called **repetition priming**. The way this experiment solved the problem of repetition priming was both to randomise the order of presentation and to ensure that there were at least 270 intervening words between the first and second presentations of any one word, rendering repetition priming ineffective. In the whole experiment there were 360 words and each was presented twice, once in each visual field. [Note that for one subject, **RL**, an error was made in the order of words presented, such that there were at least 90 intervening words between two successive presentations of any word, not 270. However, the second presentation of the words had a 50% chance of being in either visual field, so that if there were any decrease in reaction time due to increased priming, this decrease would affect both visual fields to a similar extent, such that overall the set of differences in reaction times between presentations of the same word would not be affected by this increased priming, if it were present.]

Another hypothesis which was tested was that a longer word takes more reading and preparation time before it can be uttered than does a shorter word. Therefore the words were further split into groups according to their number of syllables - one, two or three. The words all contained between 2 and 8 letters. The results were analysed to see if the average reaction time for reading the words increased with increasing word length.

The words used varied along a number of other dimensions: frequency, familiarity and typographic uniqueness. This enabled further hypotheses to be tested which concerned the nature of the reading errors, specifically whether the chance of making a reading error depended on the frequency, familiarity or uniqueness of the word. For this reason the misreadings were noted down as they occurred. In addition, and more relevant to the subject of the thesis, the likelihood of making an error as a function of these factors (frequency, familiarity and uniqueness) was investigated as a function of which visual field in which the errors were made, to try to glean more information about the hemispheric asymmetry of word processing.

It was already suggested by Experiment 9.1 C that rare words could lead to a greater LH advantage than common words, and therefore it is hypothesised that a similar effect will be found in Experiment 9.2.

9.3.2 - Method

9.3.2.1 - Subjects

Nine normal control subjects were used, all male right-handed adults. The control subjects' ages ranged from 20 to 59 years, with a mean of 31.8 years, and a standard deviation of 12.5 years. Subjects **HJ** and **RL** also participated in this experiment. They are both neurologically normal except that they have been shown to have RH language processing on the basis of PET tasks. They are described in detail in Chapter 3.

9.3.2.2 - Procedure

Each subject first filled in a handedness questionnaire, based on the Edinburgh Handedness Survey (Oldfield 1971), but using a 1-5 scale of response instead of a right / left response. A copy is included in Appendix C.2. This was to check that they were indeed right-handed. The experiment was then explained to the subject, who was given two practice blocks first.

In each trial the fixation cross was presented for 500 ms in the centre of the computer screen and then the word was presented in the centre of one half of the computer screen for 150 ms. It was then replaced by a mask (see below for details). This was thought a short enough time to ensure that the word could not be fixated before it disappeared but that it could still be read with a reasonable degree of accuracy.

The words were all between 2 and 8 letters long, and they were centred within each half of the screen. The letters were between 1.2 and 1.7 cm high and the font used was Turbo Pascal sans-serif. The subject was instructed to maintain central fixation and to read the word, saying it out loud as quickly as possible. If the subject could not read the word before it disappeared he was told to guess, and to say "don't know" only if he had no idea at all, for instance if he blinked during presentation. The subject was seated in front of a microphone which sent a signal to the computer timing board via a 'voice key' as soon as it registered a noise. The gain of the voice key was altered so that background noise, such as breathing, was not picked up but that the response word was reliably detected. After the subject had said the word, the experimenter pressed one key on the keyboard if the word had been said correctly, and a different one if not, thus recording the errors made by the subject. The experimenter had a list of the words in the order they appeared, and wrote down any incorrect responses or guesses for later analysis. The keypress signalled the start of the next trial. Thus the inter-stimulus interval (ISI) was controlled by the experimenter, who checked with the subject that it was long enough.

Two blocks of 54 words were used initially as a practice for the subject. Each block had one break in it, after 27 trials. The task was in fact extremely difficult, and subjects made between 23% and 69% errors on the practice trials, but continued on to the main blocks as soon as they themselves were happy with the procedure.

In the main part of the experiment four blocks of 180 words were used. Each block had three breaks in it, after 45, 90 and 135 trials, in order to give the subject a rest. The first and third blocks contained the same set of words, as did the second and fourth blocks. In the third and fourth blocks the words were presented in a different order from that in the first two blocks, although words in the first half of either of the first two blocks were still in the first half of the third or fourth block. This ensured, as mentioned earlier, that there were at least 270 intervening words between the two presentations of the same word. The main difference was that in the third and fourth blocks every word was shown in the opposite visual field from its first presentation. The order within each block was the same for all subjects, although the order in which the blocks were presented was counterbalanced across subjects. The four blocks are printed, with the order the words appeared in the experiment, in Appendix B.3. [As noted earlier **RL**'s blocks were done in an incorrect order - 1,2,4,3 instead of 1,3,4,2.]

The words were presented for 150 ms on one side of the screen and then replaced by a mask of asterisks to prevent any after-image. This was found to be preferable to the general grey mask used in the previous experiment which did not totally remove the after-image. Fixating in the centre of the screen and not looking directly at the words in fact made the act of reading the word very difficult, but the subjects were also told they must guess the word even if they did not see it. Analysis of the misread words was also carried out.

9.3.3 - Hypotheses

1. The control subjects will make more errors in reading words in the left visual field (LVF) than words in the right visual field (RVF) for two possible reasons: in the LVF the start of the word is further from the fixation point than the end of the word, as opposed to words in

the RVF, and the words in the LVF are accessing the right brain preferentially, which is not the expected superior side.

2. The words that are successfully read in both visual fields will be read faster by the control subjects when they are displayed in the RVF than in the LVF for both of the reasons noted above. Also, the mean reaction time for all words read correctly in the RVF will be faster than that for the words in the LVF.
3. Subjects **HJ** and **RL** will show either less asymmetry than the control subjects or a bias toward words in the LVF. This may be offset by the problem that reading the word from left to right biases against words in the LVF (as noted above), quite apart from any right hemisphere advantage they may have.
4. The average reaction times for reading the words and also the number of errors made in reading them will vary as a function of the number of syllables in the word: words containing more syllables will take more reading time and possibly more preparation time (before speaking the word), and so give longer reaction times, and there will also be more errors when reading them. It was decided to use the number of syllables as the independent variable, and not the number of letters, as the results might reflect a motor initiation process and not a reading process.
5. There may be an effect of word frequency in addition to the syllable effect: more common words may be read correctly more often than infrequent words.
6. There may be an effect of word familiarity - more familiar words may be read more correctly and faster than unfamiliar words. [Note that familiarity is not the same as word frequency although there is a significant correlation between the two measures.]
7. There may be an effect of how unique a word looks. This will be investigated by correlating the N-value of the words (how many other words can be made by altering any one letter) and the number of errors. It would be expected that the more unique a word looks, the fewer errors would be made as a result of mistaking the word for another. However, this is likely to

be a subtle effect, and also in general more unique looking words tend to be both longer (containing more syllables) and less common than words with a high N-value, both suggesting more reading errors.

8. The LH advantage for rare and unfamiliar words will be longer than for common and familiar words. There may be a difference in the number of errors in the LVF and RVF as a function of N-value.

9.3.4 - Results

9.3.4.1 - Handedness Survey Results

The handedness survey used, which was based on the Edinburgh survey used in previous experiments, was slightly more detailed, and also easier to fill in. Instead of left or right responses, the responses were on a scale of -2 to +2, with -2 being completely left-handed, and +2 being completely right-handed. A rating is then worked out by adding up all the figures. This gives a range of possible results of between 44 and -44. All 9 control subjects gave values of between 21 and 42 (mean 35.7, SD 6.5), supporting their right-handedness. **HJ** gave a value of 37, i.e. close to the mean. **RL** gave a value of 22, showing an overall right-handedness, but less so than **HJ** and at the lower end of the control subjects' range.

9.3.4.2 - Word Reading Tasks

Reaction times and errors were recorded during the tasks. The reaction times were measured as the time from the initial presentation of the word until the time when the computer detected a response from the voice key - usually the first voiced consonant or the first vowel. As each word was displayed twice, once in each visual field, it was appropriate to compare the reaction times for the two presentations of any word read correctly, as each reading started with the same initial sound.

The errors were noted by the experimenter during the actual task. When the subject said a word, a key was pressed by the experimenter to show whether there had been an error, and if it was incorrect the response word was written down. In some cases, a calculated decision had to be made by the experimenter as to which of two or more possible spellings the subject thought he had seen. Also some of the error words were not real words, so a viable spelling had to be assumed.

Occasionally the subject uttered the correct word, but too quietly for the microphone to detect (I was able to hear it but the program did not register that the microphone had detected a sound). In these cases, this was noted and the trial was counted as correct for the purposes of calculating the number of errors made, but incorrect for the reaction time calculations. If the subject was incorrect and the microphone did not detect the word, the experimenter asked the subject to repeat himself, and the word was marked down as incorrect for all purposes.

9.3.4.3 - Control Subjects - Reaction Times

Table 9.15 - Reaction time data for controls reading words out loud

Mean Reaction Time	Left visual field	Right visual field	Difference*
No. of syllables			
1	862	784	103
2	901	852	87
3	1022	902	139

*** This is the LVF - RVF difference for words read out correctly in both fields**

In order to investigate whether the reaction times for saying the words varied as an effect of either the visual field they were presented in or the number of syllables they contained, a within-subjects ANOVA was carried out for the nine control subjects, using visual field (2 levels) and number of syllables (3 levels) as the factors. Only reaction times for words read correctly were used. This analysis yielded both a significant effect of field ($F = 9.36$, $DF = 1,8$, $P = .016$) - the words in the right visual field were read faster than those on the left - and a significant effect of

syllable ($F = 22.27$, $DF = 2,16$, $P < .001$) - words were generally read more slowly the more syllables they contained.

Next, a within-subjects ANOVA was carried out, comparing the reaction times for the two readings of any word that was read correctly at both presentations (rightmost column of the above table). This meant that there was just one between-subjects variable - that of number of syllables (3 levels). This failed to give a significant effect of syllable, ($F = 2.54$, $DF = 2,16$, $P = .110$), showing that the difference in reading times between the two visual fields did not depend on the length of the word, but it was certainly the case that there was a very significant trend towards a faster reading of words in the RVF than those in the LVF ($P < .003$ for all word lengths). All of the control subjects showed a faster mean reaction time for reading any word in the RVF compared with when it was read in the LVF (if read correctly both times) for all word lengths.

9.3.4.4 - Control Subjects - Errors

Table 9.16 - Error data for controls reading words out loud

No. of errors	Left visual field	Right visual field	Words misread*
No. of syllables			
1	63	44	73
2	76	53	85
3	87	61	95

*** This is the total number of words misread in either (or both) field(s)**

Similar analyses were carried out for the number of errors made. When the number of errors made was investigated as an effect of visual field and word length, the ANOVA yielded the following results, using the same two factors (field - 2 levels, and syllable - 3 levels). Again there was both a significant effect of field ($F = 173.45$, $DF = .0001,8$, $P < .001$) - more words were misread when they were on the left than when on the right - and a significant effect of syllable ($F = 61.58$, $DF = 2,16$, $P < .001$) - the longer words were misread more than the shorter words. The interaction of field and syllable was not quite significant ($F = 2.94$, $DF = 2,16$, $P =$

.082 [n.s.]). Thus the reaction time data and the error data concur in showing a RVF advantage and an advantage for reading shorter words.

An analysis equivalent to the second one above was then carried out, investigating the total number of words that were read incorrectly on either or both sides as a function of the number of syllables in the words (the rightmost column of the above table). There was only one factor (syllable - 3 levels) in this analysis, and this gave a very highly significant result ($F = 38.94$, $DF = 2,16$, $P < .001$ [<0.1%]) - many more words were misread when they were longer than when they were shorter. Thus longer words were read correctly much less often, but although they were also read slightly slower in general, this was not a significant result.

9.3.4.5 - Subjects **HJ** and **RL**

Both **HJ** and **RL** performed the same tasks as the control subjects. They were both very good at the speed reading of the words, and made fewer errors overall than any of the control subjects. What is more interesting, however, is the pattern of their errors. They were treated as single case studies, and therefore ANOVAs were not possible. Instead their results were compared with the control sample means using Dunnett's t-tests and a k value of 3 (see Chapter 3 for further explanation). Any result was deemed significantly different from that of the controls if $|t_d| > 2.21$.

9.3.4.5.1 - **HJ** - Reaction Times

Table 9.17 - Reaction time data for HJ reading words out loud

Mean Reaction Time	Left visual field	Right visual field	Difference*
No. of syllables			
1	722	771	-70
2	789	843	-100
3	843	959	-140

*** This is the LVF - RVF difference for words read out correctly in both fields: a negative value implies a faster LVF**

HJ's actual reaction time results were not significantly different from those of the controls, but he did show a different, though insignificant, trend. Whereas most of the controls showed generally faster reaction times to words on the right of fixation, as shown above, **HJ** was generally faster at reading words on the left of fixation, and he in fact showed a greater left field advantage for longer words, whereas the controls had shown a greater right field advantage for longer words. However, even for words of one syllable, the t_d value obtained was only 1.89, which was not quite significant.

However, when his reaction times for words which were read correctly in both fields were compared with the equivalent data for the controls, he now showed a highly significant difference (t_d = 2.62, 4.13 and 3.88 for 1, 2 and 3 syllables respectively - P < 5%, <1% and <1% respectively). The controls' reaction time data showed an increase in right field advantage for longer words, whereas **HJ** showed a left field advantage for longer words. The presence of a significant difference implies that this is a better analysis to do than the above one, as it is really a within-word analysis that is being carried out, which therefore removes the problem that different words do not have the same initial vowels and consonants, causing variation in voice onset times.

9.3.4.5.2 - **HJ** - Errors

Table 9.18 - Error data for HJ reading words out loud

No. of errors	Left visual field	Right visual field	Words Misread*
No. of syllables			
1	30	39	50
2	45	43	69
3	50	49	68

*** This is the total number of words misread in either (or both) field(s)**

HJ's error data showed a greater difference from the controls' data than did his reaction time data. Again, Dunnett's t-tests were used to compare the number of errors made by **HJ** and the

controls. He made significantly fewer errors for the 1- and 3-syllable words in the left visual field (t_d = 2.38, 2.02 and 2.90 respectively for 1, 2 and 3 syllable words - P < 5%, n.s. and P < 1% respectively), although the number of errors he made for words in the right visual field was not significantly different from the number made by the controls, reflecting his overall superiority at the task. The value for 2-syllable words is only just not significant. When the difference in the number of errors between the words in the two visual fields was analysed, it was found that **HJ** was very highly significantly different from the controls: for words of one syllable, he actually showed more errors on the right than on the left, and for words of all lengths, he showed a significantly smaller right-sided bias (t_d = 3.44, 4.08 and 3.06 respectively for 1, 2 and 3 syllables, P < 1%, <1% and <1% respectively). Thus **HJ**'s error data and reaction time data both show that he has a definite LVF advantage, as opposed to the RVF advantage of the controls.

When an analysis was carried out to investigate the number of words read incorrectly on either or both sides (as earlier), **HJ** only showed a significant difference from the controls for 3 syllable words - he made significantly fewer errors (t_d = 2.29, P < 5%).

9.3.4.5.3 - **RL** - Reaction Times

Table 9.19 - Reaction time data for HJ reading words out loud

Mean Reaction Time	Left visual field	Right visual field	Difference*
No. of syllables			
1	612	676	-58
2	659	702	-38
3	710	781	-89

*** This is the LVF - RVF difference for words read out correctly in both fields: a negative value implies a faster LVF**

RL's reaction time data were on the whole not significantly different from the control data, as for **HJ**, although he too showed a trend of responding faster to words in the left visual field than to those in the right visual field. For words of one syllable, however, his left visual field

advantage was almost, though not quite, significantly different from the controls' right visual field advantage ($t_d = 2.11$). Again longer words were read more slowly than shorter words.

However, when his reaction times for words read correctly in both fields were compared with the control data, in the same way as above for **HJ**, he now showed a significant difference for words of all lengths ($t_d = 2.44$, 2.76 and 3.20 for words of 1, 2 and 3 syllables respectively - $P <$ 5%, $<$ 5% and $<$ 1% respectively). **RL**'s trend of an increasing left field advantage with increasing word length was not as clear cut as **HJ**'s, but present nonetheless.

9.3.4.5.4 - **RL** - Errors

Table 9.20 - Error data for RL reading words out loud

No. of errors	Left visual field	Right visual field	Words Misread*
No. of syllables			
1	23	35	44
2	38	35	47
3	49	48	64

*** This is the total number of words misread in either (or both) field(s)**

RL made even fewer errors overall than **HJ**, although he made roughly as many as both **HJ** and the control subjects for the words in the right visual field: thus he made remarkably few errors for the words in the left visual field. As above, Dunnett's t-tests were used to compare the number of errors he made with the control data. He made significantly fewer errors in the left visual field ($t_d = 2.89$, 2.48 and 2.98 respectively for 1, 2 and 3 syllable words - $P <$ 1%, $<$ 5% and $<$ 1% respectively), although not in the right field, where the number of errors he made was towards the lower end of the control's range. When the difference in number of errors between the two fields was analysed, **RL** was very highly significantly different from the controls, even more so than **HJ**. For words of all lengths he showed more errors on the right than on the left ($t_d = 3.81$, 3.89 and 3.06 respectively for 1, 2 and 3 syllable words - $P <$ 1%, $<$ 1% and $<$ 1% respectively).

When an analysis was carried out to investigate the number of words read incorrectly on either or both sides (as earlier), **RL** showed a significant difference from the controls for words of all lengths - he made significantly fewer errors - showing also his superiority over **HJ** (t_d = 2.26, 2.51 and 2.64 respectively for 1, 2 and 3 syllable words - P < 5%, < 5% and < 5% respectively). Thus **RL**, like **HJ**, showed a LVF advantage for reading words both in terms of error data and reaction times.

Figures 9.1, 9.2 and 9.3 display the results for the controls and for **HJ** and **RL** superimposed so that direct graphical comparisons can be made. Figure 9.2 shows the difference in reaction times between the readings in the LVF and the RVF as a function of number of syllables for words which were read correctly both times, once in each visual field. A positive value on the y axis means that the words were read more quickly in the RVF than the in the LVF, and *vice versa*. Figure 9.3 shows the difference in the number of errors made between the two visual fields. Again a positive value on the y axis means that more errors were made in the LVF, and *vice versa*. Figure 9.4 shows the number of errors made as a function of the number of syllables in the word, referring to the number of words misread in either visual field.

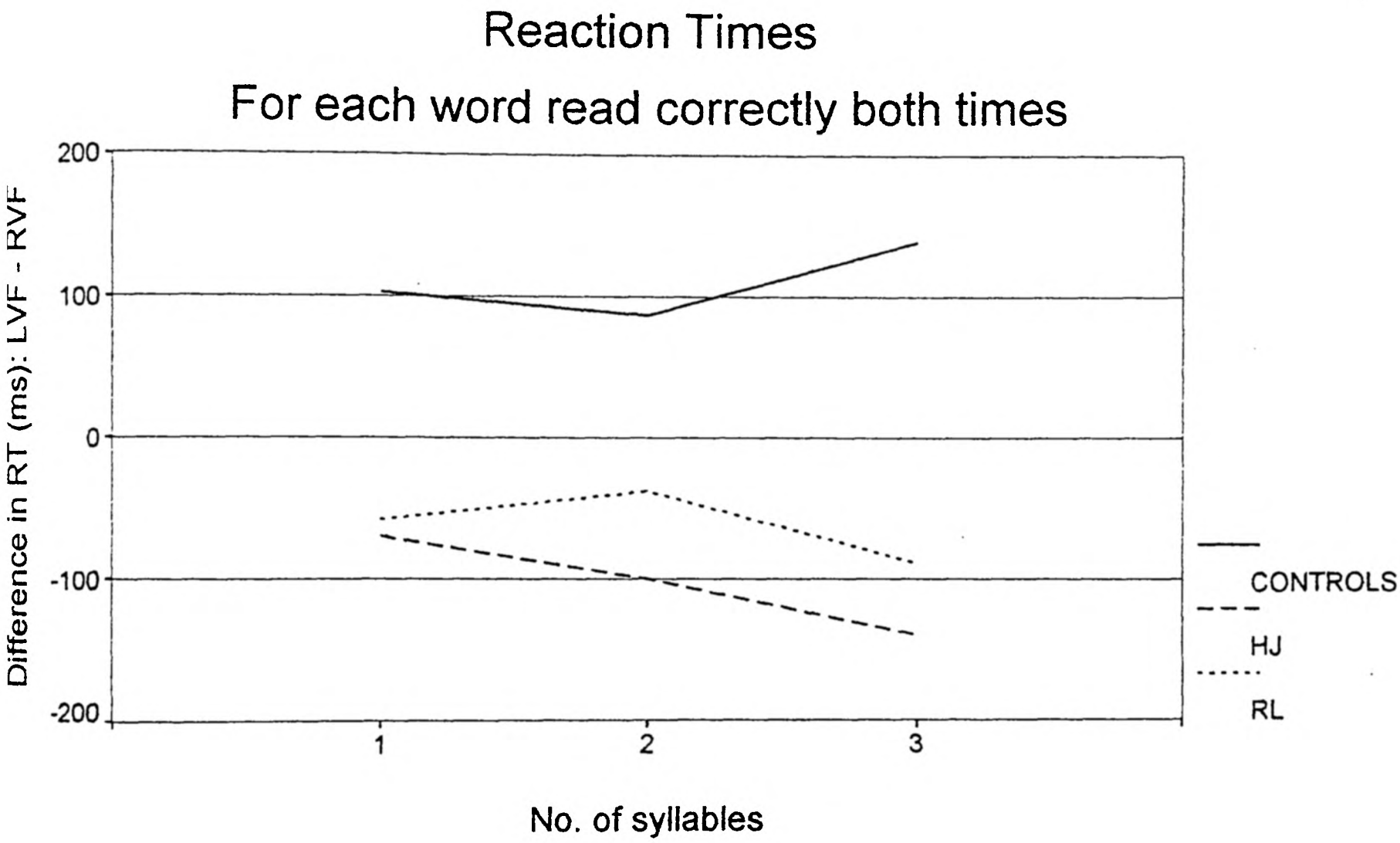


Figure 9.2 - Difference in reaction times between the two visual fields for all words read correctly, for the controls, HJ and RL as a function of the number of syllables in the word.

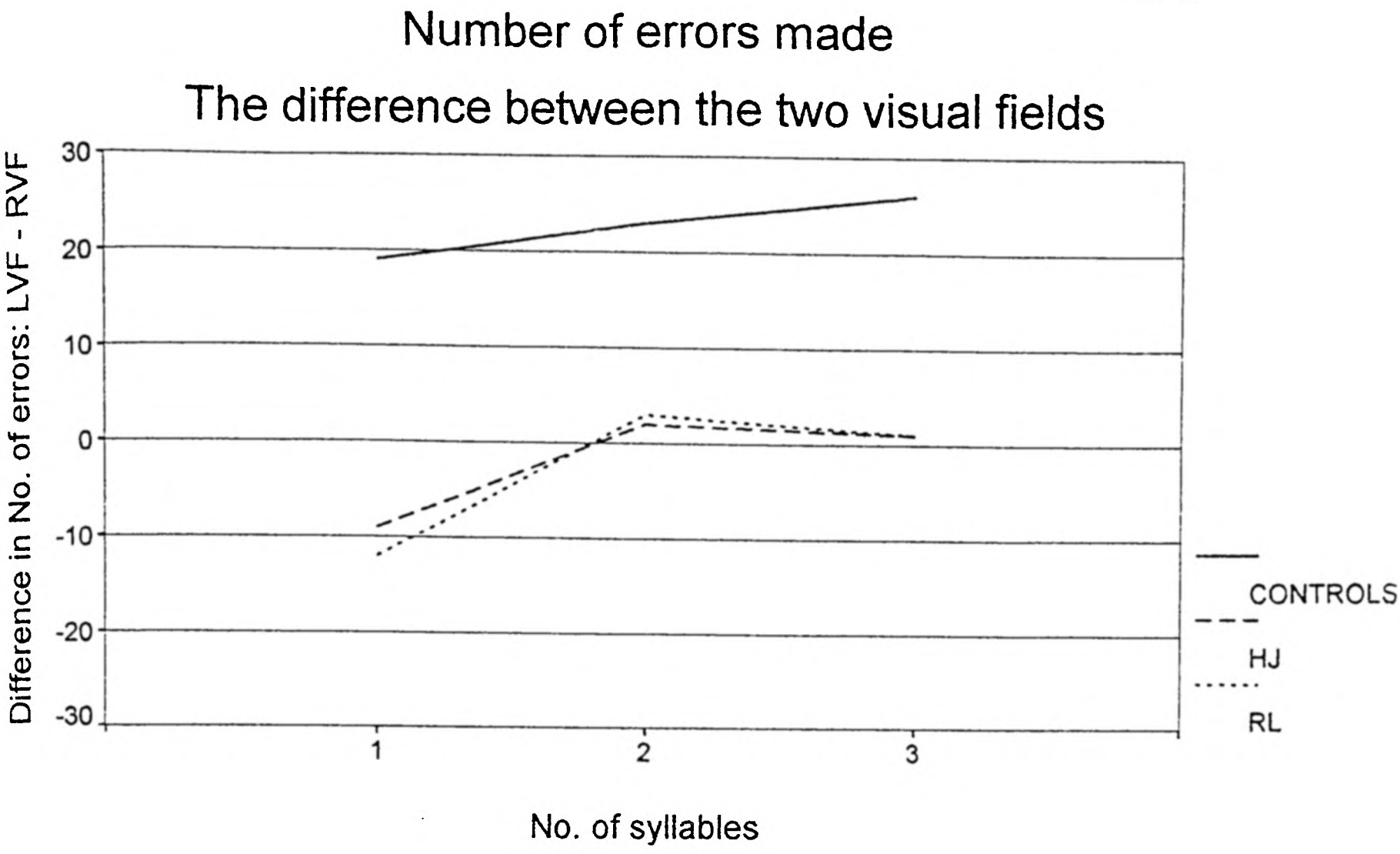


Figure 9.3 - Difference in errors made between the two visual fields for controls, HJ and RL as a function of the number of syllables in the word

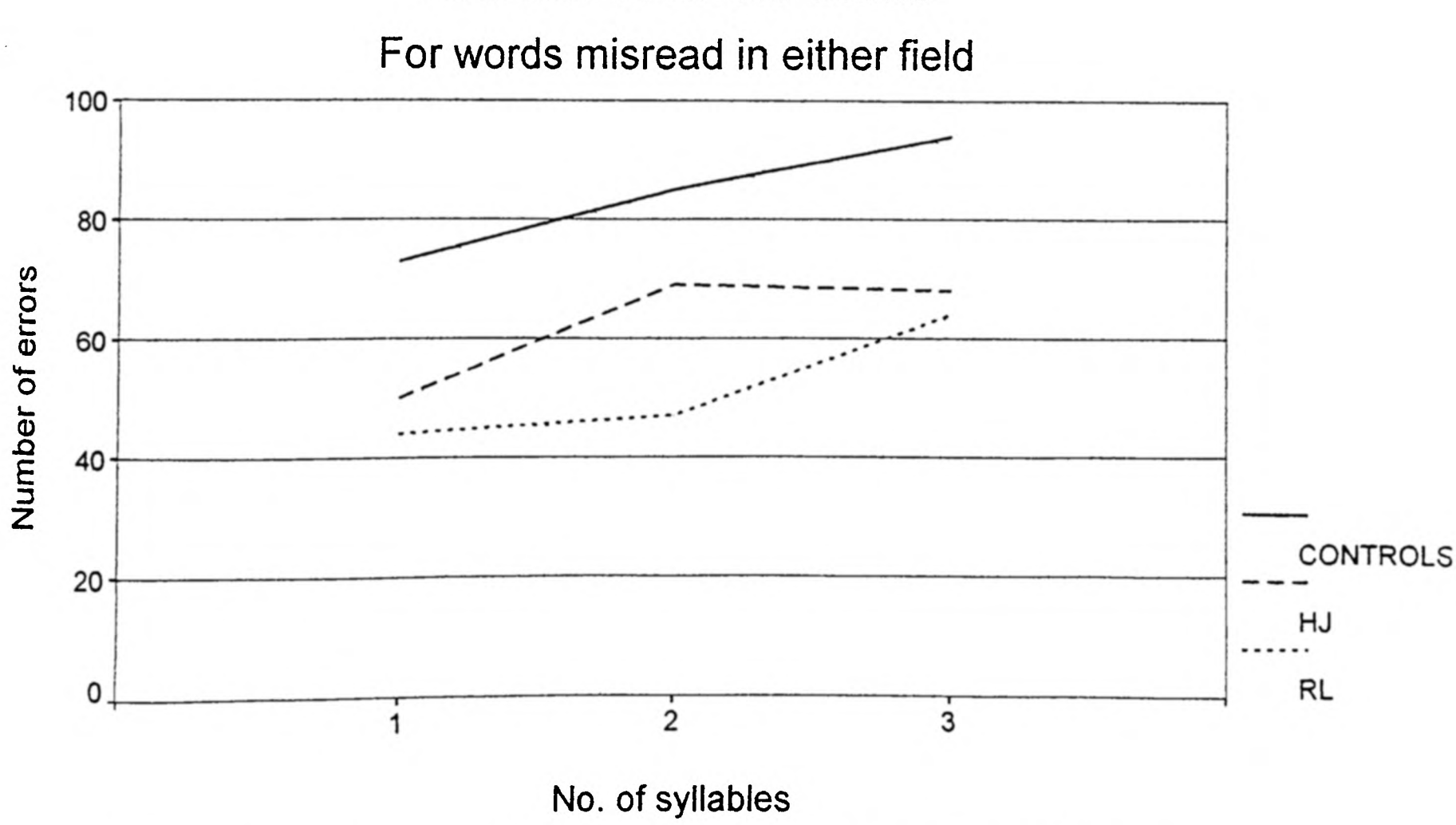


Figure 9.4 - Number of errors made by the controls, HJ and RL as a function of the number of syllables in the word.

9.3.4.6 - Word misreading errors

As well as recording the number of errors in each field to compare word reading on either side of fixation and as a function of word length, any misreadings were noted, and a detailed analysis of the actual errors was carried out, to investigate the types of errors made when speed reading words, and whether there were any significant differences in error types on the two sides of fixation.

The number of letters which were correctly read at either the start or the end of any words read incorrectly were calculated, to see if there was an effect of reading portions of words nearer fixation more easily, or whether the start of the word is normally read more easily than the end.

The results are shown in the following table (9.2), which shows the number of letters in all the misread words that were correct, and whether they were at the start or the end of the word.

Table 9.21 - number of initial and final letters correctly read in incorrectly read words in Experiment 9.2

Word length	LVF initial letters correct	LVF final letters correct	RVF initial letters correct	RVF final letters correct
1 syllable	534	420	479	453
2 syllables	555	629	479	655
3 syllables	692	764	772	568

The second table (9.3) shows the number of letters correct at the start or end of misread words per misread word - i.e. it is the above numbers divided by the number of errors in each cell.

Table 9.22 - number of initial and final letters correctly read per error in incorrectly read words in Experiment 9.2

Word length	LVF initial letters correct	LVF final letters correct	RVF initial letters correct	RVF final letters correct
1 syllable	0.88	0.69	1.01	0.96
2 syllables	0.72	0.82	0.87	1.19
3 syllables	0.79	0.87	1.19	0.88

The interpretation of these data is not straightforward, but some sense can be made out of them. The data for words of 3 syllables are the easiest to understand. The number of correct letters read in total at the ends of the words near to fixation was higher than the number of correct letters far away from fixation. Thus the end of words in the left visual field and the start of words in the right visual field were read correctly more often. For words of 1 syllable, however, letters at the start of the words in either visual field were read more often than letters at the end. This was the case even for words in the left visual field, implying perhaps that the 1 syllable words were short enough to be read as a block. The data for words of 2 syllables are much harder to understand, however. In the left visual field, more letters were read at the end than at the start of the words, but the same was also true of words in the right visual field, and no reason for such a result can be offered at the present time. One possibility, for instance, is that more of the words with 2 syllables had 'standard' suffixes which were more likely to be read correctly, than did the words with 1 or 3 syllables.

When the data from the second table are investigated, which takes into account the different number of errors made in each visual field for each different word length, a similar pattern occurs. One syllable words had their beginnings read more often than their ends, whichever side they were displayed on, the ends of 2 syllable words were more often read correctly than their initial letters, whichever side the words were displayed on, and the section of the 3 syllable words nearer to the fixation point were read more correctly than those further away.

9.3.4.7 - The Effect of Word Frequency

A possible effect of word frequency was then investigated. Linear regressions were carried out to test for a statistical relationship between the number of errors made and the frequency of the words in everyday language, obtained from two different sources. The first was *Word Frequencies in British and American English* (Hofland and Johansson 1982), the book which I used in previous experiments. The second was the Kuçera - Francis frequency obtained from the Oxford Psycholinguistics Database (Quinlan 1992), which was another corpus kept on computer. A separate analysis was carried out for each word length, and a full analysis for all the words then carried out. A discernible trend was that in general, the more common a word was the fewer errors were made overall, and regressions between the number of errors and the natural log transform of the frequency were carried out.

As the main thrust of this thesis is the investigation of hemispheric asymmetry for language and face processing, the relationship between word frequency and visual field was also investigated. To this end an ANCOVA (analysis of covariance) was carried out whereby the differences in the number of errors for each word between the LVF and RVF were correlated with the frequency of the word. A significant result would imply an interaction between visual field and frequency.

It should be noted that some of the words, which were certainly known to all, in fact had no entry in the particular corpora used. The frequency for these words was taken as 0 for the Hofland and Johansson frequencies, but the word was missed out of the analysis if it did not have an entry in the Oxford Psycholinguistics Database. As ln(0) does not exist, the log of (frequency + 1) was instead used, and this value was plotted along the x axis. The reason for using this transform was that the words used had a range of frequencies between 0 and 5287 occurrences per million words, but that only 5 words (*after*, *one*, *this*, *up* and *who*) out of the 360

words used (over 700 entries in the word lists) had more than 1000 occurrences. The log transform made the frequency range more evenly spread between 0 and 8.57.

9.3.4.7.1 - Hofland and Johansson Frequencies

The statistics between the number of errors made and ln(frequency + 1) were r = 0.3009 (118 DF, F = 11.75, P = .0008) for 1 syllable words, r = 0.1720 (118 DF, F = 3.60, P = .060 [n.s.]) for 2 syllable words and r = 0.3920 (118 DF, F = 21.43, P <.001) for 3 syllable words. Thus there is a significant negative correlation for words of 1 and 3 syllables, and a just non-significant one for words of 2 syllables. When all the data are taken together, r = 0.3511 (358 DF, F = 50.34, P < .001), again highly significant. The result of the ANCOVA for ln(frequency + 1) and visual field was not significant (r = 0.0862, 358 DF, F = 2.68, P > 0.10). Figure 9.5 shows the frequency data and best fit line for all the words combined.

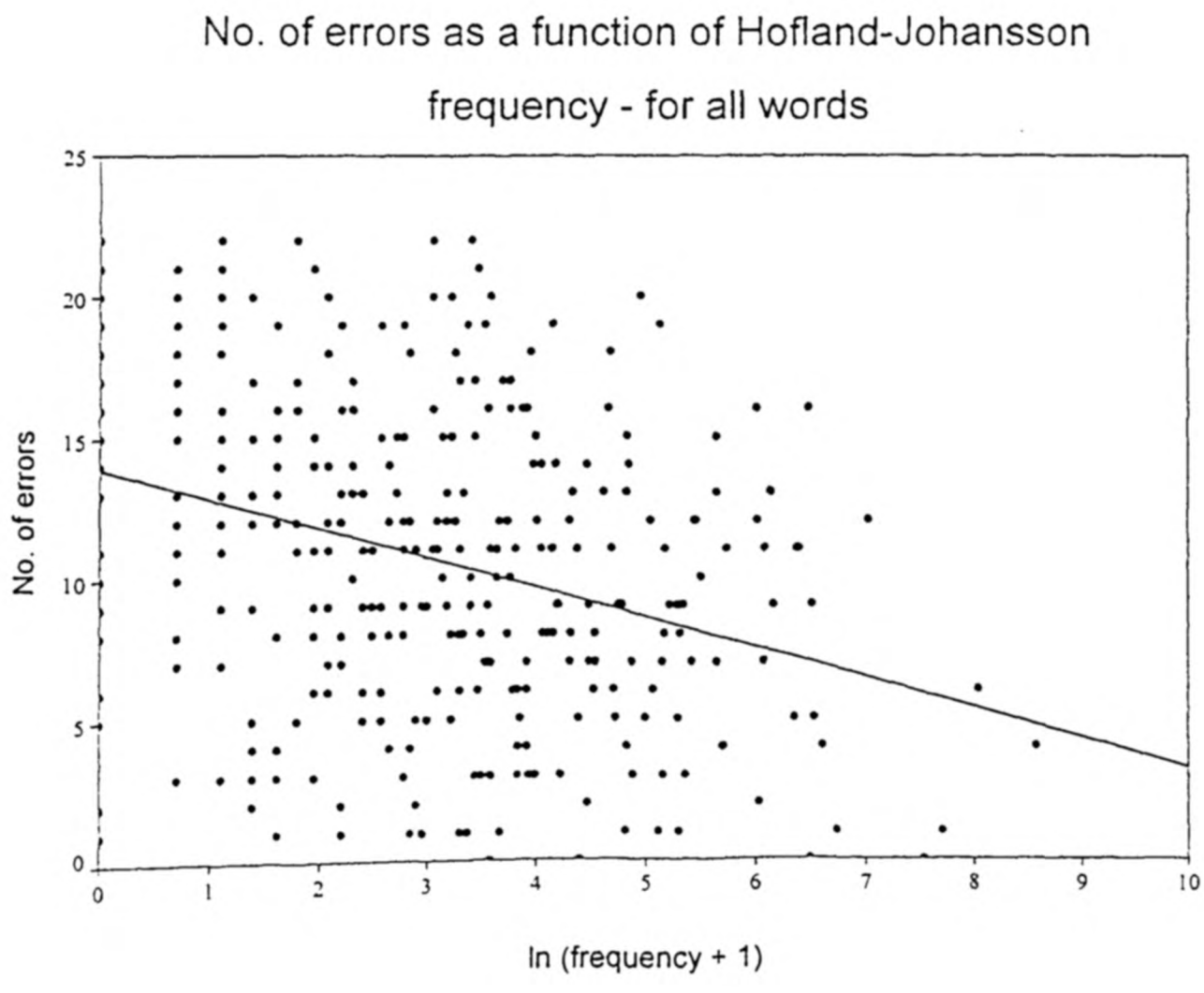


Figure 9.5 - Error data for Experiment 9.2 as a function of Hofland and Johansson word frequency

9.3.4.7.2 - Kuçera - Francis frequencies (Oxford Psycholinguistics Database)

The statistics between the number of errors made and ln(frequency + 1) were r = 0.1968 (114 DF, F = 4.593, P = .034) for 1 syllable words, r = 0.0811 (106 DF, F = 0.702, P = .40 [n.s.]) for 2 syllable words and r = 0.3819 (80 DF, F = 13.66, P =.0004) for 3 syllable words. Thus there is a significant negative correlation for words of 1 and 3 syllables, but not for words of 2 syllables. No reason can be offered for this difference as an effect of the number of syllables in the word. Note the different numbers of degrees of freedom from the analyses above - this is because some words had no entries at all in this frequency list. When all the data are taken together, r = 0.2414 (304 DF, F = 18.81, P < .001), again significant. The result of the ANCOVA for ln(frequency + 1) and visual field was not significant (r = 0.0078, 304 DF, F = 0.19, P > 0.89). Figure 9.6 shows the frequency data and best fit line for all the words combined.

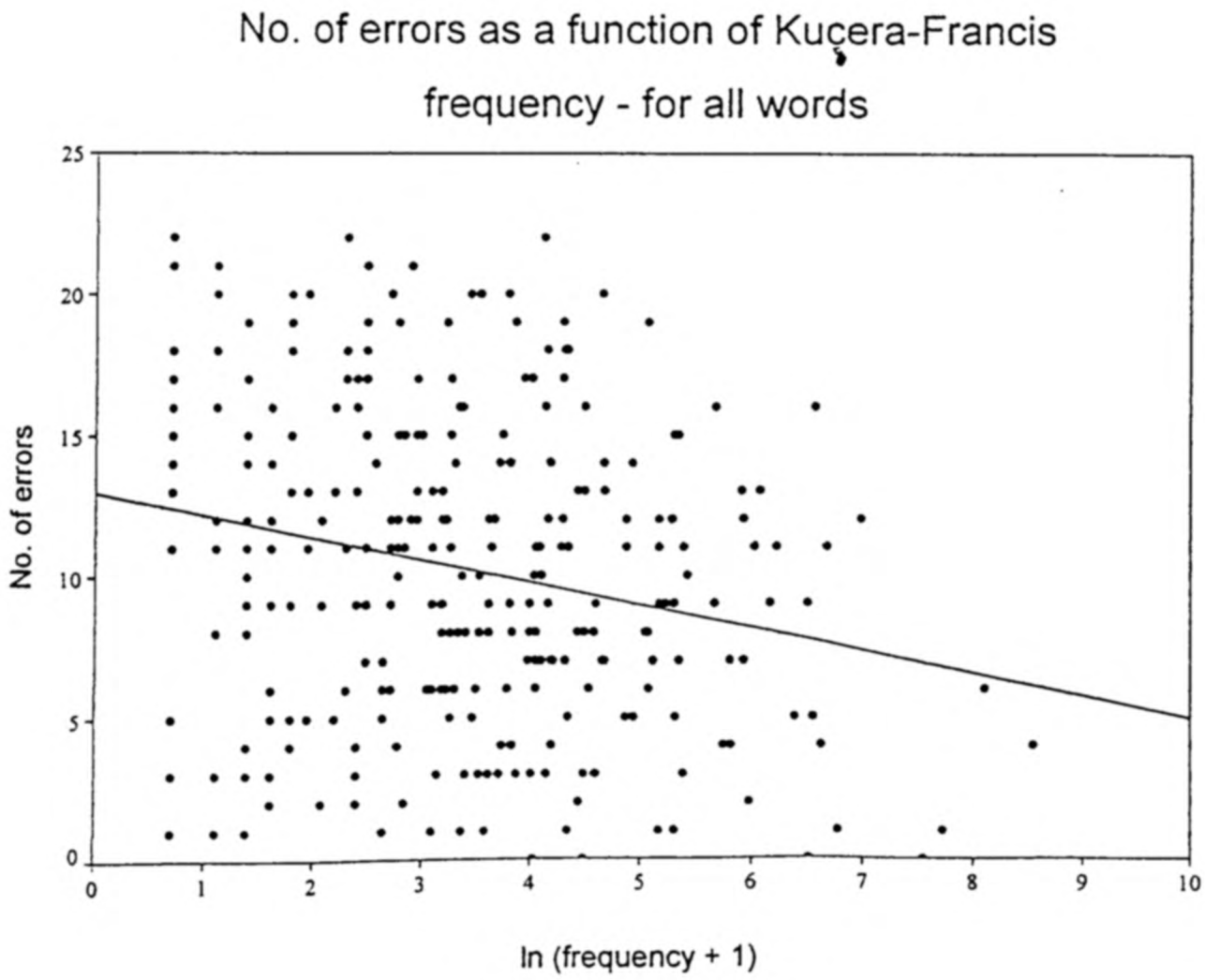


Figure 9.6 - Error data for Experiment 9.2 as a function of Kuçera - Francis word frequency

9.3.4.7.3 - Familiarity

A possible link between the familiarity and the number of reading errors made for each word was also investigated. The familiarity ratings, as given by the Oxford Psycholinguistics Database was obtained by blending together three sets of familiarity norms - Gilhooly and Logie (1980), Paivio (unpublished) and Toglia and Battig (1978), and is a number between 0 and 657. Familiarity is not quite the same as frequency although the two variables do correlate. Again linear regressions were carried out for each word length and for all the words taken together. The results of these analyses were r = 0.2755 (98 DF, F = 8.046, P = .0055) for 1 syllable words, r = .1857 (79 DF, F = 2.821, P = .097 [n.s.]) for 2 syllable words and r = 0.2198 (39 DF, F = 1.980, P = .17 [n.s.]) for 3 syllable words. When all the data were taken together, r = 0.2618 (220 DF, F = 16.182, P = .0001). Thus for one syllable words and also for all the words taken together, errors were more likely to be made for unfamiliar words than familiar ones. The result of the ANCOVA for word familiarity and visual field was not significant (r = 0.0866, 220 DF, F = 1.66, P > 0.19). Figure 9.7 shows the familiarity data and best fit line for all the words combined.

9.3.4.7.4 - N - value (uniqueness)

A further thought was that there may be some correlation between the number of errors made and how unique a word looked. This typographic uniqueness rating was obtained from the N-value in the Oxford Psycholinguistics Database. The N-value, originally defined by Coltheart et al (1977) is the number of other real English words which can be obtained by considering each letter position in turn and by substituting all other letters in the alphabet for the target letter. It is thus roughly a measure of the visual distinctiveness of the word. Examples include *read* with an N-value of 12 (the words which differ in 1 letter are *bead, dead, head, lead, mead, reed, rend, real, ream, reap, rear and road*) and *paradox*, with an N-value of 0. It was thought that if a word looked less unique it was more likely to be misread as another real word, whereas if a

word had an N-value of 0, and did not look similar to any other English word, it was less likely to be misread. This would be confirmed if there was a positive correlation between N-value and the number of errors made, showing a greater level of misreading for less unique words. Again the regression was carried out for each word length separately, and then for all the words taken together. There was only a significant correlation when all the words were taken together, when $r = .1256$ (358 DF, $F = 5.739$, $P = .0171$). However, this was a significant negative correlation - there were more errors made for words with lower N-values, that is, the more unique looking ones, than for words with high N-values. One reason for this could be that words with lower N-values tended to be both less common and also longer, both of which favoured more errors. Thus if new word lists were used which equated frequency and word length, making N-value the only variable, a positive correlation between the number of errors made and the N-value might be found.

The result of the ANCOVA for N-value and visual field was (unlike the frequency and familiarity analyses) significant ($r = 0.1093$, 358 DF, $F = 4.34$, $P < 0.038$). This again was a significant negative correlation, in that the difference between the number of errors in the LVF and RVF tended to be larger for words with small N-values, and smaller for words with large N-values. To put this more clearly, unique words (with small N-values) tended to be recognised significantly more easily in the RVF compared to the LVF, whereas words with many words very similar in form (with high N-values) tended to result in about the same number of errors in both visual fields. Figure 9.8 shows the N-value data and best fit line for all the words combined, and figure 9.9 shows the difference in number of errors between the two visual fields as a function of the N-value.

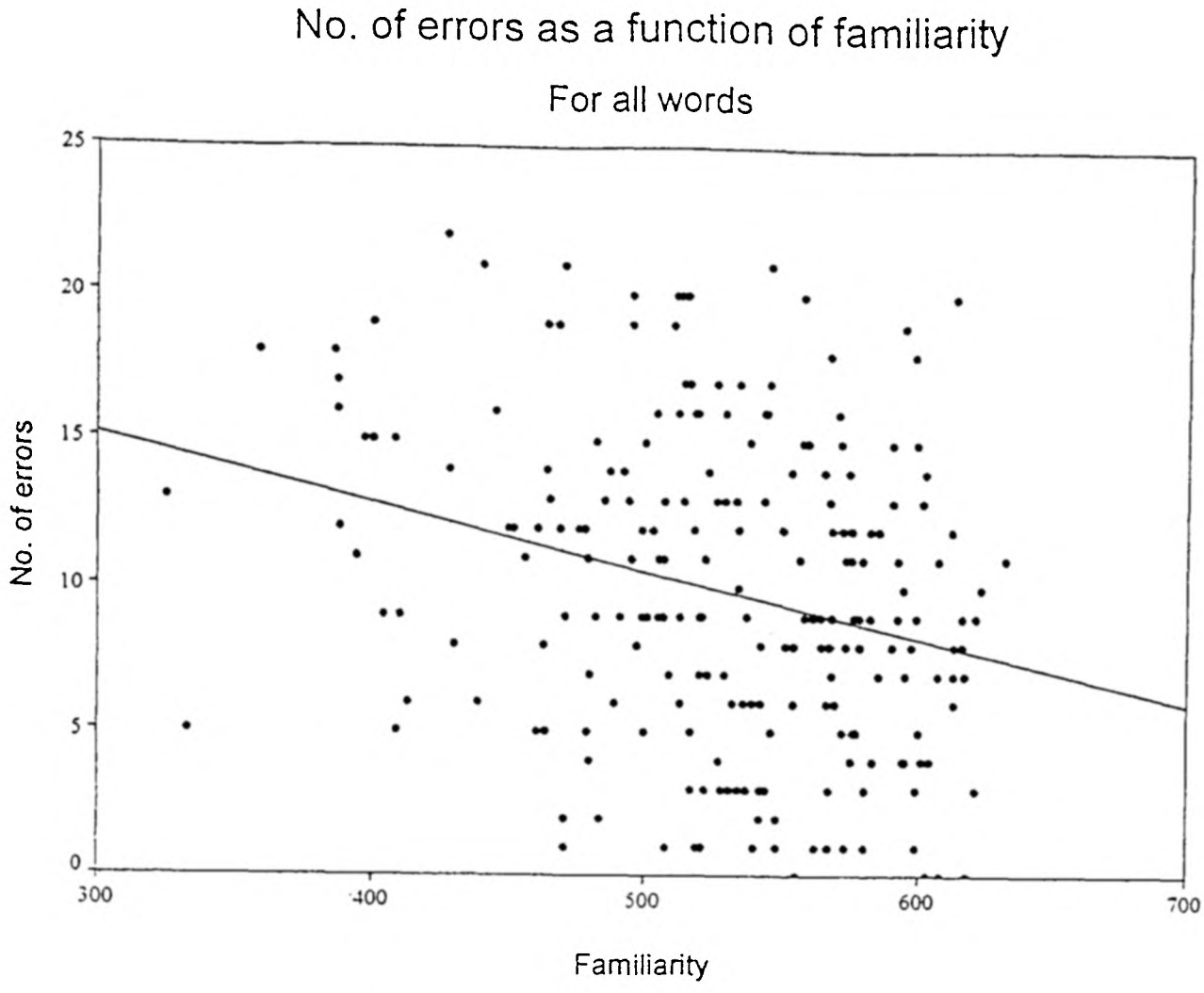


Figure 9.7 - Error data for Experiment 9.2 as a function of word familiarity

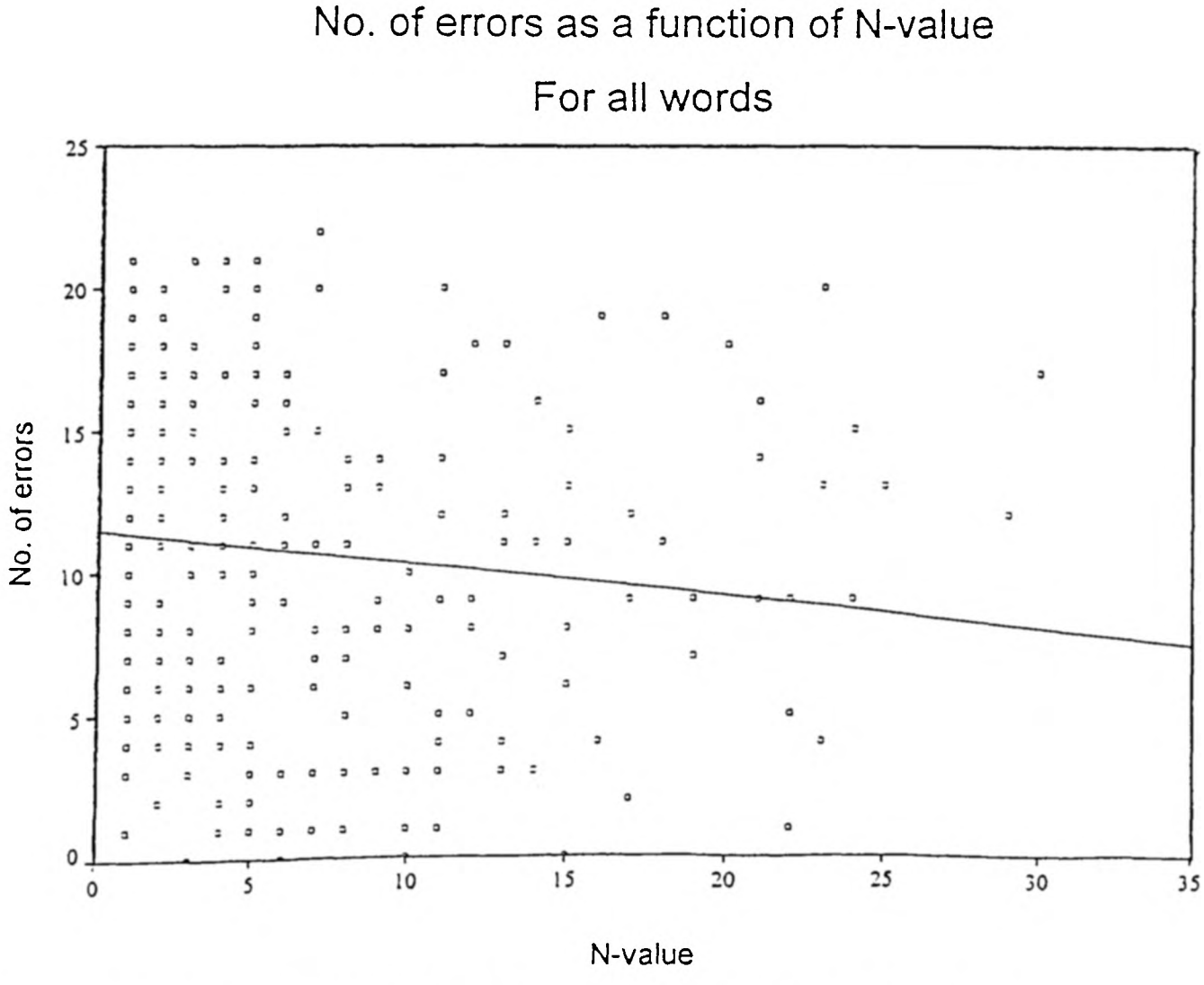


Figure 9.8 - Error data for Experiment 9.2 as a function of word uniqueness (N-value)

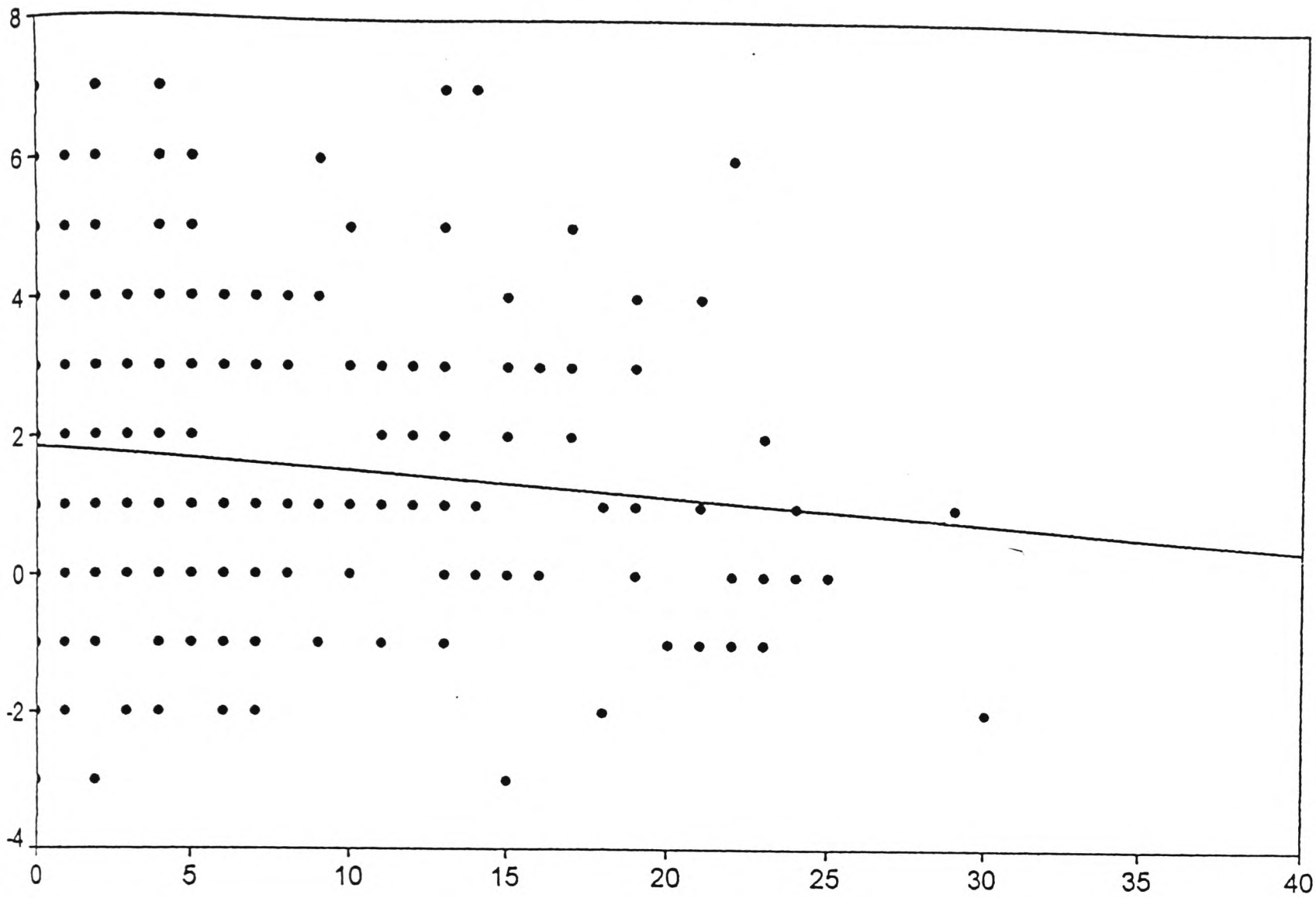


Figure 9.9 - Error data for Experiment 9.2 as a function of word uniqueness (N-value) and visual field

9.3.5 - Discussion

9.3.5.1 - Hemispheric Asymmetry Investigation

This experiment really had three main aims. The first was to investigate whether a simple word reading task with a verbal, rather than a manual response, could give a reliable indication of the cerebral hemisphere that is dominant for language abilities, albeit in a group of right-handed subjects who were already assumed (but not proven) to have normal left hemisphere dominance. The second was to test **HJ** and **RL**, two subjects previously shown on the basis of PET data to have right hemisphere language dominance, on the same task, and to see whether they would show reversed results to the control subjects tested. The third was to investigate word reading ability as a function of several aspects of the words being read (frequency, familiarity and typographic uniqueness) and their relationship to hemispheric asymmetry.

Reaction times for the correct trials and the number of errors made were used as measures of performance, and on the basis of both of these, this task certainly shows a strong right visual field (and therefore left hemisphere) advantage for word reading in normal right-handed control subjects. The use of a verbal rather than a manual response is important in that, as the task is trying to demonstrate which hemisphere is dominant for language tasks in as robust a way as possible, both the processing and the output stages are now going to take place primarily in the hemisphere dominant for language. In the previous experiment, where the subject had to determine whether a word in one visual field was a noun or a verb, the response was manual - pressing one of two keys - and even though they were both pressed with the same hand (unlike the face-matching experiments), it was still not necessarily the same hand which was controlled by the hemisphere responsible for the word processing, as the response hand used was counterbalanced between subjects. In retrospect, this very counterbalancing could have been detrimental to demonstrating the desired effect, and therefore the present experiment may be giving more significant and robust results (across subjects) for that very reason.

There was indeed a RVF advantage for reading the words, but this could have two possible sources, either that any words presented in the RVF will access the left hemisphere primarily, and therefore be processed more quickly and accurately than those in the LVF, or because we read English from left to right. The words were all centred in whichever half of the screen in which they were displayed, with the result that the words in the right visual field started closer to the fixation point than those in the left visual field. This could have the effect of making those words in the left visual field harder to read, and this difficulty would increase as the word length increased, as this would spatially move the initial letter even further from the fixation point.

This difficulty could be controlled for in one of three ways. The first is to repeat the experiment displaying the words vertically, such that they start at the same eccentricity regardless of which visual field they are displayed in. However, judging by the number of errors made when the words were horizontal and displayed briefly, such an experiment would be likely to suffer from floor effects, with very few words being read correctly at all. The second is to repeat the task with horizontal words, but control the distance between the first letter and the fixation point, rather then the distance between the centre of the word and the fixation point. This would be seen as moving all the words in the right visual field towards the lateral edge of the screen, and the words to the left of fixation closer to the fixation point. The problem with this is that the words on the right would now be at a greater eccentricity than those on the left and would therefore be harder psychophysically to resolve and see and thus harder to read, possibly overriding the hemispheric effect. A third experiment would be to test native Hebrew speakers on a similar experiment, using Hebrew words (or any other language read from right to left) to see whether there is any difference between their results and those of English speakers tested on English words.

Such an experiment has been carried out. Mishkin and Forgays (1952) showed that right-handed English subjects showed a RVF advantage for English words, but Yiddish fluent subjects showed a slight LVF advantage for reading Yiddish words (written from right to left in the Hebrew script). They concluded that acquired directional reading habits result in better processing of English words in the RVF but better reading of Yiddish words in the LVF. This explanation was widely accepted for a number of years but did not explain why the RVF advantage for English words was considerably larger than the LVF advantage for Yiddish words. A decade later, experiments on split-brain subjects demonstrated the underlying asymmetry in linguistic abilities between the two hemispheres, which had already been documented in the aphasia literature. A further experiment (Barton et al 1965) was carried out which compared the reading of English and Yiddish words which were presented vertically to negate any effects of directionality in reading. A RVF advantage for words in both languages was found, showing underlying differences in the hemispheres' linguistic processing abilities were overlaid by the effect of directionality in Mishkin and Forgays' experiment.

A further way to clarify whether the RVF advantage is due to hemispheric asymmetry or the positions of the words relative to fixation is to test subjects shown by other methods to have reversed asymmetry for language tasks. In this experiment **HJ** and **RL** were such subjects, and their results, showing a left visual field advantage as hypothesised, support the view that hemispheric superiority overrides the effect of word position on the screen. **HJ** made roughly the same number of errors on each side, and **RL** made more errors for words in the right visual field, both patterns significantly different from the controls, who made more errors in the left visual field. On the basis of their reaction time data, they both read words on the left faster than those on the right, and this was significantly different from the controls when the reaction times for the two readings of the same word read correctly both times were used.

Why **HJ** showed a significant RH advantage for this task but not for Experiment 9.1, whereas **RL** showed a significant RH advantage for both tasks is possibly due to the greater sensitivity of this task. Also, this task requires different processing and a different response of the subjects, so it possible that particular subjects will show different hemispheric advantages on one compared with the other.

In conclusion to this section, the experiment described above seems to be a viable procedure for testing which hemisphere is dominant for language tasks, at least on the basis of testing two right hemisphere language subjects (known) and 9 left hemisphere language subjects (assumed). More work is needed, and it is vital that other subjects shown to have right dominance for language tasks on the basis of functional neuro-imaging data are tested in this way too, to support these results. However, if other subjects are found who do support the above findings, then this task, with some refinement, could possibly be used when the results of the WADA test are inconclusive. This task is also of interest in correlating the results of different methods of measuring hemispheric asymmetry in a quantitative way.

9.3.5.2 - Linguistic Investigation

Additional data were collected on the linguistic side of the task. This involved investigating the pattern of errors made when the words were misread as a function both of their number of syllables and of various of their attributes, such as their frequencies in everyday language, according to two frequency corpora, their familiarity and their visual uniqueness.

As has been previously shown, longer words (i.e. those with three syllables) led to more reading errors and longer reaction times for correctly read words. Longer words included letters further from fixation than shorter words: this greater eccentricity would decrease the acuity with which they could be recognised, making the distant letters, and therefore the whole word harder to

read. It was generally the case that those words with more syllables were longer, although the number of letters in each word was not used in the analyses. The increased reaction times could be due to an increase in time taken at any or all of the processing stages involved in the task: actual reading time, processing time, and output (speech) time. It is certainly possible that there is some 'preparation time' needed in preparing for speaking the word, and that this may be increased for words of more syllables. An explanation for this could be that multi-syllabic words are planned as well as uttered syllable by syllable, therefore taking longer to prepare to say than monosyllabic words of the same length. This is similar in idea to the increased preparation time in the Tower of London or Tower of Hanoi tasks used on some patients with frontal cortical damage (e.g. Shallice 1982). Some phonemes take longer to say than others, due to voice onset time differences, but this was controlled for both between words and within words. It is quite likely therefore that the longer words take longer to read as well as longer to say. It is not possible to distinguish from the results of this experiment whether the longer words took more reading time, more preparation time or both. Subjects **HJ**, **RL** and the controls showed this same pattern. Also longer words tended to be less familiar and less common - see below.

An effect of frequency was also found, which, although it did not look very convincing from the graphs, was significant in that more common words were read correctly more often that rarer words. It would not be surprising to find that more common words are read more easily (note that this analysis was only carried out with error data, not reaction time data). Familiarity had a similar effect to frequency - the more familiar a word, the more likely it was that it was read correctly.

However, both introspectively and from the number of errors made on some words, there was apparently another factor which affected the number of errors made. This was the typographical

'uniqueness' of the word. Certain words, such as date, north, and table are all common and familiar, yet similar in structure to many other words, hence they all lead to large numbers of reading errors (19, 14 and 15 errors out of 20 respectively), whereas certain other words, such as ugly, banana and kangaroo, do not look similar to any other words, and were therefore read correctly most times, even though they are much less common than the three words noted above (1, 4 and 2 errors out of 20 respectively). However, when the N-value (a rating of the visual distinctness of the word) was correlated with the number of errors made for each word, a contrary result was shown, in that more unique words were actually read incorrectly more often, unlike the example words above. Possible reasons for this include the high correlation between N-value and both word length (negative) and frequency (positive) - words with higher N-values tend to be more common and shorter, both of which favour fewer errors. If there is in fact an overall effect of uniqueness, as shown in the example words above, then in order to find it, it would be necessary to use words which were matched for length and frequency: this has not been done.

When the aspects of word frequency, familiarity and N-value were investigated as a function of visual field and thus cerebral hemisphere, it was found that there was no significant difference in the errors in the two visual hemifields as a function of either word frequency or familiarity but that there was a significant interaction between visual field and N-value; unique looking words (with small N-values) were more easily identified in the RVF than the LVF, but there was less difference between the two visual hemifields for words with high N-values. This suggests that the LH has an advantage for recognising unique looking words over common looking words whereas the RH does not. One possible explanation, as mentioned earlier, is that the RH has some language capabilities including word comprehension (e.g. Sperry 1982), but generally only for more common, concrete words, which in turn tend to look less unique. Thus the LH is better at recognising more unique words, which are often rarer and more abstract, than less unique words

compared to the RH. However, a similar effect for frequency and familiarity would be expected, but were not apparent.

Another problem with the words was due to the font used. It was slightly stylised, and some of the letters were possibly different from 'normal' letters used in common fonts. Some letters were often read incorrectly as a result, for instance, '**n**' and '**m**' were mixed, and '**d**' would be read as '**cl**' and *vice versa.* However, detailed analysis of this sort has not been carried out.

In conclusion to this section, then, more common, shorter words were read more correctly and quickly than longer, rarer words, although there is probably an effect of word 'uniqueness' as well as word frequency. More unique words are more easily identified than common words in the RVF compared to the LVF. It may be interesting to repeat the experiment with different words, where the length of word in letters is controlled, rather than the number of syllables.

CHAPTER 10 - GENERAL CONCLUSIONS

10.1 - Introduction

Reflecting the ever-evolving nature of scientific research, the aims and areas of investigation covered in this thesis altered during its course. I started out by investigating various aspects of face processing in prosopagnosic subjects, partly to see what abilities were spared by their prosopagnosia, and also to ascribe more importance to reaction times as well as error data, the latter measurement being generally more commonly used in the literature.

However, during the early course of the thesis, a search through the relevant literature led me to the area of the hemispheric asymmetry of face processing. This was of more interest to me when concerned with normal subjects than with prosopagnosic subjects, and so in addition to testing the prosopagnosic subjects on a number of face processing tasks and comparing their results with those of the control subjects, I also investigated hemispheric asymmetry in normals on a number of face processing tasks using visual split-field tachistoscopic procedures. In addition, as a control task for an early experiment investigating this, I used words rather than faces as test stimuli.

A further turn that the thesis took arose from the opportunity to test two subjects who, on the basis of previous PET neuro-imaging data, had been shown to have mainly right-hemisphere activation for linguistic tasks. I wished to test them on the face processing tasks to investigate their pattern of hemispheric asymmetry for face processing and see whether this, too, was reversed, but also, in order to investigate further their pattern of hemispheric asymmetry and provide confirmatory evidence for the PET findings, I tested them on split-field tachistoscopic language tasks. For this reason, together with the fact that I had already carried out one language task on the control subjects, I devised another two language related experiments, which

are covered in Chapter 9. These investigated further questions, such as the effect of word length and frequency on the speed of reading tachistoscopically presented words and their relation to hemispheric asymmetry, a central theme in the thesis.

Thus there were several lines of enquiry which were pursued, some of which seemed to be fairly separate, hence the thesis title having two distinct parts. However, the link should be evident, in that the thesis mostly grew out of an investigation into face processing, both in prosopagnosic subjects and its hemispheric asymmetry in normal subjects. The language-related tasks were carried out both as a comparison set of experiments for face processing and also to investigate more thoroughly the subjects with reversed hemispheric asymmetry. In the next three sections of this chapter I will endeavour to gather together and discuss the major findings of the thesis in terms of the areas mentioned above.

Section 10.5 outlines the problems encountered during the research and also criticises the research methods that were used. There are many things that, with hindsight, would have been better done differently, and I will point the reader towards these and make suggestions for improving the quality of the research done.

Section 10.6 covers questions which have been raised by my findings and outlines possible future research to answer some of these questions. In this section I also suggest other experiments which I would have liked to have carried out, had time and resources allowed, in order to answer other questions which arose during the course of the research.

10.2 - Experimental Findings on Prosopagnosic Subjects

Three prosopagnosic subjects were tested in some of the experiments described in this thesis. Two of them, **PH** and **NR**, became prosopagnosic as a result of brain injury due to automobile

accidents. The third, **SS**, is a developmental prosopagnosic who may easily have had this cognitive impairment since childhood: it was first documented at the age of 12 years and there were no precipitating head injuries.

It has been shown on numerous occasions (de Renzi 1986, Takahashi et al 1995) that prosopagnosia is not a unitary disorder. There are different specific impairments which may or may not be associated with or accompany prosopagnosia. It should be remembered that the term prosopagnosia itself refers to an inability to recognise familiar faces, and all other face processing deficits which have been mentioned and investigated in this thesis are not truly prosopagnosia.

A number of tasks were completed by these subjects, investigating facial identity matching (6.1 and 7.3), facial expression matching (7.1 and 7.2) and eye gaze perception (8.1 and 8.2). These three types of face processing task will be dealt with in turn.

10.2.1 - Facial Identity Matching

Face matching was investigated in two experiments, the first matching across view and the second across facial expression and view. Both tasks required the subject to decide whether a centrally presented face and a subsequent tachistoscopically presented lateral face were of the same person. In both cases, the photographs were of real people rather than Mac-a-Mug faces, on which the prosopagnosic subjects were not tested.

The first experiment, 6.1, tested matching of both upright and inverted faces. I will discuss upright face matching first. **SS**, was not impaired at this task, but both the other two subjects were significantly impaired. **NR** made more errors and was slower than the controls, but **PH** did not make significantly more errors than the controls, his only impairment being that he was

slower than the controls. Note, however, that Experiment 4.1 showed that he was impaired at a simple reaction time task compared to controls. The implications of this on the interpretation of his reaction time data were discussed in Chapter 4 and in the relevant sections in Chapters 6 and 7. In Experiment 7.3, when identity was matched, ignoring facial expression, all three prosopagnosic subjects performed significantly worse than controls, making more errors. However, **PH** was significantly slower, and **NR** was at the very slow end of the control subjects, possibly just significantly, but **SS** was no slower than the normals. Considering the findings of these two experiments together, it can be seen that **NR** is highly impaired at facial identity matching, whereas both **PH** and **SS** are impaired to a lesser extent, **PH** showing long reaction times but more errors for only one of the two experiments, and **SS** showing more errors only for one experiment and normal reaction times for both. Why there should be a difference between the two experiments is uncertain, as both tested matching facial identity in unfamiliar faces across view. It is possible that the added dimension of different facial expressions confused the prosopagnosic subjects in Experiment 7.3.

All three prosopagnosic subjects were faster at matching inverted faces than upright faces, whereas the controls were faster at matching upright faces, and only **NR** made significantly more errors matching inverted faces than the controls. All three prosopagnosic subjects made more errors for matching inverted faces than for matching upright faces, but in no case was this decrease in performance as a result of inversion significantly worse than the controls' decrease in performance for inverted face matching compared to upright face matching. These results suggest that the prosopagnosic subjects were on the whole better at matching inverted faces than upright faces (although **NR** made significantly more errors than the controls for both orientations of faces), in turn suggesting that their impairments may be specific to upright faces. They were not tested on any other object recognition task, although previous investigation suggests that both **PH** and **NR** have some object agnosia and all three prosopagnosic subjects

have some difficult with recognition of stimuli taken from categories containing many similar exemplars. However, **SS** and **PH**, and possibly **NR**, showed less impairment for inverted face matching than for upright face matching, as the prosopagnosic **LH** had done (Farah et al 1995a).

10.2.2 - Facial Expression Matching

Two experiments were carried out to investigate the matching of facial expressions. Experiment 7.1 required subjects to choose from an array of photographs both the photograph with the same expression as the probe photograph and the photograph which showed the same identity as the probe. Neither **SS** nor **PH** were impaired on this task, but **NR** was greatly impaired, scoring only 8 correct out of 14 trials. All three were impaired on the identity matching task, **NR** to a great extent, but there are two caveats: firstly, the control subjects performed at ceiling, making absolutely no errors, and **SS** and **PH** made only 2 out of 14 errors, and secondly, clothes were not taken into account when the photographs were taken, with the result that on most occasions the identity could be matched on the basis of the clothing rather than by matching the face. It is worth noting that both **SS** and **PH** made errors of identity only when the two photographs of the same person showed them wearing different clothes (their photographs were taken in 2 sessions).

The second experiment, 7.2, measured both reaction times and error scores for matching facial expressions across both view and identity. The results of this experiment were that only **NR** made significantly more errors than the controls and only **PH** was significantly slower than the controls. When the reaction time data are manipulated in a similar way to that carried out above, the following is found. **PH** took 1689 ms and the controls took 887 ms. When 140 ms is added to the controls' RT, **PH** is still significantly slower ($t_d = 3.26$). Thus it can be concluded from the results of both experiments that **PH** and **NR** are to an extent impaired at facial expression matching, **NR** much more severely, but that **SS** is not.

10.2.3 - Eye Gaze Perception

Two experiments were carried out investigating the perception of eye gaze direction. Experiment 8.1 tested the subjects' ability to determine whether a centrally displayed face was looking directly at them or not as a function of the angle of regard. Not surprisingly, for all subjects it became more difficult to make this decision as the angle of regard decreased. On the basis of the error data, **SS** and **NR** were only slightly impaired, specifically at a gaze angle of 15°. However, **PH** was greatly impaired at all angles of gaze. On the basis of reaction times, both **NR** and **PH** were significantly slower than the controls, except when the angle was 0°, but **SS** was not significantly slower than the controls. Even when it is taken into account that **PH** would be 140 ms slower than expected, there is no change in the overall result: he is still significantly slower, except when the person in the photograph is looking straight ahead. Thus this experiment shows that, although **SS** has previously been shown to have poor eye gaze perception (Campbell et al 1990), this impairment is very mild compared to both **PH** and **NR**. It is notable that all three prosopagnosic subjects and also the controls were faster at correctly deciding that a face was looking at them than correctly deciding that a face looking at either 5° or 10° to one side: **PH** was faster at responding correctly that a face was looking at him than that any other face was <u>not</u> looking at him, even faces with a gaze angle of 40°. This suggests that all the subjects found it easier to determine that they were being looked at when indeed they were, than to determine that they were not being looked at when the angle of regard was small. It is interesting that both **NR** and **PH**, who showed a large impairment on this task, made very few errors and were quite fast for faces which were looking straight forward. However, on the basis of the pattern of their errors, they made very few misses and many false positives, suggesting that if they were at all unsure, they automatically responded that the face <u>was</u> looking at them.

Experiment 8.2 investigated the subjects' ability to tell where someone was looking, rather than whether the person in the photograph was looking at them or not. In other words, a third object is now included in the spatial representation. Only errors were noted in this experiment, and reaction times were not recorded. All three prosopagnosic subjects made significantly more errors than the controls, who made very few errors. **PH** made the fewest errors of the three. Both **SS** and **NR** also found it a harder task when the face was not directly facing the camera but seen from the side, suggesting that head position may lend an additional cue to the direction in which the eyes are pointing. Note that this is a different task from Experiment 8.1, which may explain why **SS** performed normally at that one, but was impaired on this experiment.

10.2.4 - Summary

All three prosopagnosic subjects are termed prosopagnosic on the basis of their inability to recognise familiar faces. This particular ability was not tested in this thesis, but a range of other face processing abilities were investigated. **SS** was found to be impaired at facial identity matching (although not in Experiment 6.1), but not at either facial expression matching or eye gaze perception (or possibly only very slightly impaired at the latter), although there was an impairment at determining at which object a person is looking. It should be noted that all experiments in this thesis used either photographs or images presented on a computer screen. **SS** is more impaired at face processing tasks such as eye gaze perception on photographs than in real life, when 3-D faces are present. **NR** is the most impaired of the three prosopagnosic subjects tested, being poor at facial identity matching, facial expression matching and the perception of eye gaze direction. The nature of his brain damage and cognitive deficits made it more difficult to explain to him the instructions for the experiments and he took longer to understand what was involved in the task, and it is possible that some of his face processing impairments found may be due to his still not being totally comfortable with some or all of the tasks when he finally came to perform them. **PH** shows increased reaction times to all tasks, but

when this elevation is taken into account, he is shown to be impaired at facial identity matching and facial expression matching to an extent, although not when photographs are to be matched with no restriction on time either of presentation or response. He is also the most impaired of the three at determining whether he is being looked at or not, although he is less impaired than **SS** and **NR** at determining where someone is looking, when the question is not whether he is being looked at or not. A major aspect of the tasks in this thesis was the measurement of reaction times, and when these are considered together with error data, they paint a more complete picture of the prosopagnosic subjects' cognitive impairments. However, as in the case of **PH**, the measurement and interpretation of reaction times may not be straightforward, and the error data are therefore still of great importance.

Thus the three prosopagnosic subjects tested show slightly different patterns of face processing deficits, possibly reflecting the different underlying causes of their impairments.

10.3 - Experimental Findings on Normal Subjects

Normal control subjects participated in a number of experiments during the course of this thesis. Some of these were concerned with face processing, and some concerned with word processing. The majority of these experiments were carried out to investigate any hemispheric asymmetry inherent in the tasks, although in several cases the results (either with or without the investigation of hemispheric asymmetry) were recorded primarily for comparison with the prosopagnosic subjects. I will discuss the conclusions that can be gained from the results of the experiments in two sections.

10.3.1 - Face Processing Experiments

Experiments discussed in Chapters 5, 6 and 7 involved the subjects in matching faces on the basis of identity. These experiments were carried out partly to try to demonstrate a RH

advantage for face processing on the basis of tachistoscopic face presentation. Three sets of facial stimuli were used: in Chapter 5, Identikit-style faces produced by the program Mac-a-Mug were used; in Chapter 6, computer-displayed images of real black and white photographs of male faces (Israeli) were used; in Chapter 7, black and white computer-displayed images of photographs of graduate students portraying a variety of facial expressions were used. Note that in Chapter 6 the tasks involved stimulus matching, whereas in Chapters 6 and 7 the tasks involved face matching. This distinction (Bruyer et al 1987, Hay and Young 1982), says that stimulus matching involves making an identical / different judgement, and may not require the formation or accessing of a 3-D representation of the face, whereas face matching involves making a same face / different face judgement for pairs of faces which differ in one or more other aspects, such as view or facial expression, and would require a 3-D representation to judge whether the stimuli are matched.

The results for full-face matching (Experiments 5.1, 5.5, 6.1 and 7.3) in all cases did not show the hypothesised RH advantage, except in Experiment 7.3, in which the results are confusing: the reaction time data did show a RH advantage, in that responses were faster for trials in the LVF than trials in the RVF, but the error data showed a LH advantage, in that more errors were made in the LVF. This suggests that there were different speed accuracy trade-offs in the two hemispheres, and a possible explanation is put forward in Chapter 7. With this possible exception, it can be stated that full-face matching in this thesis did not yield a RH advantage.

Other experiments were therefore carried out in which various alterations were made to the stimuli and procedures, in order to investigate both the reasons for this lack of RH superiority, and possible manipulations which would induce the appearance of a RH advantage. It had been hypothesised that the hairstyles, especially in the Mac-a-Mug faces, were extremely distinct, causing the subjects to use a matching strategy on the basis of the hair rather than the other

features (which was confirmed by comments from some subjects). This strategy is an example of local feature matching rather than holistic matching on the basis of the configurational arrangement of the features, which is one explanation put forward as the source of the RH advantage typically described in the literature. Therefore, in experiments 5.3 and 5.6 internal features only were used, in order to force the subjects to respond on the basis of matching the configurational arrangement of features, rather than on the basis of one distinct feature. Both experiments now showed a significant RH advantage, confirming the hypothesis that attention to the hairstyles was one source of the lack of RH superiority.

In Experiment 5.2, a further manipulation was carried out. This task compared the importance of internal and external features in producing the RH advantage typically found for face matching. The two faces presented in each trial were either identical or differed in either internal features or external features but not both. Overall, a significant RH advantage was not found, but there was a significant interaction between trial type and visual field in that responses to trials in the RVF were faster than those in the LVF only where there was a difference in the external features, and the opposite field asymmetry, faster responses in the LVF, was found for trials in which there was a difference in internal features. This can be explained by assuming that the LH advantage for external feature matching was due to the matching of hairstyles, whereas the RH advantage for internal feature matching was due to the matching of the holistic configurational arrangement of those internal features. It was also found to be significantly more difficult to detect a change in internal features than to detect a change in external features, again presumably because the first part of the face to capture the subjects' attention was the hairline, the stimuli being unfamiliar faces.

The findings of these experiments discussed above suggest that a RH advantage is more likely to occur if the subjects' attention is directed to the internal features, specifically away from the

distinctive hairstyles which are seen in the Mac-a-Mug faces. No similar manipulations were carried out using images or photographs of real faces; all experiments involving images of real faces used full faces, rather than internal features only.

Another finding was that an increase in delay between the presentations of the two faces leads to a decrease in performance, presumably as the memory of the face fades. This effect was larger when internal features only were presented (Experiment 5.6) than when full faces were presented (Experiment 5.5).

In addition to testing face matching on the basis of identity, further experiments were also carried out on normal subjects to investigate both facial expression matching (Experiment 7.2) and the perception of eye gaze direction (Experiments 8.1 and 8.2). It would be expected that expression matching would yield a RH advantage, as has been documented in some of the relevant literature (e.g. Ley and Strauss 1986), as expression perception probably relies to a large extent on the arrangement of the features in the face rather than the features themselves, although these will also change (closed mouth opening and eyes becoming wider for the expression of surprise, for instance), but possibly to a lesser extent. In the task carried out in this thesis, however, expression matching did not produce a RH advantage. However, such an asymmetry is not always found, and some investigators have suggested that different facial expressions may be processed in different ways, some studies finding, for instance, a RH advantage for negative expressions only (e.g. Reuter-Lorenz and Davidson 1981). Possible reasons for the lack of a RH advantage in this case include the artificial nature of the expressions, which were produced on demand by people who were not actors by profession, rather than being produced spontaneously, and hence may not have been typical. They were labelled by an independent panel of 8 people, but photographs similarly labelled by only 6 members of this panel were accepted for use in the experiment, possibly leading to atypical

examples of the facial expressions used. Another reason may be that a range of expressions were used, including negative, neutral and positive ones, and as has already been pointed out, not all expressions may yield the same hemispheric advantage. Also, there is the question of individual differences between subjects in terms of their laterality. This will be addressed at the end of Section 10.3.3.

The experiments which were conducted to investigate the perception of eye gaze direction did not investigate hemispheric asymmetry, but the prosopagnosic subjects' abilities, whose data have been discussed in section 10.2. In Experiment 8.1 subjects were asked to decide whether a presented face was looking directly at them or not. As expected, the subjects found it increasingly easy to tell that the face was not looking at them as the eccentricity of eye gaze increased. In Experiment 8.2 the subjects were required to determine which out of an array of possible objects a person in a photograph was looking at, using their eye gaze direction as the cue. The photographs were either taken with the model directly facing the camera, or the camera was moved a few feet to one side so that when the model was looking straight ahead at the middle object in the array, he or she was not looking at the camera (examples are shown in Appendix A.4). The controls found this task fairly easy, making few errors, and they did not appear to find it more difficult when the faces were not looking at the camera, marking only marginally more errors.

10.3.2 - Language Processing Experiments

The control subjects participated in 3 language tasks in the course of the thesis, Experiments 5.4, 9.1 and 9.2. The first experiment was carried out as a control task for the face matching experiments described in Chapter 5. It is now accepted that there is a LH dominance for language tasks in the majority of people tested. Evidence for this comes from functional neuro-imaging data, for instance from PET and fMRI, together with the findings firstly that most

aphasics have suffered LH brain damage, and secondly that most tachistoscopic split-field linguistic tasks give a reliable RVF advantage. Experiment 5.4 was performed by the same subjects who had completed the face processing tasks described in Chapter 5 in the hope of finding a RH advantage for face processing and a LH advantage for the language task. The task was to make a syntactic judgement whether a word presented briefly to one side of fixation was a noun or a verb. The words were chosen such that it was assumed that they had to be read pretty much completely and understood before such a decision could be made. There was a small but non-significant LH advantage. The fact that it was not significant suggested that there may have been a problem with the experimental set-up. Another possible reason was that the group of subjects participating in this particular experiment were very heterogeneous both in terms of gender and handedness, which might have affected the overall findings. I will mention this aspect in more detail in Section 10.3.3.

The second language experiment, 9.1, was very similar to Experiment 5.4. The same noun / verb judgement was required of the subjects. There were two reasons why this experiment was run. The first was that in Experiment 5.4 there had been an unexpected effect of word type, in that nouns had been classified and recognised significantly faster than verbs. This was totally unexpected, and only afterwards was it realised that it might stem from a difference in word frequency between the nouns and verbs used. When a frequency corpus was consulted, it was found that the nouns in the list were much more common than the verbs in the list. The experiment was therefore repeated using word frequency as a controlled variable. Four word lists were prepared, consisting respectively of common and rare verbs and common and rare nouns. The subjects were tested on each of the pairs of noun-verb lists. The second reason for carrying out Experiment 9.1 was that I had been fortunate to find two subjects with reversed cerebral asymmetry on the basis of neuro-imaging data who would be prepared to be tested by me: I therefore wished to test them on a language task in order to try to replicate the findings of

the PET scans, that they showed RH dominance for language. Their results are discussed later in Section 10.4.

For all combinations of word lists there was a consistent significant LH advantage for reaction times, although not a significant one for error data. More data were collected in this experiment than in Experiment 5.4, and this may explain the presence of a significant LH advantage where one was absent in Experiment 5.4. Also, all those participating in Experiment 9.1 were right-handed, forming a less heterogeneous group of subjects than those in Experiment 5.4. This may have increased the likelihood of finding a significant LH advantage, as a greater proportion of left-handers (30%) would be expected to have either bilateral or RH language processing.

Experiment 9.1 also confirmed that common words were recognised faster and more accurately than rare words. This is not unexpected - we have more experience with common words than rare words (the measure of frequency is mirrored by our level of experience) and would therefore expect to respond to them more efficiently. These frequency findings confirmed the hypothesis that the nouns had been better recognised in Experiment 5.4 due to their greater frequency than the verbs. It was notable that where the word lists were similar in frequency (both common) there was still an almost significant effect of word type in that verbs were recognised faster than nouns. This was eventually explained by taking into account the frequencies of all word derived from the test words in the list in addition to the frequency of the test words themselves. It was found that the verbs plus their derivatives were significantly more common than the nouns plus their derivatives. Thus the recognition of a word may be affected not just by the frequency of that word but also involve other words which are related or derived from that word.

Experiment 9.2 differed from the other two linguistic tasks. In this experiment the subject was

required to read out loud into a microphone a word presented on the computer screen. One possible problem with the previous language tasks was that although a linguistic judgement was required which would presumably use the cerebral hemisphere specialised for language, the response had been manual, requiring the pressing of two computer keys, one for 'noun' and the other button for 'verb'. Although the two keys were pressed with different fingers of the same hand, in Experiment 9.1, the response hand was counterbalanced between subjects. This meant that some subjects would be using their left hand to respond, which is controlled by the RH, requiring interhemispheric transfer of information from the LH, increasing their reaction times. In Experiment 5.4 all subjects used their preferred hand, but as 6 of the subjects were left-handed it was likely that about four of them had LH language (based on Rasmussen and Milner's 1977 findings), and hence using their left hands (RH controlled) would have required interhemispheric transfer of information from the LH in the same way as above. Using a verbal response removed the problem of which hand to use and therefore which hemisphere was controlling the output: speech as well as language comprehension are controlled by the language-dominant hemisphere, so there should be no additional interhemispheric transfer of information between the processing and output stages. Rather than use the verbal response of 'noun' or 'verb' it was decided that the most sensible response would be to say the word itself. Again this task was devised to test the two reversed hemispheric asymmetry subjects, whose data are discussed in Section 10.4.

In addition, various other aspects of the words being read were investigated in this experiment. These were the length of the word, measured as its number of syllables, the frequency of the word occurring in the English Language, the familiarity of the word and its typographical uniqueness (N - value). Word length was investigated on the basis of the number of syllables rather than the number of letters as this was thought to reflect reading time and certainly time of utterance to a larger extent than the number of letters in the word; for instance, the word *iota*

contains only 4 letters but 3 syllables, and the word *strengths* contains 9 letters but only one syllable, and probably takes a shorter time to say and possibly read (if reading is syllable-by-syllable as mentioned in Chapter 9) than *iota*. Word frequency, familiarity and uniqueness were rated using a number of word frequency corpora. It was hypothesised that fewer syllables, a greater frequency, a greater familiarity and a greater degree of uniqueness (lower N - value) would lead to more efficient reading, seen either as shorter reaction times or as fewer errors. These aspects were also investigated in terms of hemispheric asymmetry.

As hypothesised, words with more syllables took longer to read and led to more reading errors than shorter words. More frequently occurring words and more familiar words led to fewer errors in reading. These findings reflect the fact that increased experience of a stimulus increases our efficiency of processing it. However, uniqueness did not act as expected; a lesser degree of uniqueness (higher N - value) lead to fewer errors. This was explained by more unique words generally being longer and less familiar, both of which lead to more errors. It is likely that if there is an effect of uniqueness, as hypothesised, then word lists would have to be used which differ only in the N - value, and are matched in both frequency and number of syllables - such a word list would in practice be difficult to construct.

There was no effect of visual field on either frequency or familiarity, but words with greater typographic uniqueness were better recognised by the LH than the RH in comparison to less unique looking words. This could be due to the RH 's ability to recognise simple concrete nouns, many of which tend to be less typographically unique, but on this basis it is surprising that there was no similar effect found for word frequency, as it is common words which the RH tends to recognise in split-brain studies (e.g. Sperry and Gazzaniga 1967). Such an effect was found in one part of experiment 9.1 (part C) but the effect was weak.

To summarise, these experiments concerned with linguistic processing demonstrated a LH advantage for syntactically classifying words and reading visually presented words out loud. When word frequency was investigated, it was shown that more frequent words are classified as nouns or verbs faster and more accurately than rare words, and also read out more accurately when tachistoscopically presented. The LH advantage was larger and more definite than any RH advantage for face processing, which was only found when internal features were matched in isolation. This is reflected in the literature, where it is generally accepted that language dominance is stronger than face processing dominance.

10.3.3 - Other Findings on Normals

There were a number of other findings of note from the experiments on normals. One important one was that in some of the experiments trial type was found to be a significant factor. Trial type refers to the type of stimuli that were shown and the response that was expected. In various experiments these included: *same, different* (Experiments 5.1, 5.3, 5.5, 5.6 and 6.1) or *same, different internal features, different external features* (Experiment 5.2) or even *noun, verb* (Experiments 5.4 and 9.1). Prior to testing, hypotheses were not put forward to explain any significant effects in trial type for any of the experiments except 5.2 (it was expected that it would be easier to match faces which differed in external features than those which differed in internal features) and 9.1 (it was expected that the word type containing more common words would be recognised more easily than the word type containing rarer words). As has been explained earlier, both of these hypotheses were upheld. The source of the difference between nouns and verbs in Experiment 5.4 has also been explained as being due to the effect of word frequency.

However, it was found that in some of the other experiments there was a significant effect of trial type which required further explanation. In a number of experiments, there was a

significant effect of trial, where 'same' trials were responded to significantly more efficiently than 'different' trials, as in Experiment 6.1 (real face matching), or vice versa, as in Experiments 5.5 (delayed Mac-a-Mug face matching) and 7.2 (expression matching). These findings are best explained in terms of signal detection theory, in that the subjects set their criterion (β) such that they were either more or less likely to make misses than false positives: for instance, in Experiment 5.5 they would not respond that the faces were the same unless they were sure. The source of the interaction between trial type and delay in Experiment 5.5 can be explained by the subjects' having a different criterion (β) at higher delays, so that they were more likely to make false positives than misses. This could be because as the delay increased, the representation of the face in their memory faded, so that they were less sure about its identity, and therefore were forced to relax their criterion and guess to a larger extent.

One possible explanation for the trial type effect found in Experiment 7.2 (facial expression matching across view and identity) is that the subjects set a stringent criterion, which would only accept faces as having the same expression if they were sure; if they were uncertain, they were more likely to classify the trial as being 'different'. Identity is an all-or-nothing thing - two photographs either are of the same person or are not, and it should be possible, given enough time, to be convinced of this on most occasions (except in special circumstances, such as the two photographs being of identical twins). However, facial expression does not exist naturally in clear-cut categories, and although happy and sad are rarely confused, the difference between scared and surprised, or between angry and disgusted, are much slighter, and different viewers may not agree on the facial expression of a face in a photograph even given unlimited time, as seen in the responses of the panel of 8 people who labelled the expressions for use in the experiments. I had taken the photographs and knew what expressions I had asked the models to adopt, but even with this knowledge I was not convinced by the expression in a number of the photographs. This confusion between different expressions, especially similar ones, may have

led the subjects to adopt a more stringent criterion, only accepting expressions as the same if they were sure, and therefore any confusion between expressions which were the same would lead them to be classified as different.

In Experiment 7.3, which was very similar to Experiment 6.1, there was no significant main effect of trial type, but there was a significant interaction between trial type and visual field on the basis of the error data. This experiment only differed from Experiment 6.1 in that as well as a difference in view between the two faces in each trial, there was now, in some trials, a difference in facial expression. This interaction was explained by there being more false positives in the LVF than in the RVF, but the number of misses was roughly the same in both visual fields, and appears due to a difference in criterion between the two hemispheres, although the cause of such a difference is difficult to explain. The cause would have to be that the RH would be more likely to accept pairs of faces as having the same identity than the LH. If the RH is specialised for face processing and face matching, then it would be assumed that it would be more stringent in its judgement of facial identity than the LH, rather than less, and therefore this finding is unexpected. No other explanation for this finding can be offered at this time.

The last point to make about the control data involves the nature of the subjects participating in the experiments and the nature of hemispheric asymmetry tasks, whose aim is to elucidate differences between the processing mechanisms of the two cerebral hemispheres. When tasks such as those in this thesis are carried out, a large number of subjects must participate in order to obtain enough data to uncover small effects. However, a major aspect of hemispheric asymmetry, both anatomical and functional, is that the degree of laterality differs between individuals, depending on a number on factors. These include handedness, gender, and possibly environmental factors (Kolb and Whishaw 1990, Chapter 16 and see Section 2.2.3).

In this thesis, the majority of the subjects were students. They were a mixture of dextrals and sinistrals, although as the thesis progressed, fewer sinistrals were used, as it became apparent that this might be a contributing factor to the absence of a RH advantage in face processing. There was also a mixture of male and female subjects who participated in some experiments, although only male subjects were used in some later experiments in the thesis. If there are indeed significant differences between dextrals and sinistrals, and between males and females, then any hemispheric asymmetry might have been obscured. Another important point is that there exist people who have reversed asymmetry, showing RH language processing. Two such subjects were tested in this thesis and will be discussed in the next section. However, this is mentioned here because an assumption that had to be made was that all the control subjects, whether dextral or sinistral, had LH language processing. Based on the proportions of LH and RH linguists that have been shown to exist, it is very likely that virtually all the right-handed subjects tested in the thesis did indeed have LH language dominance, but several of the sinistrals tested may not have done. It is also noteworthy that of the two subjects with reversed asymmetry who were tested, one is certainly right-handed and the other is now right-handed, although he was naturally left-handed in childhood. It is not known what the existence of RH language implies for the laterality of other processes, such as face processing. To answer this question was one of the aims of the thesis, and this too will be discussed in the next section.

10.4 - Experimental Findings on Subjects with Reversed Asymmetry

Two male subjects who, on the basis of previous neuro-imaging findings, were shown to have reversed asymmetry for language, i.e. RH language processing, were tested on a number of tasks in this thesis, investigating both face processing and word processing. Both of these subjects had participated as control subjects on different PET language tasks (detailed in Chapter 3) and were found to show RH activation, where the other control subjects on the PET tasks showed LH activation. My interest in them was two-fold: firstly, I wished to repeat these findings using

an experimental psychology procedure which measured reaction times and errors and was not in the least invasive or potentially uncomfortable for the subjects; and secondly, I wished to discover whether they would similarly show reversed asymmetry for face processing, i.e. a LH advantage. The findings on these two questions are dealt with in the next two sections.

10.4.1 - Word Processing Tasks

Subjects **HJ** and **RL** were tested on the word processing tasks in this thesis in order to try to repeat the PET findings and show a reliable RH and LVF advantage for word processing. If this result were found then it should be possible to use one of these tasks or a similar one to investigate both laterality where the result of a WADA test prior to surgery are inconclusive, and also to investigate quantitatively the correlation between different methods of laterality measurements, including neuro-imaging.

The results of Experiment 9.2 were clear. Whereas the controls had shown a significant LH and RVF advantage for reading tachistoscopically presented words out loud, both **HJ** and **RL** showed a significant RH and LVF advantage. This corroborated the PET evidence illustrating their RH superiority for language. The results of Experiment 9.1 were slightly less clear: **RL** showed a RH advantage, but **HJ** did not. However, he did not show a LH advantage either, which had been found in the control subjects. The PET tasks which the two subjects had been tested on in the past were different, requiring different types of language processing. Therefore direct comparison of their laterality for language is impossible, and this might explain the different findings in Experiment 9.1, if for instance **RL** had a greater degree of laterality than **HJ**.

On the basis of these two experiments, it is clear that both subjects with reversed asymmetry did under some circumstances show the expected RH advantage, and therefore it would be

acceptable to assume that the experiments, especially 9.2, are a reliable indicator of hemispheric dominance for language. Note that the assumption was also made that all the controls (who were right-handed) did not have reversed asymmetry, and neither PET scans nor any other form of neuro-imaging data were available for this to be checked. Therefore it would be a sensible move to test a number of other subjects shown on the basis of neuro-imaging to have RH language.

10.4.2 - Face processing Tasks

Both **HJ** and **RL** have been shown to have RH language, as have a number of other subjects in previous literature (e.g. Rasmussen and Milner 1977). The question therefore arises of the organisation of the cerebral hemispheres in those subjects with RH language processing: i.e. what is replaced in the RH by Wernicke's and Broca's areas, and what replaces them in the LH. Of course, the brain structure is still the same, and there may be no gross anatomical differences between the subjects showing LH language and those showing RH language, but there is certainly a difference in the allocation of functional processes between the two hemispheres. One possibility is that there is a straight reversal of functions, which would suggest a LH advantage for face processing tasks which give a RH advantage in other subjects. Little is known about the organisation of reversed asymmetry brains, but evidence from those patients with LH temporal lobe lesions and RH language does not suggest a simple reversal is what occurs (Kolb and Whishaw 1990). It is worth pointing out that one theory for why some people have RH language is that they suffered some LH damage early in life, perhaps before birth, and this damage may determine the processes which are specialised in the LH in later life.

Both subjects carried out one face matching task (Experiment 6.1) to investigate whether they would show a LH advantage, which would provide evidence for a more complete reversal of processes than just a shift of the language processes from the LH to the RH. The results did not

confirm this, as no visual field advantage was found. However, the control data did not show a RH advantage either, so it is entirely possible that this experiment was not testing face matching in a way predisposed to producing a hemispheric advantage, as has been discussed in an earlier section. Based on these results, **HJ** and **RL** do not show face processing superiority located in the LH. Due to the lack of any control RH advantage the question of whether **HJ** and **RL** show reversed asymmetry for tasks other than language processing cannot be answered.

10.5 - Criticisms

Many of the results in this thesis failed to replicate standard findings, the main one being my inability to demonstrate a RH advantage for face matching. There are a number of possible reasons for this which are outlined below.

The first concerns the scientific literature itself. There are a large number of scientific papers investigating face matching in neurologically normal adults, but almost all of them differ in the exact procedure and stimuli which were used. By no means all of them show a RH advantage, and where one was demonstrated it was generally found to be small. It must therefore be concluded that the RH advantage for face matching in the literature is not easy to demonstrate, and it is not therefore necessarily a surprise that no clear RH advantage was shown in this thesis. However, suggestions can be put forward as to why such a hemispheric asymmetry was not found, generally and also specifically in this case.

There are a large range of facial stimuli used in the literature. I myself used at least three types of stimuli. Firstly, highly schematic line drawings of an Identikit style were used (Mac-a-Mug faces) in Experiments 5.1, 5.2, 5.3, 5.5 and 5.6. These show schematic features which are just outlines with no shading. In Experiments 5.3 and 5.6 internal features only were presented, again using the same schematic faces. In the experiments described in Chapter 6, photographs

of faces were used. These were all Israeli men, who posed for photographs with neutral expressions. Their clothing was not visible, but their hair was. I tried to crop the photographs so that as little information could be gained from the hair as possible by mainly using photographs of men with dark hair against a dark background. However, on the basis of the comments made by the subjects, the hairline was still a major cue, which the subjects then had trouble using as a cue, for instance, when the faces were inverted. The last type of facial stimulus used were photographs taken of work colleagues and friends showing specific facial expressions from two viewpoints. These were colour photographs (used as such) and were also converted to black and white images on the computer for testing expression and identity matching. In this case the collar was sometimes visible (the subjects had all worn different clothes) and also the subjects did not all have dark hair, such that the hair, which was easily visible in the images, was a major cue to identity. In the expression matching experiments using these images this did not matter, but the identity matching experiments were exceptionally easy for the controls, especially Experiment 7.1, when all 6 controls made no errors. In retrospect, the photographs should have been taken again, firstly making sure all the models wore the same clothing on their top halves, so that collar and clothing (which was visible to a large extent in the photographs used in Experiment 7.1) were not a cue. Secondly, a larger number of models who were less visually distinct would have been useful. Unfortunately I did not have access to a large number of people who could pose for photographs. Thirdly, the expressions produced were not spontaneous and the models producing them were not actors, resulting in fairly atypical expressions in some cases. It would have been preferable to have used actors to produce standard expressions which could be agreed on more definitely and consistently by an independent panel of people than the images which were in the end used.

Another problem with many of the experiments carried out concerns the small number of control subjects used. As more subjects are used, the statistical effects which are found become more

robust. I was fortunate to have access to quite a large number of subjects through the Oxford Psychology Department Subject Panel, but even so, time and money constrained the number of subjects that could be tested for each experiment. If many more subjects had been used in experiments where there were non-significant trends found, it might have been able to demonstrate that some of these effects were significant. As has been discussed in Section 10.3.3, the heterogeneity of handedness and gender of the subjects used might also have led to the occlusion of some laterality effects. Ideally, all such control subjects on any task would be scanned using PET or fMRI in order to check their language dominance, but given the current cost and demand of such imaging, this is currently an impossibility, even if the ethical considerations allowed it!

10.6 - Future Work

There are a number of experiments which I either hoped to carry out and was not able to for various reasons, or experiments which could now be done as a result of the findings of experiments in this thesis, to answer questions posed by the work contained herein.

Appendix E covers experiments that were either only carried out as pilots or never got beyond the planning stage. Of those mentioned, the one of most interest for future research is the attentional aspect of eye gaze. Baron-Cohen has done much work on the EDD and SAM, covered elsewhere in this thesis, and it would be very interesting to find out whether a shift in someone else's eye gaze causes an automatic shift in our own eye gaze to the object at which the other person is looking, using Posner's attention-orienting procedure described in Appendix E. A positive result would give added strength to Baron-Cohen's hypotheses, suggesting that the formation of the triadic representation occurs easily and automatically. This has been investigated in monkeys by Perrett and colleagues (personal communication - David Perrett to Alan Cowey) who found that if an experimenter and a monkey were looking at each other, then

if the experimenter suddenly moved his eyes to one side, then the monkey also moved its eyes (noted by a second observer). Perrett has also shown that some cells in the STS are sensitive to eye position, head position or body posture of an observed person or monkey, all of which indicate where the owner is looking: thus these cells code information concerning where someone is looking (Perrett et al 1992).

A possible future experiment raised by the findings in Chapter 5 is to repeat the delayed matching of faces (Experiments 5.5 and 5.6) using a simultaneous secondary distracting task to see whether memory for faces and performance on the task can be further impaired. There is much evidence that dual-task performance is worse than single-task performance due to the competition for resources, an example being that short-term memory for words is disrupted by a simultaneous verbal task (Glanzer and Cunitz 1966). Therefore it would be expected that performance would decline when a second distracting task is performed by the subjects.

Looking at all the facial identity matching tasks, it can be seen that there was in general no hemispheric advantage demonstrated for any subjects. If any of these experiments are repeated, it is important to choose the stimuli carefully. The best course of action would be to use non-distinctive faces, all of one sex (as I used) but showing no clothing and no hair, requiring all those in the photographs to wear a cap to hide the hair, or cropping the photographs. However, as has been pointed out, we do not recognise faces in isolation - these are an intrinsic part of a person who also has clothing (usually) and hair (usually) visible. Therefore trying to find a RH advantage (and a LH advantage in those with RH language processing) using very artificial stimuli may not be useful. However, it would still allow us to answer the question of the pattern of cerebral organisation for non-linguistic processing in subjects with RH language processing, as long as it borne in mind that the stimuli are far from natural. Another comment that was said by one of the prosopagnosic subjects is that there is sometimes a difference in abilities between

processing information from faces in real life (3-D) and from photographs, which are both static and two dimensional: this particular subject finds it easier to use information from real faces than from photographs.

As was mentioned in the previous section, one problem with the expression matching experiments lay in the photographs of the expressions themselves. It would be interesting to repeat these experiments using a larger set of photographs either of actors producing the expressions, or better still using spontaneous expressions, although these are harder to obtain. Experiment 7.1 could also be repeated where all the subjects are wearing the same jumper, for instance, so that clothing ceases to be a cue.

It has been suggested by Passingham (1997) that Wernicke's area in the LH of man may have an anatomical homologue in the left STS in monkeys, the removal of which causes problems with eye gaze direction perception (Heywood and Cowey 1992), as mentioned in Chapters 7 and 8. Desimone (1990) has suggested a possible functional homology. A relevant finding that may suggest a possible functional homology between the two areas was shown by Dewson and colleagues (e.g. Cowey and Dewson 1972) who found that monkeys with STS lesions were not able to discriminate vowel sounds. If there is a functional homology and the STS is responsible for a range of social communication processes, and if language comprehension, facial expression perception and eye gaze perception are all forms of communication processing, then it may follow that Wernicke's aphasics would show poor expression perception and eye gaze detection. Wernicke's aphasics have problems with language comprehension, so the evidence for a functional homology would be strengthened if Wernicke's patients were impaired on both eye gaze perception and expression perception in comparison to controls. I had hoped to test Wernicke's aphasics on the experiments in Chapters 7 and 8, but unfortunately was not able to

gain access to any Wernicke's aphasics at the time. This is a possible subject for future research.

Possible further experiments suggested by Chapter 8, investigating eye gaze perception in both controls and prosopagnosic subjects, include the perception of gaze deviations in a number of radial directions, not just in the lateral direction. Also, a more systematic investigation of the effect of relevant and irrelevant head direction in determining eye gaze direction in prosopagnosic subjects would be of interest. Finally, the question of whether one eye is being looked at more consistently by subjects can be asked, and whether, if this is the case, this can explain the difference in error rates between right and left looking faces found for some subjects.

An important finding, discussed in Chapter 9, is that both subjects with reversed hemispheric asymmetry were shown, on the basis of a non-invasive experiment involving sitting in front of a computer screen and reading words into a microphone, to have RH language, which had already been shown by previous functional neuro-imaging. If this finding were consistent over a large number of subjects and also shown to be reliably correlated with the results of the WADA test used on epilepsy patients prior to surgery, then such a task could be used when the results of the WADA test are inconclusive, as is sometimes the case. What is required now is to repeat the task on a larger number of subjects, all of whose language-dominant hemisphere is known, either by neuro-imaging (PET or fMRI) or the results of the WADA test. Another important use of such a task is to provide a quantitative correlation with neuro-imaging laterality measurements.

Finally, a general improvement on all experiments investigating hemispheric asymmetry would be to use larger numbers of control subjects, and also either specifically to use only right-handed male subjects, as described in previous sections of this chapter, or to include gender and handedness as factors in the analyses. The experiments carried out in this thesis did not test enough subjects to

investigate the issues of gender or handedness, nor was it possible to obtain enough controls if only right-handed males were used. Note however, that as will now be clear, handedness does not correlate closely with laterality, and if the interest is really in laterality of function, then handedness may not be a useful factor to take into account - the direct measurement of laterality, for instance for language as measured by neuro-imaging, would be better, but is not a possible method at present.

BIBLIOGRAPHY

Allison, T., Ginter, H., McCarthy, G., Nobre, A.C., Puce, A., Luby, M. and Spencer, D.D. (1994) Face recognition in human extrastriate cortex. *Journal of Neurophysiology* **71(2)**: 821-825.

Annett, M. (1970) A classification of hand preference by association analysis. *British Journal of Psychology* **61**: 303-321.

Anstis, S.M., Mayhew, J.W. and Morley, J. (1969) The perception of where a face or television 'portrait' is looking. *American Journal of Psychology* **82**: 474-489.

Aptman, M., Levin, H. and Senelick, R.C. (1977) Alexia without agraphia in a left-handed prosopagnosic. *Neurology* **27(6)**: 533-536.

Ardila, A. and Rosselli, M. (1994) Spatial acalculia. *International Journal of Neuroscience*. **78(3-4)**: 177-184.

Assal, G., Favre, C., and Anderes, J. (1984) Nonrecognition of familiar animals by a farmer: Zooagnosia or prosopagnosia for animals. *Revue Neurologique.* **140**: 580-584.

Baron-Cohen, S. (1993) The eye-direction detector: a case for evolutionary psychology. Unpublished lecture at the International Conference on Face Processing, Cardiff, UK.

Baron-Cohen, S. (1994) How to build a baby that can read minds: Cognitive mechanisms in mindreading. *Cahiers de Psychologie Cognitive, Current Psychology of Cognition* **13(5)**: 513-552.

Baron-Cohen, S., Campbell, R., Karmiloff-Smith, A., Grant, J. and Walker, J. (1995) Are children with autism blind to the mentalistic significance of the eyes? *British Journal of Developmental Psychology* **13**: 379-398.

Barton, M.I., Goodglass, H. and Shai, A. (1965) Differential recognition of tachistoscopically presented English and Hebrew words in right and left visual fields. *Perception and Motor Skills* **21**: 431-437.

Bauer, R.M. (1986) The cognitive psychophysiology of prosopagnosia. In *Aspects of Face Processing*, Ellis, H.D., Jeeves, M.A., Newcombe, F. and Young, A. (eds.). NATO ASI Series D: Behavioural and Social Sciences. Martinus Nijhoff.

Bentin, S., Allison, T., Puce, A., Perez, E. and McCarthy, G. (1996) Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience* **8(6)**: 551-565.

Benton, A.L. and van Allen, M.W. (1973) *Test of Face Recognition Manual.* Neurosensory Center Publication no. 287, Department of Neurology, Iowa, USA.

Bertelson, P., Vanhaelen, H. and Morais, J. (1979) Left hemifield superiority and the extraction of physiognomic information. In *Structure and Function of Cerebral Commissures*, Steele Russell, I., van Hof, M.W. and Berlucchi, G. (eds.) The Macmillan Press Ltd., London.

Bodamer, J. (1947) Die Prosop-Agnosie (Die Agnosie des Physiognomieerkennens). *Archives fur Psychiatrie und Zeitschrift fur Neurologie* **179**: 6-53.

Bornstein, B. (1963) Prosopagnosia. In *Problems of Dynamic Neurology*, Halpern, L. (ed.). The Department of Nervous Diseases of the Rothschild Hadassah University Hospital and the Hebrew University Hadassah Medical School, Jerusalem, Israel.

Bornstein, B., Stroka, H. and Munitz, H. (1969) Prosopagnosia with animal face agnosia. *Cortex* **5**: 164-169.

Boucher, J. (1993) Why study face processing in autistic children? Unpublished lecture at the International Conference on Face Processing, Cardiff, UK.

Bradshaw, J. (1989) *Hemispheric specialisation and psychological function*. Wiley, Chichester

Bremner (1994) *Infancy* (2nd edition). Blackwell, Oxford.

Brennen, T., David, D., Fluchaire, I. and Pellat, J. (1993) Naming famous faces without correct category information - a case study. Unpublished lecture at the International Conference on Face Processing, Cardiff, UK.

Bruce, C. (1982) Face recognition by monkeys: absence of an inversion effect. *Neuropsychologia* **20(5)**: 515-521.

Bruce, V. (1988) *Recognising Faces*. LEA, Hillsdale, New Jersey.

Bruce, V. (1995) Perceiving and Recognizing Faces. In *Perception and Representation: Current Issues (2nd edition),* Roth I. and Bruce, V. Open guides to Psychology, Open University Press.

Bruce, V. and Valentine, T. (1986) Semantic priming of familiar faces. *Quarterly Journal of Experimental Psychology* **38A**: 125-150.

Bruce, V. and Valentine, T. (1988) When a nod's as good as a wink: the role of dynamic information in facial recognition. In *Practical Aspects of Memory: Current Research and Issues, Vol. 1 (Memory in Everyday Life)*, Gruneberg, M.M., Morris, P.E. and Sykes, R.N. (eds.). John Wiley and Sons.

Bruce, V. and Young, A. (1986) Understanding face recognition. *British Journal of Psychology* **77**: 305-327.

Bruyer, R. (1986) Face processing and brain damage: group studies. In *The Neuropsychology of Face Perception and Facial Expression*, Bruyer, R. (ed.). LEA.

Bruyer, R., Abdi, H. and Benoit, J. (1987) Stimulus versus face recognition in laterally displaced stimuli. *American Journal of Psychology* **100**: 117-121.

Bruyer, R. and Velge, V. (1981) Lesions cérébrale unilaterale et trouble de la perception des visages: Specifité du déficit? *Acta Neurological Belgica* **81**: 321-332.

Bryden, M.P. (1981) *Laterality: Functional Assymetry in the Intact Brain*. Academic Press, New York.

Buchtel, H., Campari, F., DeRisio, C. and Rota, R. (1978) Hemispheric difference in the discrimination reaction time to facial expression. *Italian Journal of Psychology* **5**: 159-169.

Burt, D.M. and Perrett, D.I. (1997) Perceptual asymmetries in judgements of facial attractiveness, age, gender, speech and expression. *Neuropsychologia* **35(5)**: 685-693.

Burton, A.M. and Bruce, V. (1992) I recognize your face but I can't remember your name: a simple explanation? *British Journal of Psychology* **83**: 45-60.

Burton, A.M., Bruce, B. and Johnston, R.A. (1990) Understanding face recognition with an interactive activation model. *British Journal of Psychology* **81(3)**: 361-380.

Burton, L.A. and Levy, J. (1991) Effects of processing speed on cerebral asymmetry for left- and right-oriented faces. *Brain and Cognition* **15**: 95-105.

Campbell, R. (1978) Asymmetries in interpreting and expressing a posed facial expression. *Cortex* **14(3)**: 327-342.

Campbell, R. (1992) The neuropsychology of lip-reading. In *Processing the Facial Image*, Bruce, V., Cowey, A., Ellis, A.W. and Perrett, D.I., (eds.), *Philosophical Transactions of the Royal Society of London B* 335: 39-45.

Campbell, R., Heywood, C.A., Cowey, A., Regard, M. and Landis, T. (1990) Sensitivity to eye gaze in prosopagnosic patients and monkeys with superior temporal sulcus ablation. *Neuropsychologia* 28: 1123-1142.

Campbell, R., Regard, M. and Landis, T. (1986) Face recognition and lip-reading: a neurological dissociation. *Brain* 109: 509-521.

Campbell, R. and Walker, J. (1993) Face fragments: coherent processing of faces and face parts in children with autism. Unpublished lecture at the International Conference on Face Processing, Cardiff, UK.

Cavegn, D. and d'Ydewalle, G. (1996) Presaccadic attention allocation and express saccades. *Psychological Research; Psychologische Forschung* **59(3):** 157-175.

Cermak, L.S., Lewis, R., Butters, N. and Goodglass, H. (1973) Role of verbal mediation in performance of motor tasks by Korsakoff patients. *Perceptual and Motor Skills* **37**: 259-262.

Christen, L., Landis, T. and Regard, M. (1985) left hemispheric functional compensation in prosopagnosia? A tachistoscopic study with unilaterally lesioned patients. *Human Neurobiology* **4**: 9-14.

Cohen, G. (1990) Why is it difficult to put names to faces? *British Journal of Psychology* **81**: 287-298.

Cohen, N.J. (1984) Preserved learning capacity in amnesia: Evidence for multiple memory systems. In *Neuropsychology of Memory*, Squire, L.R. and Butters, N. (eds.). New York: Guildford Press.

Colheart, M., Davelaar, E., Jonasson, J.T. and Besner, D. (1977) Access to the internal lexicon. Chapter 25 in *Attention and Performance VI*, Dornic, S. (ed.). LEA: Hillsdale, NJ.

Corkin, S. (1968) Acquisition of motor skill after bilateral medial temporal lobe-excision. *Neuropsychologia* **6**: 255-265.

Cowey, A. (1979) Cortical maps and visual perception: The Grindley memorial lecture. *Quarterly Journal of Experimental Psychology* **31(1)**: 1-17.

Cowey, A. and Stoerig, P. (1991a) The neurobiology of blindsight. *Trends in Neurosciences* **14**: 140-145.

Cowey, A. and Stoerig, P. (1991b) Reflections on blindsight. Chapter 2 in *The Neuropsychology of Consciousness*, Milner, A.D. and Rugg, M.D. (eds.). Academic Press.

Cowey, A. and Dewson, J.H. (1972) Effects of unilateral ablation of superior temporal cortex on auditory sequence discrimination in *Macaca mulatta. Neuropsychologia* **10:** 279-289.

Craik, F.I.M. and Lockhart, R.S. (1972) Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior* **11**: 671-684.

Damasio, A.R. (1985) Disorders of complex visual processing: agnosias, achromatopsia, Balint's Syndrome, and related difficulties of orientation and construction. In *Principles of Behavioural Neurology*, Mesulam, M.M. (ed.). Contemporary Neurology Series.

Damasio, A.R. and Damasio, H. (1986) The anatomical substrate of prosopagnosia. In *The Neuropsychology of Face Perception and Facial Expression*, Bruyer, R. (ed.). LEA.

Damasio, A.R., Damasio, H. and van Hoesen, G.W. (1982) Prosopagnosia: anatomic basis and behavioural mechanisms. *Neurology* **32**: 331-341.

Damasio, A.R., Tranel, D. and Damasio, H. (1990) Face agnosia and the neural substrates of memory. *Ann. Rev. Neuroscience* **13**: 89-109.

De Gelder, B. (1993) In search of a lost effect: face superiority and its normal or impaired development. Unpublished lecture at the International Conference on Face Processing, Cardiff, UK.

De Haan, E.H.F. and Campbell, R. (1991) A fifteen year follow-up of a case of developmental prosopagnosia. *Cortex* **27**: 489-509.

De Haan, E.H.F. and Hay, D.C. (1986) The matching of famous and unknown faces, given either the internal or the external features: a study on patients with unilateral brain lesions. In *Aspects of Face Processing*, Ellis, H.D., Jeeves, M.A., Newcombe, F. and Young, A. (eds.) NATO ASI Series D: Behavioural and Social Sciences. Martinus Nijhoff.

De Haan, E.H.F., Young, A. and Newcombe, F. (1987a) Face recognition without awareness. *Cognitive Neuropsychology* **4(4)**: 385-415.

De Haan, E.H.F., Young, A. and Newcombe, F. (1987b) Faces interfere with name classification in a prosopagnosic patient. *Cortex* **23**: 309-316.

De Haan, E.H.F., Young, A. and Newcombe, F. (1991a) A dissociation between the sense of familiarity and access to semantic information concerning familiar people. Special issue: face recognition. *European Journal of Cognitive Psychology* **3**: 51-67.

De Haan, E.H.F., Young, A. and Newcombe, F. (1991b) Covert and overt recognition in prosopagnosia. *Brain* **114**: 2575-2591.

De Haan, E.H.F., Young, A. and Newcombe, F. (1992) Neuropsychological Impairment of Face Recognition Units. *Quarterly Journal of Experimental Psychology* **44A(1)** 141-175

De Renzi, E. (1986) Current issues on prosopagnosia. In *Aspects of Face Processing*, Ellis, H.D., Jeeves, M.A., Newcombe, F. and Young, A. (eds.) NATO ASI Series D: Behavioural and Social Sciences. Martinus Nijhoff.

De Renzi, E. (1993) The anatomical basis of prosopagnosia. Unpublished lecture given at the International Conference on Face Processing, Cardiff, UK.

De Renzi, E., Perani, D., Carlesimo, G.A. and Silveri, M.C. (1994) Prosopagnosia can be associated with damage confined to the right hemisphere: an MRI and PET study and a review of the literature. *Neuropsychologia* **32(8)**: 893-902.

Desimone, R. (1991) Face-selective cells in the temporal cortex of monkeys. *Journal of Cognitive Neuroscience* **3**: 1-8.

Diamond, R. and Carey, S. (1986) Why faces are and are not special: an effect of expertise. *Journal of Experimental Psychology: General* **115**: 107-117.

Eacott, M.J., Heywood, C.A., Gross, C.G. and Cowey, A. (1993) Visual discrimination impairments following lesions of the superior temporal sulcus are not specific for facial stimuli. *Neuropsychologia* **31(6)**: 609-619.

Efron, R. (1990) *The decline and fall of hemispheric specialization*. LEA, Hillsdale, NJ, USA.

Ehrlich, S. and Field, D. (1993) Why is the acuity for the direction of gaze so good? *Investigative Ophthalmology and Visual Science* **34**: 778.

Ekman, P. (1973) Universal facial expression in emotion. *Studia Psychologica* **15(2):** 140-147.

Ellis, H.D., Shepherd, J.W. and Davies, G.M. (1979) Identifaction of familiar and unfamiliar faces from internal and external features: Some implications for theories of face recognition. *Perception* **8(4)**: 431-439.

Ellis, H.D., Young, A.W. and Koenken, G. (1993) Covert face recognition without prosopagnosia. *Behavioural Neurology* **6:** 27-32.

Erickson, T.C. (1940) Spread of the epileptic discharge. *Archives of Neurology and Psychiatry* **43:** 429-453.

Etcoff, N.L., Freeman, R. and Cave, K.R. (1991) Can we lose memories of faces? Content specificity and awareness in a prosopagnosic. *Journal of Cognitive Neuroscience* **3**: 25-41.

Ettlin, T.M., Backson, M., Benson, D.F., Langfitt, J.T., Amos, E.C. and Pineda, G.S. (1992) Prosopagnosia - a bihemispheric disorder. *Cortex* **28**: 129-134.

Fagot, J. (1992) Cognition et lateralite chez l'animal. (Cognition and laterality in animals.) Special issue: Animal cognition. *Psychologie Française* **37(1)**: 73-79.

Farah, M.J. (1990) *Visual Agnosia: Disorders of Object Recognition and What They Tell Us about Normal Vision.* MIT Press, Cambridge, Mass.

Farah, M.J. (1994) Specialization within visual object recognition: Clues from prosopagnosia and alexia. In *The Neurology of High-level Vision: Collected Tutorial Essays,* Farah, M.J. and Ratcliff, G. (eds.). LEA, New Jersey.

Farah, M.J. (1996) Is face recognition "special"? Evidence from neuropsychology. *Behavioural Brain Research* **76(1-2)**: 181-189.

Farah, M.J., Wilson, K.D., Drain, H.M. and Tanaka, J.R. (1995a) The inverted face inversion effect in prosopagnosia: Evidence for mandatory, face-specific perceptual mechanisms. *Vision Research* **35(14)**: 2089-2093.

Farah, M.J., Klein, K.L. and Levinson, K.L. (1995b) Face perception and within-category discrimination in prosopagnosia. *Neuropsychologia* **33(6)**: 61-674.

Fried, I., Mateer, C., Ojemann, G., Wohns, R. and Fedio, P. (1982) Organization of visuospatial functions in human cortex: evidence from electrical stimulation. *Brain* **105**: 349-371.

Gaffan, D., Harrison, S. and Gaffan, E.A. (1986) Visual identification following inferotemporal ablation in the monkey. *Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology* **38B(1)**: 5-30.

Gazzaniga, M.S., Fendrich, R. and Wessinger, C.M. (1994) Blindsight reconsidered. *Current Directions in Psychological Science.* **3(3)**: 93-6.

Geffen, G., Bradshaw, J.L. and Wallace, G. (1971) Interhemispheric effects on reaction time to verbal and non-verbal stimuli. *Journal of Experimental Psychology* **87**: 415-422.

Geschwind, N. and Levitsky, W. (1968) Left-right asymmetries in temporal speech region. *Science* **161**: 186-187.

Gilhooly, K.J. and Logie, R.H. (1980) - Age of acquisition, imagery, concreteness, familiarity and ambiguity measures for 1944 words. *Behavioural Research Methods and Instrumentation* **12**: 395-427.

Glanzer, M. and Cunitz, A.R. (1966) Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behaviour* **13**: 114-131.

Gregory, R.L. (1980) Perceptions as hypotheses. *Philosophical Transactions of the Royal Society of London: Series B* **290**: 181-197.

Gross, C.G. (1992) Representation of visual stimuli in inferior temporal cortex. In *Processing the Facial Image*, Bruce, V., Cowey, A., Ellis, A.W. and Perrett, D.I., (eds.), *Philosophical Transactions of the Royal Society of London B* **335**: 3-10.

Gross, C.G., Rocha-Miranda, C.E. and Bender, D.B. (1972) Visual properties of neurones in inferotemporal cortex of the macaque. *Journal of Neurophysiology* **35**: 96-111.

Grüsser, O-J. (1984) Face recognition within the reach of neurobiology and beyond it. *Human Neurobiology* **3**: 183-190.

Grüsser, O-J. and Landis, T. (1991) Faces lost: prosopagnosia. In *Visual Agnosias, Volume 12 of Vision and Visual Dysfunction*, Cronly Dillon, J.R. (gen. ed.). The Macmillan Press.

Hanley, J.R. (1995) Are names difficult to recall because they are unique? A case study of a patient with anomia. *Quarterly Journal of Experimental Psychology* **48A(2)**: 487-506.

Harries, M.H. and Perrett, D.I. (1991) Visual processing of faces in temporal cortex: physiological evidence for a modular organisation and possible anatomical correlates. *Journal of Cognitive Neuroscience* **3**: 9-24.

Hasselmo, M.E., Rolls, E.T. and Baylis, G.C. (1989) The role of expression and identity in the face-selective responses of neurons in the temporal visual cortex of the monkey. *Behavioural Brain Research* **32(3)**: 203-218.

Hay, D.C. and Young, A.W. (1982) The human face. In *Normality and Pathology in Cognitive Functions*, Ellis, E.W. (ed.), Academic Press.

Hellige, J.B. and Sergent, J. (1986) Role of task factors in visual field asymmetries. *Brain and Cognition* **5**: 200-222.

Henke, K., Schweinberger, S.R., Grigo, A., Klos, T. and Sommer, W. (1998) Specificity of face recognition: recognition of exemplars of non-face object in prosopagnosia. *Cortex* **34**: 289-296.

Hertz, S., Porjesz, B., Begleiter, H. and Chorlian, D. (1994) Event-related potentials to faces: the effects of priming and recognition. *Electroencephalography and Clinical Neurophysiology Evoked Potentials* **92(4)**: 342-351. (abstract)

Heywood, C.A., Cowey, A. and Newcombe, F. (1994) On the role of parvocellular (P) and magnocellular (M) pathways in cerebral achromatopsia. *Brain* **117**: 245-254.

Heywood, C.A. and Cowey, A. (1992) The role of the 'face-cell' area in the discrimination and recognition of faces by monkeys. In *Processing the Facial Image*, Bruce, V., Cowey, A., Ellis, A.W. and Perrett, D.I., (eds.), *Philosophical Transactions of the Royal Society of London B* **335**: 31-38.

Hillger, L.A. and Koenig, O. (1991) Separable mechanisms in face processing: evidence from hemispheric specialisation. *Journal of Cognitive Neuroscience* **3**: 42-58.

Hofland, K. and Johansson, S. (1982) *Word frequencies in British and American English.* NAVF.

Horel, J.A. (1993) Retrieval of a face discrimiation during suppression of monkey temporal cortex with cold. Special Issue: The neuropsychology of animal memory. *Neuropsychologia* **31(10)**: 1067-1077.

Howell, D.C. (1992) *Statistical Methods for Psychology*, 3rd edition. Duxbury Press.

Hugdahl, K., Nordby, H. and Kvale, G. (1989) Conditional learning and brain asymmetry: Empirical data and a theoretical framework. *Learning and Individual Differences* **1**: 385-406.

Humphreys, G.W. and Riddoch, M.J. (1987) *To see but not to see: A case of visual agnosia.* LEA.

Humphreys, G.W., Donnelly, N. and Riddoch, M.J. (1993) Expression is computed separately from facial identity, and it is computed separately for moving and static faces neuropsychological evidence. *Neuropsychologia* **31**: 173-181.

Hurtig, R.R. (1982) Cerebral asymmetry in the strategies used in processing random line stimuli. *Cortex* **18**: 337-343.

Iaccino, J.F. (1993) *Left brain - right brain differences: Inquiries, Evidence, and New Approaches.* LEA, Hillsdale, New Jersey.

Jeeves, M.A. (1984) The historical roots and recurring issues of neurobiological studies of face perception. *Human Neurobiology* **3**: 191-196.

Johansson, G. (1973) Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics* **14**: 201-211.

Johnsen, B.H. and Hegdahl, K. (1991) Hemispheric asymmetry in conditioning to facial emotional expressions. *Psychophysiology* **28(2)**: 154-162.

Jonides, J. (1981) Voluntary versus automatic control over the Mind's Eye's movement. *Attention and Performance IX*, Long, J. and Baddeley, A. (eds.) 187-204. LEA: Hillsdale, New Jersey.

Kendrick, K.M. and Baldwin, B.A. (1987) Cells in temporal cortex of conscious sheep can respond preferentially to the sight of faces. *Science* **236**: 448-450.

Kimura, D. (1961) Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology* **15**: 166-171.

Kimura, D. (1967) Functional asymmetry of the brain in dichotic listening. *Cortex* **3**: 163-178.

Kolb, B. and Whishaw, I.Q. (1990) *Fundamentals of Human Neuropsychology* (3rd edition). W.H.Freeman and Company, New York.

Ladavas, E., Umilta, C. and Ricci-Bitti, P.E. (1980) Evidence for sex differences in right hemisphere dominance for emotions. *Neuropsychologia* **18**: 361-366

Landis, T., Assal, G. and Perrett, E. (1979) Opposite cerebral hemispheric superiorities for visual associative processing of emotional facial expressions and objects. *Nature* **278**: 739-740.

Landis, T., Cummings, J.L., Christen, L., Bogen, J.E. and Imhof, H-G. (1986) Are unilateral right posterior cerebral lesions sufficient to cause prosopagnosia? Clinical and radiological findings in six additional patients. *Cortex* **22**: 243-252.

Landis, T., Regard, M., Bliestle, B. and Kleihues, P. (1988) Prosopagnosia and agnosia for noncanonical views: an autopsied case. *Brain* **111**: 1287-1297.

Leehey, S., Carey, S., Diamond, R. and Cahn, A. (1978) Upright and inverted faces: the right hemisphere knows the difference. *Cortex* **14**: 411-419.

Levine, D.N. (1978) Prosopagnosia and visual object agnosia: a behavioural study. *Brain and Language* **5(3)**: 341-365.

Levine, S.C., Banich, M.T. and Koch-Weser, M.P. (1988) Face recognition: a general or specific right hemisphere capacity? *Brain and Cognition* **8(3)**: 303-325.

Levy, J., Trevarthen, C. and Sperry, R.W. (1972) Perception of bilateral chimeric figures following hemispheric deconnexion. *Brain* **95**: 61-78.

Ley, R.G. and Strauss, E. (1986) Hemispheric asymmetries in the perception of facial expressions by normals. In *The neuropsychology of face perception and facial expression*, Bruyer, R. (ed.). LEA, London.

MacCoby, E. and Jacklin, C. (1974) *The Psychology of Sex Differences*. Stanford University Press, Stanford, CA.

Magaro, P.A. and Moss, B.F. (1989) The effect of analytic versus holistic encoding instructions on hemispheric superiority. *Cortex* **25(2)**: 317-324.

Malone, D.R., Morris, H.R., Kay, M.C. and Levin, H.S. (1982) Prosopagnosia: A double dissociation between the recognition of familiar and unfamiliar faces. *Journal of Neurology, Neurosurgery and Psychiatry* **45(9)**: 820-822.

Marciani, M.G., Carlesimo, G.A., Maschio, M.C.E., Sabbadini, M., Stefani, N. and Caltagirone, C. (1991) Comparison of neuropsychological, MRI and computerized EEG findings in a case of prosopagnosia. *International Journal of Neuroscience* **60:** 27-32.

Marzi, C.A. and Berlucchi, G. (1977) Right visual field superiority for accuracy of recognition of famous faces in normals. *Neuropsychologia* **15**: 751-756.

Marzi, C.A., Tassinari, G., Tressoldi, P.E., Barry, C. and Grabowska, A. (1985) Hemispheric asymmetry in face perception tasks of different cognitive requirement. *Human Neurobiology* **4**: 15-20.

McKelvie, S.J. (1995) Emotional expression in upside-down faces: Evidence for configurational and componential processing. *British Journal of Social Psychology* **34(3)**: 325-334.

McLeod, P., Dittrich, W., Driver, J., Perrett, D. and Zihl, J (1996) Preserved and impaired detection of structure from motion in a "motion-blind" patient. *Visual Cognition* **3(4)**: 363-391.

McNeil, J.E. and Warrington, E.K. (1993) Prosopagnosia: a face-specific disorder. *Quarterly Journal of Experimental Psychology* **46(A)**: 1-10.

Meadows, J.C. (1974) The anatomical basis of prosopagnosia. *Journal of Neurology, Neurosurgery and Psychiatry* **37**: 489-501.

Menza, M.A., Mark, M.H., Burn, D.J. and Brooks, D.J. (1995) Personality correlates of (-sup-1-sup-8F)dopa striatal uptake: results of positron-emission tomography in Parkinson's disease. *Journal of Neuropsychiatry and Clinical Neurosciences* **7(2)**: 176-179.

Michel, S., Poncet, M. and Signoret, J.L. (1989) Les lésions responsables de la prosopagnosie sont elles toujours bilatérales? *Revue Neurologique, Paris* **145**: 764-770.

Mishkin, M. and Forgays, D.G. (1952) Word recognition as a function of retinal locus. *Journal of Experimental Psychology* **43**: 43-48.

Moscovitch, M., Winocur, G. and Behrmann, M. (1997) What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Neuroscience* **9**: 555-604.

Moses, Y., Adini, Y. and Ullman, S. (1997) Face recognition: the problem of compensating for changes in illumination direction. *IEEE Transactions on Pattern Analysis and Machine Intelligence* **19**: 721-732.

Moses, Y., Ullman, S. and Edelman, S. (1996) Generalization to novel images in upright and inverted faces. *Perception* **25**: 443-461.

Myers, R.E. and Sperry, R.W. (1953) Interocular transfer of a visual form discrimination in cats after section of the optic chiasma and corpus callosum. *The Anatomical Record* **115**: 351-352.

Nebes, R.D., Brady, C.B. and Huff, F.J. (1989) Automatic and attentional mechanisms of semantic priming in Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology* **2**: 219-230.

Nelson, C.A. and de Haan, M. (1996) Neural correlates of infants' visual responsiveness to facial expression of emotion. *Developmental Psychobiology* **29(7)**: 577-595. (abstract)

Newcombe, F., Young, A.W. and de Haan, E.H.F. (1989) Prosopagnosia and object agnosia without covert recognition. *Neuropsychologia* **27**: 179-191.

Nottebohm, F. (1977) Asymmetries in neural control of vocalization in the canary. In *Lateralization in the Nervous System*, Harnad, S., Doty, R.W., Goldstein, L., Jaynes, J. and Krauthamer, G. (eds.). Academic Press, New York.

Oldfield, R.C. (1971) The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia* **9(1)** 97-113.

Ojemann, J.G. and Mateer, C. (1979) Cortical and subcortical organization of human communication: Evidence from stimulation studies. In *Neurobiology of Social Communication in Primates: An Evolutionary Perspective*, Steklis, H.D. and Raleigh, M.J. (eds.) Academic Press, New York.

Ojemann, J.G., Ojemann, G.A. and Lettich, E. (1992) Neuronal activity related to faces and matching in human right non-dominant temporal cortex. *Brain* **115**: 1-13.
Paivio (unpublished) - cited in Quinlan (1992).

Passingham, R.E. (1997) The specialization of the human cerebral cortex. In *Brain and Cognition in monkeys, apes and man*, Milner, A.D. (ed.) OUP.

Paulesu, E., Frith, C.D. and Frackowiak, R.S.J. (1993) The neural correlates of the verbal component of working memory. *Nature* **362**: 342-344.

Penfield, W. and Rasmussen, T. (1950) *The Cerebral Cortex of Man: A Clinical Study of Localization*. Little, Brown & Co., Boston.

Penfield, W. and Roberts, L. (1959) *Speech and Brain Mechanisms.* Princeton University Press, Princeton.

Perrett, D.I., Rolls, E.T. and Caan, W. (1982) Visual neurons responsive to faces in monkey temporal cortex. *Experimental Brain Research* **47:** 329-342.

Perrett, D.I., Smith, P., Potter, D., Mistlin, A., Head, A., Milner, A. and Jeeves, M. (1984) Neurones responsive to faces in the temporal cortex: studies of functional organisation, sensitivity to identity and relation to perception. *Human Neurobiology* **3**: 197-208.

Perrett, D.I., Mistlin, A.J., Chitty, A.J., Smith, P.A., Potter, D.D., Broennimann, R. and Harries, M. (1988) Specialised face processing and hemispheric asymmetry in man and monkey: evidence from single unit and reaction time studies. *Behavioural Brain Research* **29**: 245-258.

Perrett, D.I., Hietanen, J.K., Oram, M.W. and Benson, P.J. (1992) Organization and functions of cells responsive to faces in the temporal cortex. In *Processing the Facial Image*, Bruce, V., Cowey, A., Ellis, A.W. and Perrett, D.I., (eds.), *Philosophical Transactions of the Royal Society of London B* **335**: 23-30.

Pineda, J.A., Sebestyen, G. and Nava, C. (1994) Face recognition as a function of social attention in non-human primates: an ERP study. *Cognitive Brain Research* **2(1)**: 1-12. (abstract)

Posner, M.I. (1980) Orienting of Attention. *Quarterly Journal of Experimental Psychology* **32**: 3-25.

Posner, M. I. and Cohen, Y. (1984) Components of visual orienting. *Attention and Performance X*, Bouma, H. and Bouwhuis, D.G. (eds.) 531-556. LEA: London.

Price, C.J., Wise, R.J.S., Warburton, E.A., Moore, C.J., Howard, D., Patterson, K., Frackowiak, R.S.J. and Friston, K.J. (1996) Hearing and saying: the functional neuro-anatomy of auditory word processing. *Brain* **119**: 919-931.

Quinlan, P.T. (1992) *The Oxford Psycholinguistic Database*, OUP.

Rasmussen, T. and Milner, B. (1977) The role of early left brain injury in determining lateralization of cerebral speech functions. *Annals of the New York Academy of Sciences* **299**: 355-369.

Ratcliffe, G. and Newcombe, F. (1973) Spatial orientation in man: effects of left, right and bilateral posterior cerebral lesions. *Journal of Neurology, Neurosurgery and Psychiatry* **36**: 448-454.

Renault, B., Signoret, S-L., Debruille, B., Breton, F. and Bolgert, F. (1989) Brain potentials reveal covert facial recognition in prosopagnosia. *Neuropsychologia* **27(7)**: 905-912.

Reuter-Lorenz, P. and Davidson, R.J. (1981) Differential contributions of the two cerebral hemispheres to the perception of happy and sad faces. *Neuropsychologia* **19**: 609-614

Rizzo, M., Hurtig, R. and Damasio, A.R. (1987) The role of scanpaths in facial learning and recognition. *Annals of Neurology* **22**: 41-45.

Rizzolatti, G., Umilta, C. and Berlucchi, G. (1971) Opposite superiorities of the right and left cerebral hemispheres in discriminative reaction time to alphabetical and physiognomical material. *Brain* **94**: 431-442.

Rolls, E.T. (1984) Neurons in the cortex of the temporal lobe and in the amygdala of the monkey with responses selective for faces. *Human Neurobiology* **3**: 209-222.

Rolls E.T. (1992) Neurophysiological mechanisms underlying face processing within and beyond the temporal cortical visual areas. In *Processing the Facial Image*, Bruce, V., Cowey, A., Ellis, A.W. and Perrett, D.I., (eds.), *Philosophical Transactions of the Royal Society of London B* **335**.

Schmitt, J.J., Hartje, W. and Willmes, K. (1997) Hemispheric asymmetry in the recognition of emotional attitude conveyed by facial expression, prosody and propositional speech. *Cortex* **33(1)**: 65-81.

Sergent, J. (1982) The cerebral balanace of power: confrontation or cooperation? *Journal of Experimental Psychology: Human Perception and Performance* **8**: 253-272.

Sergent, J. and Hellige, J.B. (1986) Role of input factors in visual-field asymmetries. *Brain and Cognition* **5**: 174-199.

Sergent, J., Ohta, S. and MacDonald, B. (1992) Functional neuroanatomy of face and object processing. A PET study. *Brain* **115**: 15-36.

Shallice, T. (1982) Specific impairments of planning. *Philosophical Transactions of the Royal Society* **B298**: 199-209.

Shallice (1988) *From Neuropsychology to Mental Structure*. Cambridge University Press, New York.

Small, M. (1986) Hemispheric differences in the evoked potential to face stimuli. In *Aspects of Face Processing*, Ellis, H.D., Jeeves, M.A., Newcombe, F. and Young, A. (eds.). NATO ASI Series D: Behavioural and Social Sciences. Martinus Nijhoff.

Sommer, W., Schweinberger, S.R., Stefan, R. and Matt, J. (1991) Human brain potential correlates of face encoding into memory. *Electroencephalography and Clinical Neurophysiology* **79(6)**: 457-463. (abstract)

Sommer, W., Heinz, A., Leuthold, H., Matt, J. and Schweinberger, S.R. (1995) Metamemory, distinctiveness, and event-related potentials in recognition memory for faces. *Memory and Cognition* **23(1)**: 1-11.

Sperry, R.W. (1982) Some effects of disconnecting the cerebral hemispheres. *Sciencei 217: 1223-1226.*

Sperry, R.W. and Gazzaniga, M.S. (1967) *Language following surgical disconnection of the hemispheres*. New York: Grune, Stratton.

Springer, S.P. and Deutsch, G. (1993) *Left brain, right brain* (4^{th} edition). W.H.Freeman and Company, New York.

Takahashi, N., Kawamura, M., Hirayama, K. and Shiota, J. (1995) Prosopagnosia : a clinical and anatomical study of 4 patients. *Cortex* **31**: 317-330.

Tanaka, J.W. and Farah, M.J. (1993) Parts and wholes in face recognition. *Quarterly Journal of Experimental Psychology* **46A** 225-245.

Teuber, H.-L. (1955) Physiological psychology. *Annual Review of Psychology* **6**: 267-296.

Toglia, M.P. and Baltig, W.R. (1978) *Handbook of Semantic Word Norms.* LEA: New York.

Tomonaga, M. (1994) How laboratory-raised monkeys (Macaca fuscata) perceive rotated photographs of monkeys: evidence for an inversion effect in face perception. *Primates* **35(2)**: 155-165.

Torii, H. and Tamai, A. (1985) The problem of prosopagnosia: Report of 3 cases with occlusion to the right posterior cerebral artery. *Journal of Neurology* **232** (Supplement): 140.

Tovée, M.J. and Cohen-Tovée, E.M. (1993) The neural substrates of face processing models: A review. *Cognitive Neuropsychology* **10(6)**: 505-528.

Tranel, D. and Damasio, A.R. (1985) Knowledge without awareness: an autonomic index of facial recognition by prosopagnosics. *Science* **228**: 1453-1454.

Tranel, D. and Damasio, A.R. (1988) Non-conscious face recognition in patients with face agnosia. *Behavioural Brain Research* **30**: 235-249.

Tranel, D., Damasio, A.R. and Damasio, H. (1988) Intact recognition of facial expression, gender, and age in patients with impaired recognition of face identity. *Neurology* **38**: 690-696.

Trope, I., Rozin, P., Nelson, D.K. and Gur, R.C. (1992) Information processing in the separated hemispheres of callosotomy patients: Does the analytic-holistic dichotomy hold? *Brain and Cognition* **19(2)**: 123-147.

Tulving, E., Schacter, D.L. and Stark, H.A. (1982) Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory and Cognition* **17**: 595-617.

Uhl, F., Lang, W., Spieth, F. and Deecke, L. (1990) Negative cortical potentials when classifying familiar and unfamiliar faces. *Cortex* **26(1)**: 157-161.

Umilta, C. (1986) Models of Laterality effects in face perception. In *Aspects of Face Processing*, Ellis, H.D., Jeeves, M.A., Newcombe, F. and Young, A. (eds.). NATO ASI Series D: Behavioural and Social Sciences. Martinus Nijhoff.

Umilta, C., Rizzolatti, G., Anzola, G.P., Luppino, G. and Porro, C. (1985) Evidence of interhemispheric transmission in laterality effects. *Neuropsychologia* **23(2)**: 203-213.

Vaina, L.M., Lemay, M., Bienfang, D.C., Choi, A.Y. and Nakayama, K. (1990) Intact "biological motion" and "structure from motion" perception in a patient with impaired motion mechanisms: a case study. *Visual Neuroscience* **5**: 353-369.

Valentine, T. (1988) Upside-down faces: a review of the effect of inversion upon face recognition. *British Journal of Psychology* **79**: 471-491.

Valentine, T. and Bruce, V. (1986) The effect of race, inversion and encoding activity upon face recognition. *Acta Psychologica* **61**: 259-273.

Vanderploeg, R.D., Brown, W.S. and Marsh, J.T. (1987) Judgements of emotion in words and faces: ERP correlates. *International Journal of Psychophysiology* **5(3)**: 193-205. (abstract)

Van Kleeck, M.H. (1989) Hemispheric differences in global versus local processing of hierarchical visual stimuli by normal subjects: New data and a meta-analysis of previous studies. *Neuropsychologia* **27(9)**: 1165-1178.

Van Wagenen, W.P. and Herren, R.Y. (1940) Surgical division of commisural pathways in corpus callosum: relation to spread of epileptic attack. *Archives of Neurology and Psychiatry* **44**: 740-759.

Walsh, V. and Perrett, D.I. (1994) Visual attention in the occipitotemporal precessing stream of the macaque. Special Issue: The cognitive neuropsychology of attention. *Cognitive Neuropsychology* **11(2)**: 243-263.

Weiskrantz, L. (1986) *Blindsight - a case study and implications*. Oxford Psychology Series, OUP.

Yin, R.K. (1969) Looking at upside-down faces. *Journal of Experimental Psychology* **81**: 141-145.

Yin, R.K. (1970) Face recognition: a dissociable ability? *Neuropsychologia* **23**: 397-402.

Young, A.W. (1994) Face Recognition. Ch. 1 in *International Perspectives on Psychological Science, Volume 2: The state of the art*, d'Ydewalle, G., Eelen, P. and Bertelson, P. (eds.). LEA, Hove.

Young, A.W., McWeeny, K.H., Hay, D.C. and Ellis, A.W. (1986) Matching familiar and unfamiliar faces on identity and expression. *Psychological Research* **48(2)**: 63-68.

Young, A.W. and de Haan, E.H.F. (1992) Face recognition and awareness after brain injury. In *The Neuropsychology of Consciousness*, Milner, A.D. and Rugg, M.D. (eds.). Academic Press Ltd: London.

Young, A.W., Newcombe, F., de Haan, E.H.F., Small, M. and Hay, D.C. (1993) Face perception after brain injury: Selective impairments affecting identity and expression. *Brain* **116**: 941-959.

Young, M.P. and Yamane, S. (1992) Sparse population coding of faces in the inferotemporal cortex. *Science* **256**: 1327-1330.

APPENDICES

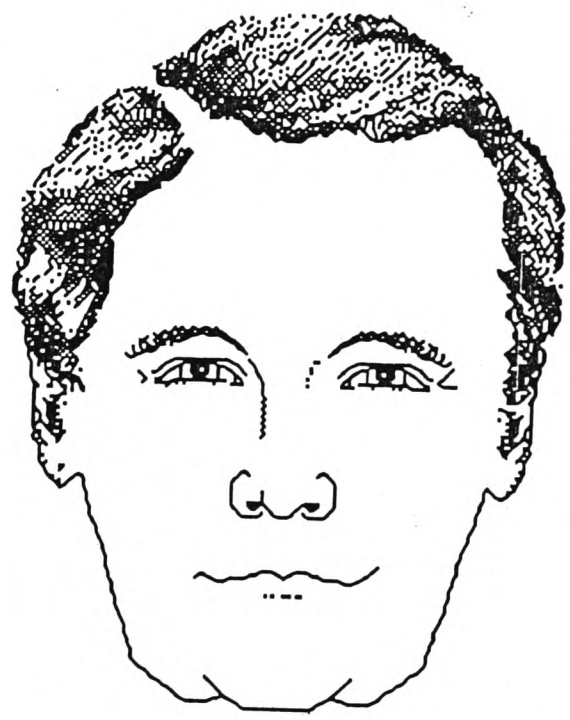
Appendix A - Face Stimuli used in the thesis

Appendix A.1 - Examples of Mac-a-Mug faces used in Experiments 5.1, 5.2, 5.3, 5.5 and 5.6

Shown are examples of both full faces and internal features only which were used in the above experiments.



Face 1



Face 2



Face 5



Face 6

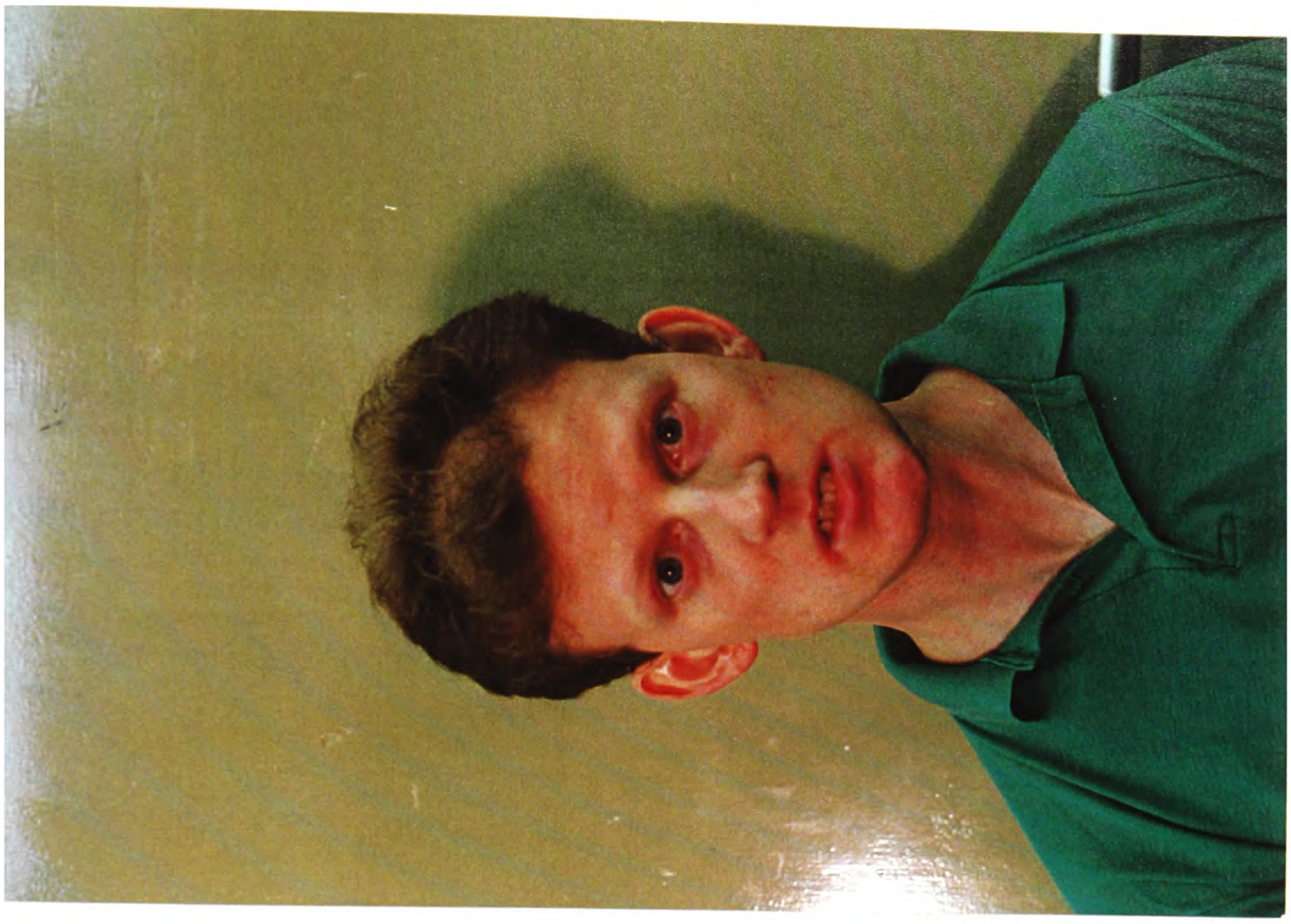
Appendix A.2 - Examples of Israeli faces used in Experiments 6.1

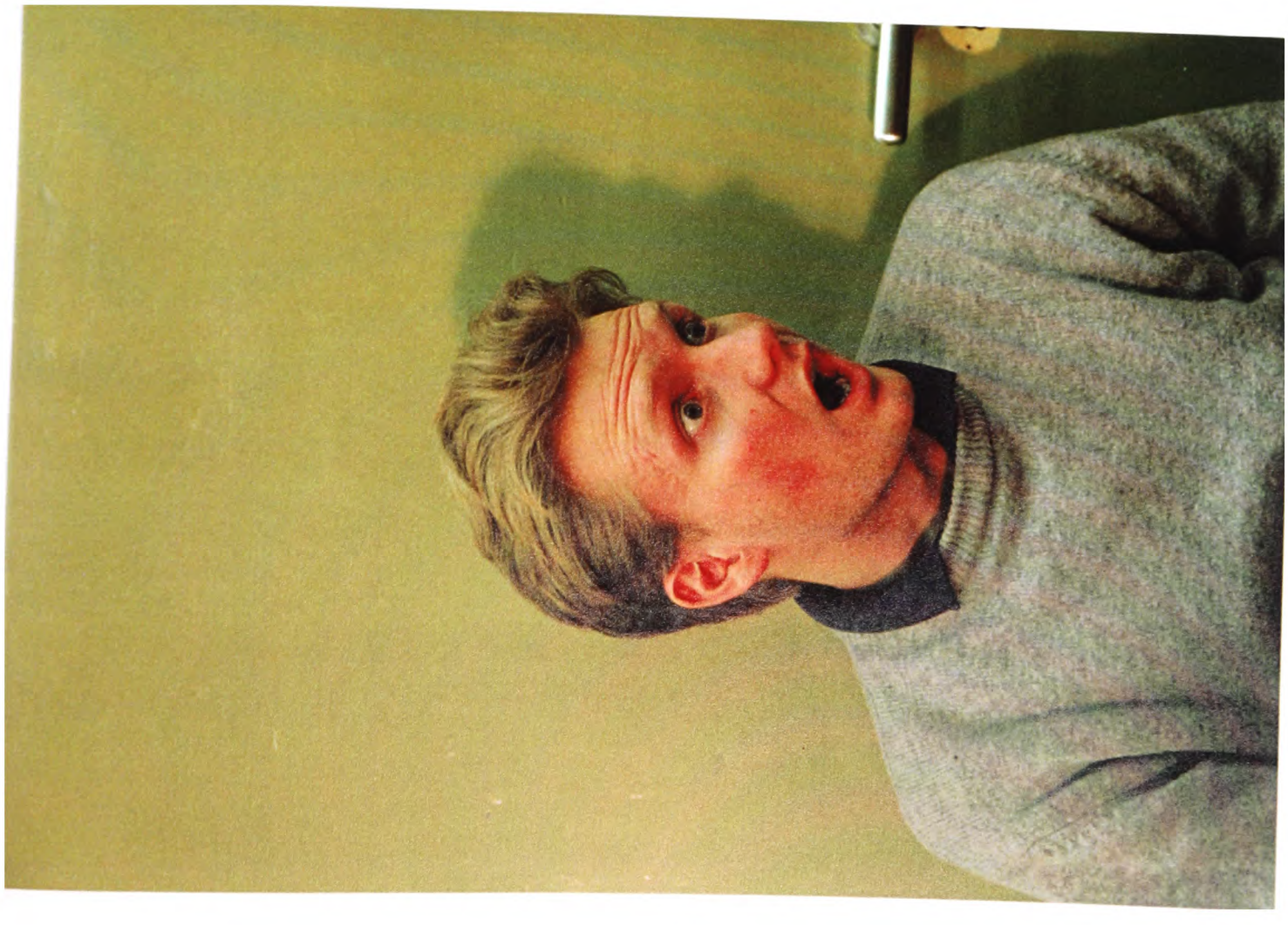
Shown are examples of two of the faces used in the above experiment.



Appendix A.3 - Examples of expression photos used in Experiments 7.1, 7.2 and 7.3

Shown are copies of photographs used in Experiment 7.1. The images used in the next two experiments were similar, but black and white and were cropped at about the level of the neck.





Appendix A.4 - Examples of eye gaze photographs used in Experiment 8.2

Shown are copies of photographs used in the second eye gaze experiment.





Appendix B - word lists

Appendix B.1 - List of words used in Experiment 5.4

Verbs			Nouns		
Word	**A**	**B**	**Word**	**A**	**B**
begin	86	544	bread	42	43
behave	22	179	belief	60	426
choose	37	259	cheese	15	15
eat	42	125	ear	38	76
feel	247	730	foot	115	337
give	446	1529	girl	307	450
kill	52	137	king	172	218
mutate	0	0	meadow	8	16
ponder	2	4	pond	19	22
prefer	50	127	prince	62	77
pray	9	98	prayer	48	98
read	229	335	road	205	240
shine	5	49	shelf	12	31
sing	25	205	song	51	205
sit	70	446	sea	159	171
speak	105	391	story	202	261
tell	282	872	town	262	357
write	101	658	woman	243	486
SUM	1810	6688	**SUM**	2020	3529

A is the number of times that word occurs in a sample of a million words, according to *Word Frequencies in British and American English* (Hofland and Johansson 1982).

B is the number of times that word or any of its derivatives in all parts of speech occur in a sample of a million words, according to the same corpus.

Note: the derivatives of the word feel occur 752 times, but this includes the word felt, which could either be the past tense of the verb or also the noun with an unrelated meaning, on 352 occasions. A score of 730 is an estimate.

Appendix B.2: the word lists used in Experiment 9.1

Verbs						Nouns					
High frequency			Low frequency			High frequency			Low frequency		
	A	B		A	B		A	B		A	B
begin	86	541	berate	1	1	breath	78	152	beret	2	2
become	331	482	beware	4	4	belief	60	427	belfry	3	3
choose	37	259	cleave	0	5	church	332	392	celery	6	6
eat	42	126	err	2	3	ear	38	76	eel	1	1
follow	111	603	flee	2	6	foot	115	337	flea	3	4
get	735	1219	gnaw	1	5	girl	307	450	gent	2	4
live	165	581	laze	1	18	lady	141	184	liar	4	18
marry	83	406	mutate	0	0	method	152	318	meadow	8	16
prefer	50	127	pierce	2	13	prayer	48	98	prism	1	2
prove	80	245	preach	4	18	peace	159	184	peach	6	8
please	94	157	ponder	2	4	prince	62	74	peril	5	12
read	229	525	raze	0	2	road	205	240	rind	2	2
speak	105	239	steal	6	57	sheet	47	77	siren	1	1
sing	25	222	sift	2	5	song	51	222	serf	1	3
sit	70	341	sue	8	10	sea	159	171	sty	0	0
save	72	271	stifle	2	8	story	202	261	saga	2	3
tell	282	872	tempt	3	57	town	262	357	teat	0	0
write	101	658	wield	0	6	woman	243	486	wafer	1	2
SUM	2698	7874	**SUM**	40	222	**SUM**	2661	4506	**SUM**	48	87

A is the number of times that word occurs in a sample of a million words, according to *Word Frequencies in British and American English* (Hofland and Johansson).

B is the number of times that word or any of its derivatives in all parts of speech occur in a sample of a million words, according to the same corpus.

Note: the derivatives of the word liar occur 280 times, but this includes the verb lie and its derivatives (i.e. to lie down). 18 is an estimate.

Appendix B.3 - The four word lists used in Experiment 9.2

Test List 1

gallery	garage	after	pest
edgy	scenery	crack	banister
old	ultimate	route	jerboa
morbid	ebb	house	north
mouse	eat	zone	gentle
opponent	vacant	knife	formula
wash	foreign	mist	jupiter
heart	history	gazebo	harmony
eleven	origin	happy	fly
chair	thematic	vile	wafer
germ	saga	kangaroo	never
grammar	marina	canal	quart
brother	verify	cover	unity
zodiac	watery	willowy	bat
swine	flower	direct	us
hurry	cup	icicle	zero
rivulet	error	immune	table
purple	sugary	light	remove
genius	joke	channel	rigid
fantasy	cyan	woman	natural
primary	decay	sharp	vase
dream	number	parade	bought
eight	jargon	acre	diary
liar	ratify	item	one
thimble	season	axe	enquiry
utensil	triangle	desk	story
dunce	knuckle	similar	ghost
cat	physical	banana	yacht
heaven	robot	vivid	kettle
yellow	near	rhetoric	apricot
whistle	king	leotard	camera
possible	quiz	various	rare
density	idiot	query	orange
soul	jade	foliage	fight
duty	qualify	paradox	begin
abacus	thumb	jelly	charity
oblige	tempt	shimmer	lost
korea	hyacinth	ludo	photo
music	memory	zebra	under
quiet	trifle	alien	cell
latitude	buffalo	motorway	get
mend	white	space	itch
ice	celery	twice	pure
risk	fish	nitrogen	ask
timpani	gnat	meadow	armada

Test List 2

edgy	jargon	under	crack
dunce	germ	foliage	kettle
dream	jade	lost	twice
grammar	watery	quart	never
origin	trifle	wafer	jerboa
latitude	vacant	meadow	table
chair	ebb	get	diary
yellow	heaven	item	itch
primary	swine	us	bought
heart	utensil	vile	zebra
flower	thimble	remove	kangaroo
wash	opponent	apricot	formula
celery	soul	route	happy
abacus	cat	cover	motorway
triangle	mend	rigid	parade
ice	fantasy	house	canal
physical	joke	photo	ask
scenery	morbid	after	natural
cyan	music	harmony	ghost
sugary	brother	armada	banister
gnat	hurry	jupiter	various
thematic	old	north	cell
ultimate	zodiac	jelly	icicle
genius	near	pure	channel
hyacinth	season	orange	similar
eight	history	story	zone
quiz	garage	immune	willowy
error	marina	banana	paradox
oblige	white	query	one
ratify	fish	shimmer	acre
korea	tempt	charity	axe
buffalo	possible	bat	space
king	foreign	fly	fight
eleven	rivulet	vivid	begin
number	quiet	woman	light
verify	timpani	pest	zero
gallery	purple	knife	mist
memory	robot	desk	rhetoric
liar	eat	vase	unity
qualify	mouse	leotard	gazebo
saga	idiot	camera	ludo
decay	knuckle	sharp	enquiry
duty	cup	gentle	rare
density	thumb	direct	yacht
whistle	risk	nitrogen	alien

Test List 3

matador	italic	burial	literal
code	halibut	giggle	worry
family	volcano	bush	gemini
tap	plume	kitten	sanity
potato	tomato	vague	museum
easily	barrier	deer	lemon
phantom	quarrel	super	curry
kimono	art	minute	gorilla
rotation	master	gossip	chorus
yawn	hand	rabbit	opening
up	sensible	festival	mute
computer	theory	sadist	negative
elk	friday	vicar	temple
horrible	artifact	unicorn	read
gas	nausea	earn	dynamic
part	able	panda	opt
yonder	queen	dozen	bend
amber	end	vodka	cider
ant	penny	thundery	cinema
deviate	ace	briar	fairy
tiger	champion	nucleus	tumult
isle	quantity	steam	sympathy
workable	video	tubular	diet
who	atomic	boring	orbit
break	jungle	galleon	yolk
low	scene	key	jewel
type	temporal	obvious	jovial
face	rhyme	sort	chop
wind	ingest	zambia	kingdom
winery	this	phase	silver
truce	rust	odd	colony
bacon	gin	jealousy	poetry
draw	local	idea	zinc
next	entry	laugh	ink
unusual	just	sand	lunch
prize	argue	rosary	ruler
fog	latin	halo	quotable
cherry	nasal	ruminant	isomer
world	library	domino	relax
vote	sorcery	dagger	ecstasy
emu	wearily	normal	ugly
yodel	queue	oboe	hover
poison	date	lottery	ankle
caviar	walnut	december	help
guess	mark	giant	jasmine

Test List 4

face
truce
isle
nausea
friday
halibut
sensible
unusual
argue
emu
master
kimono
plume
guess
yawn
bacon
entry
matador
art
prize
low
mark
cherry
ace
computer
break
latin
yonder
world
wind
poison
winery
yodel
workable
next
potato
vote
code
who
walnut
wearily
gin
temporal
champion
family

up
local
theory
atomic
ant
this
able
rhyme
barrier
phantom
fog
penny
scene
elk
hand
date
tomato
jungle
sorcery
rotation
part
nasal
queue
rust
amber
volcano
type
ingest
artifact
italic
deviate
end
queen
caviar
horrible
draw
gas
quantity
easily
quarrel
just
library
tap
tiger
video

nucleus
gorilla
deer
steam
lemon
unicorn
silver
burial
zambia
negative
jewel
obvious
festival
ink
sadist
relax
diet
yolk
chop
vodka
sanity
galleon
vicar
literal
tubular
vague
jealousy
help
idea
bush
rabbit
museum
read
ankle
sort
zinc
mute
dagger
dozen
lottery
jovial
poetry
ruler
laugh
quotable

opening
super
fairy
worry
tumult
key
colony
minute
orbit
lunch
temple
cider
thundery
december
sympathy
curry
giant
ruminant
bend
kingdom
opt
earn
dynamic
panda
ecstasy
normal
briar
domino
cinema
gemini
sand
chorus
halo
kitten
giggle
hover
boring
isomer
gossip
phase
oboe
jasmine
odd
ugly
rosary

Appendix C - Edinburgh Handedness Questionnaires

Appendix C.1 - The Edinburgh Inventory Test

The questionnaire used first was taken from Oldfield (1971). An example is shown on the next page.

HANDEDNESS INVENTORY

NAME.....
DATE OF BIRTH.....
SEX.....

Have you ever had any tendency to left-handedness? YES NO

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent put + in both columns.
Some of the activities require both hands. In these cases the part of the task, or object, for which hand-preference is wanted is indicated in brackets.

		L	R
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Comb		
6	Toothbrush		
7	Knife (without fork)		
8	Spoon		
9	Hammer		
10	Screwdriver		
11	Tennis Racket		
12	Knife (with fork)		
13	Cricket bat (lower hand)		
14	Golf club (lower hand)		
15	Broom (upper hand)		
16	Rake (upper hand)		
17	Striking match (match)		
18	Opening box (lid)		
19	Dealing cards (card being dealt)		
20	Threading needle (needle of thread, whichever is moved		
40	Which foot do you prefer to kick with?		
41	Which eye do you use when only using one?		

Appendix C.2 - The revised Handedness Questionnaire used

The following questionnaire was used after the first one caused problems for the subjects in terms of the instructions for filling them in.

HANDEDNESS INVENTORY

NAME.....
DATE OF BIRTH.....
SEX.....

Have you ever had any tendency to left-handedness? YES NO (please circle)

Please indicate your hand preferences for the following activities by putting a tick in the appropriate column in the table on the next page.

If you **always** use your **left** hand for an activity, tick column **1**.
If you **usually** use your **left** hand but **can** use your **right** hand, tick column **2**.
If you use **either** hand equally, tick column **3**.
If you **usually** use your **right** hand but **can** use your **left** hand, tick column **4**.
If you **always** use your **right** hand for an activity, tick column **5**.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand-preference is wanted is indicated in brackets.

	ACTIVITY	1 always left	2 usually left	3 either hand	4 usually right	5 always right
1	Writing					
2	Drawing					
3	Throwing					
4	Scissors					
5	Comb					
6	Toothbrush					
7	Knife (without fork)					
8	Spoon					
9	Hammer					
10	Screwdriver					
11	Tennis Racket					
12	Knife (with fork)					
13	Cricket bat (lower hand)					
14	Golf club (lower hand)					
15	Broom (upper hand)					
16	Rake (upper hand)					
17	Striking match (match)					
18	Opening box (lid)					
19	Dealing cards (card being dealt)					
20	Threading needle (needle or thread, whichever is moved)					
40	Which foot do you prefer to kick with?					
41	Which eye do you use when only using one?					

Appendix D - Statistical analyses

Appendix D.1 - The effect of log transforms on error data

Comparisons of percentage errors before and after log transforms:

Expression experiment (Ch. 7 Exp. 2)

Without log transform:

	F	P
Field	0.01	.913
Trial type	4.91	.014*
Interaction	1.70	.199

With log transform (note log[errors + 1]):

	F	P
Field	1.99	.178
Trial type	5.37	.010*
Interaction	2.45	.102

Identity experiment (Ch. 7 Exp. 3)

Without log transform:

	F	P
Field	9.75	.007*
Trial type	0.46	.637
Interaction	5.25	.011*

With log transform:

	F	P
Field	9.78	.006*
Trial type	1.87	.170
Interaction	2.88	.071

There is a difference in the interaction which ceases to be significant when the log transform is carried out.

Appendix D.2 - The difference between mean and median RTs

The following is a comparison of the mean and median reaction time data from Experiments 7.2 and 7.3.

The controls' mean reaction times for all correct trials as a function of both visual field and trial type for Experiment 7.2 are shown below.

Table D.2.1 - Control Reaction Time Data for Expression Matching (Experiment 7.2) (n=17)

Mean RT (ms)	Left visual field	Right visual field	Total
Different	877	885	881
Same expression	903	906	905
Same identity	871	898	884
Total	887	906	893

Note that these data are worked out by the TurboPascal analysis program putting all the control data together in one file rather than using SPSS to calculate overall means from each subject's data separately. However, the ANOVAs use each subject's data separately.

This table, based on mean reaction times with outliers removed shows no main effect of either visual field or trial type. This is borne out by the results of the ANOVA carried out as before: visual field ($F = 0.47$, $DF = 16,1$, $P = .502$ [n.s.]) and trial type ($F = 0.63$, $DF = 32,2$, $P = .539$ [n.s.]) are both clearly not significant, as is their interaction ($F = 1.41$, $DF = 32,2$, $P = .260$ [n.s.]). Thus on the basis of mean reaction time data for the controls there is no difference in speed of response as a function of either visual field of presentation or trial type. When compared with Table 7.5 it can be seen that whether median or mean reaction times are used, the analysis is equivalent.

The controls' mean reaction times for all correct trials as a function of both visual field and trial type for Experiment 7.3 are shown below.

Table D.2.2 - Control Reaction Time Data for Identity Matching (Experiment 7.3) (n=17)

Mean RT (ms)	Left visual field	Right visual field	Total
Different	779	796	788
Same expression	766	820	793
Same identity	796	805	800
Total	785	806	795

To investigate these reaction time data statistically the same ANOVA as described above was carried out. This yielded a significant main effect of visual field ($F = 7.85$, $DF = 16,1$, $P = .013$) but not of trial type ($F = 0.16$, $DF = 32,2$, $P = .850$ [n.s.]), nor was the interaction significant ($F = 2.88$, $DF = 32,2$, $P = .071$ [n.s.]), although this is approaching significance. As can be seen from the table this visual field effect is due to the subjects being faster when the second face is displayed in their left visual field than when it is displayed in the right visual field. This is the same as the findings using the median reaction times, and thus again the analysis gives similar results whichever method is used.

Appendix E - Pilot Experiments and Planned Experiments

E.1 - Introduction

This chapter outlines pilot experiments that were carried out in order to assess the feasibility of certain paradigms and to investigate whether certain experimental courses of action were useful. In most cases they did not lead to full experiments for a variety of reasons, due to problems with the procedure or the fact that their results were not going to be of overall interest and relevance to the thesis. The chapter also covers experiments that were designed in part but not carried out at all, such as the Posner attention shifting task (Section E.4). I will outline five sets of experiments that were carried out or planned early in the thesis to follow lines of enquiry which were eventually discarded. Although these experiments did not lead to usable data in themselves they are being included because they show why subsequent experiments were carried out in a particular way.

There were firstly a number of experiments carried out to investigate the cues for eye gaze perception. These involved presenting stimuli which were reminiscent of eyes to differing degrees, and investigating the subjects' abilities to make perceptual decisions about them. It was initially planned to test prosopagnosic subjects on these tasks but in fact only a small amount of control data were collected before it was decided that this set of experiments would not be followed up and the prosopagnosic subjects would not be tested. These experiments are outlined in Section E.2. The first experiment described in this section lead to Experiment 4.1 in the previous chapter, the estimation of baseline simple reaction times as a function of the inter-stimulus interval: this is the only experiment in this Chapter which was used in the main body of the thesis.

In Section E.2, tasks which tested subjects' estimation of line lengths as a parallel task to the estimation of whether one stimulus is centred in another are also reported. On the basis of these, there appeared to be perceptual enlargement of the upper visual field, and this was tested in a further experiment, outlined in Section E.3.

I then planned to repeat Posner's paradigm of attention shifting (Posner 1980), using eyes looking to one side or the other as a central cue, to investigate whether they acted in the same way as the arrows in his initial findings. At first this appeared to be a possible set of experiments to carry out, but they were difficult to program and due to time constraints and the number of other experiments planned for the thesis they were not in the end used. They are outlined in Section E.4.

Finally, it was planned to test Wernicke's aphasics on the experiments on facial expression and eye gaze perception covered in Chapters 7 and 8. The reasons why these experiments were planned but did not eventually take place are explained in Section E.5.

One other note is that during the early stages of the thesis it was originally planned to test 4 prosopagnosic subjects, the three who were eventually tested, and also **MS**, who has been well documented (Heywood et al 1994). As well as being prosopagnosic, he is hemianopic, and for this reason some of these early pilot experiments tried to take account of the fact that he would not be able to carry out split-field tasks or tasks where he had to fixate in the middle of a visual stimulus, as any part of the stimulus to the left of his point of fixation would be in his blind field. In the end, however, **MS** was not tested and none of the experiments had to be rewritten for a hemianopic subject.

E.2 - Formal Eye-gaze Experiments Eventually Meant for Prosopagnosics

E.2.1 - Introduction

Campbell et al (1990) tested two prosopagnosic subjects on eye gaze direction perception, one of whom, **SS**, is tested further in this thesis. Both were found to be impaired, but to different extents. A 2AFC (two-alternative forced-choice) task was used, the subjects being instructed to choose the face looking at them out of two presented. Reaction times were not recorded. **KD** (who had a stroke at the age of 60) showed poor sensitivity to angular deviation at low deviations, e.g. 5°, but normal performance at higher deviations. **SS** (a developmental prosopagnosic, described in detail in Chapter 3), however, showed poor sensitivity at all angular deviations up to the tested 20°. It was in fact shown that head deviation was used to solve the task. **SS** was perfect at Benton's test of line orientation matching, identification of a target dot specified by the direction of a pointing arrow, and an 'odd-one-out' task for concentric circles. Some of this has already been mentioned in section 1.3.3. and will be covered again in Chapter 9 which discusses two experiments that were carried out to investigate the perception of eye gaze direction in normals and prosopagnosic subjects.

Their different impairments suggest a dissociation of eye gaze perception from other classical face perception processes, as suggested in models of face processing (see Section 1.4). For normal viewers, inverting the face only impairs accuracy of gaze detection when angular deviations are small. **KD**'s results at 5° fall within the results for controls with inverted faces, suggesting a small loss of configurational skill.

The normal results of **SS** on the visuospatial tasks suggest in the first instance that there is no visual deficit underlying the results of the eye gaze task. However, reaction times were not measured, and it is possible that, as has been found with certain other tasks of face matching, there is in fact a deficit that only demonstrates itself as an increase in processing time, and therefore reaction time, and not as a decrease in accuracy, whatever the duration. The aim of these experiments was to carry out various formalised visuospatial tests, including a dot in a circle task (like the pupil or iris in the eye), on prosopagnosics and normal controls, and to measure reaction times in order to determine if there is any impairment in visuospatial processing.

It would also have been interesting to see whether **SS**, a developmental prosopagnosic, shows different results on these tasks from all other stroke-related or accident-related prosopagnosics, as was found by comparison with **KD**, i.e. whether there is a link between developmental prosopagnosia and poor sensitivity to eye gaze. The original plan was to test the three prosopagnosics described in Chapter 3 on the following tasks. However, in the end only three control subjects were tested.

A second and linked question is the nature of the cues which are used in determining eye position. Is it the disruption of these cues which account for poor eye gaze perception in prosopagnosics such as **SS**, or the disruption of a more general face processing mechanism? Possible cues for eye gaze perception include:-

- the shape of the iris, which becomes both more elliptical and more deformed as its deviation is increased;
- the position of the iris relative to the centre of the eye;
- the progressively larger asymmetry of the white of the eye as the deviation increases;
- the fact that when an eye is looking in the periphery, some of the iris is occluded by the eyelids so the shape of the iris changes even more.

Baron-Cohen (1994) has suggested that the d:w (dark : white) ratio is important in determining the direction of gaze. This ratio specifies the relative geometry of the dark iris and the white sclera which surrounds it. If this is the case, then prosopagnosic subjects such as **SS** who appear to be able to do odd-one-out tasks for stimuli which look similar to eyes ought to be able to determine the direction of eye gaze as well as controls: the evidence does not support this view, suggesting that the perception of eye gaze direction does not rely solely on visuospatial abilities and the determination of the d:w ratio.

The aims of this set of experiments were to determine firstly whether the difficulty which some prosopagnosics have in perceiving angle of regard is due in fact to poor pattern discrimination, and secondly to investigate the cues used in determining eye position.

Firstly, Experiment E.1 was designed to measure baseline simple reaction times, so that any general cognitive impairments could be detected in the prosopagnosic patients. This is the only experiment outlined in this appendix which was used in the main body of the thesis, being covered in Chapter 4.

In Experiment E.2, the subject was asked to decide whether or not a dot was centred in a surrounding circle. This was thought to be preferable to the odd-one-out paradigm, as the deficit in eye gaze actually occurs in the absence of a comparison stimulus. A single stimulus was used, centred on the midline. Reaction times (RT) to state whether the dot was centred were measured, as good performance in terms of accuracy does not imply unaffected processes, which might be slowed markedly. A 2AFC paradigm was used, the question being, 'Is the dot in the centre of the circle?'. The offset of the dot was graded so that the minimum detectable offset could be determined.

Subsequent experiments (E.3 to E.6) added more features to the visual stimulus to make it appear more like an eye. Experiments E.7 and E.8 are control tasks requiring a similar degree of spatial discrimination but not using stimuli reminiscent of eyes.

E.2.2 - Procedure

On the following tasks three right-handed subjects were used, **P**, **B** and **S**. Both **B** and **P** (the experimenter) were experienced in carrying out reaction time tasks, whereas **S** was a naïve subject as far as such tasks are concerned. All 3 were graduate students at the time.

Firstly, a measure of simple reaction time was carried out - this became experiment 4.1 already covered in the previous chapter.

A number of 2-alternative forced choice (2AFC) tasks (Experiments E.2 to E.6) were then carried out, in which the subjects had to decide whether a small filled circle was centred in a larger circle presented at the visual midline. In each subsequent task the stimuli looked more eye-like and in the latter tasks the subjects were told that they were rudimentary drawings of eyes, and they had to decide whether these 'eyes' were looking at them or not. For all of these tasks the stimulus was presented until the response button was pressed. The subject responded as quickly as possible, using a bimanual response, pressing one button for 'yes' and the other button for 'no' responses. The buttons used are those outlined in Section 3.3.2. The reaction times and errors were recorded. Blocks of 60 trials were carried out, where the 'centred' or 'looking at you' response was required on 30 of them, and there were 3 trials for each of the other 10 offsets, in a similar fashion to Experiment 8.1.

When the eye is rotated the iris changes from a circle to a deformed ellipse. This was modelled using a drawing package and the 2D shape of a circle on the surface of a sphere which then rotates.

Could this change in shape to being more elliptical be a cue for eye position? If so, then we must be good at discriminating between circles and ellipses, and to test this a tachistoscopic discrimination test between a circle and an ellipse was carried out (Experiment E.7).

Some of the tasks described in this section involve deciding whether a circle is exactly in the middle of another circle. Two control tasks were carried out (Experiment E.8), investigating subjects' acuity in bisecting short lines, in which they were asked whether a mark was in the centre of the line. This was carried out both with horizontal and vertical lines. The main reason for using vertical lines in addition to horizontal ones is that **MS**, who was at this stage expected to be tested, would not be able to bisect horizontal lines easily due to his left field hemianopia.

E.2.3 - Results

Each subject performed a number of blocks on each experiment and reaction times and (where applicable) error rates were measured. This summary will not contain any statistics, just overall trends and values. It should be noted that all reaction times noted are medians and not means, and that only reaction times for correct responses were used in the calculation of these values, the method used in the remainder of the thesis. The reaction times for any displacements of the inner circle with an error rate greater than 75% were not calculated.

Experiment E.1

This experiment measured the simple reaction time (RT) to respond to the presentation of a circle on the computer screen, obtained by pressing two buttons, one in either hand, and the RT taken as the moment when the first button was pressed. The delay before each presentation (interstimulus interval - ISI) varied between 0 and 1800 ms (+35 ms drawing time for the stimulus) and there were 6 trials for each ISI per block, giving a total of 60 trials per block.

All three subjects completed 240 trials. All three sets of data showed the highest RT for an ISI of 0 ms and then a consistent decrease in RT up to an ISI of about 800 ms. Thereafter there was little more decrease in RT. The median RT for the subjects for trials with ISIs of 800 ms or over was also worked out, as this value can be taken as a baseline RT for the other experiments where there is an ISI of 1.5 seconds. These values ranged from 175.5 ms to 197.0 ms with an overall median of 189.0 ms. The median RT for all data points with 0 ms ISI was 282 ms.

Experiment E.2

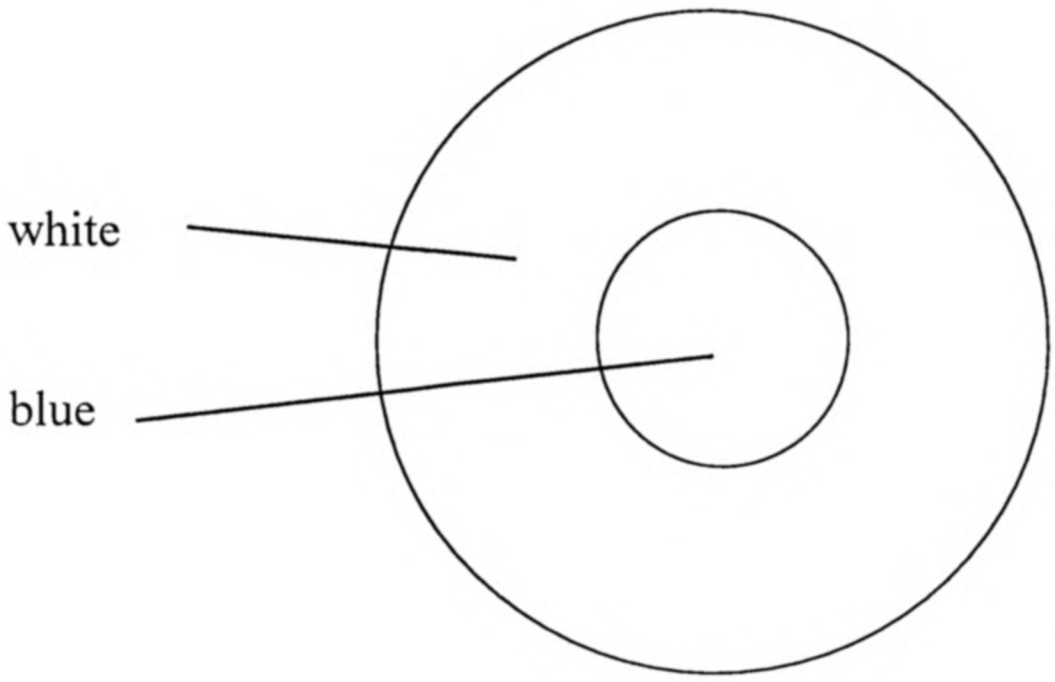
This experiment concerned the judgement as to whether a small white circle was centred in a larger white-bounded black circle. On half the trials the smaller circle was centred, and in the other half the smaller circle was offset by 2, 4, 6, 8 or 10 pixels either to the right or left (only horizontal offsets were used). In each block, 30 trials were centred and 3 trials were presented for each of the 10 offset amounts. The subjects pressed one button for 'centred' and the other for 'not centred'. **S** and **P** used their dominant hand for 'centred' responses - **B** used his non-dominant hand for 'centred' responses.

All three subjects generally made more errors for smaller offsets, and this was more prominent for a negative offset (the small circle shifted to the left) than for a positive one (shifted to the right). For a shift of 2 pixels to the left, all subjects made at least 75% errors, whereas for a shift of 2 pixels right, none made over 60% errors. The average error rate for the three subjects varied between 10.8% and 12.9%.

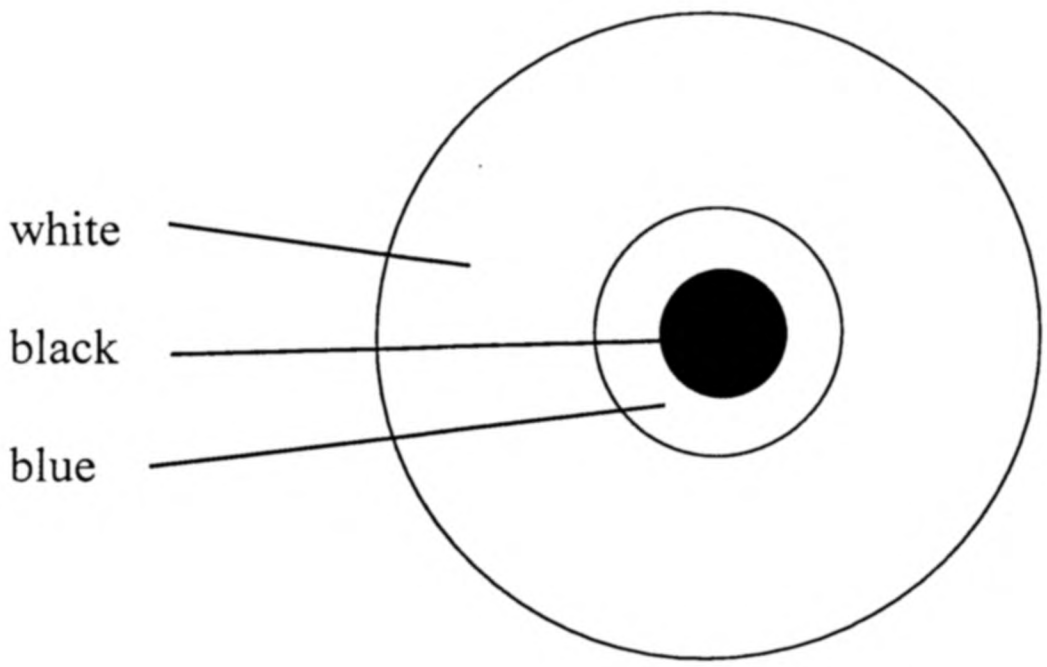
The RT for making the judgement increased as the offset was decreased, for both a positive and a negative shift. The time taken for a correct 'centred' response was slightly above the median RT for all correct responses combined for each subject: this was extrapolated as roughly the time taken to respond to a trial with an offset of between 3 and 4 pixels. **S** was generally quicker but he had

been tested on a different computer using a different version of the program, which might have been the source of some differences. Indeed, this "discovery" highlighted the pitfalls in measuring RTs with raster displays and the computer's clock. To take this difference into account, 17 ms were added on to each data point of his to counteract one particular change in the program between versions. The median RTs varied between 390.0 ms and 515.5 ms for the three subjects.

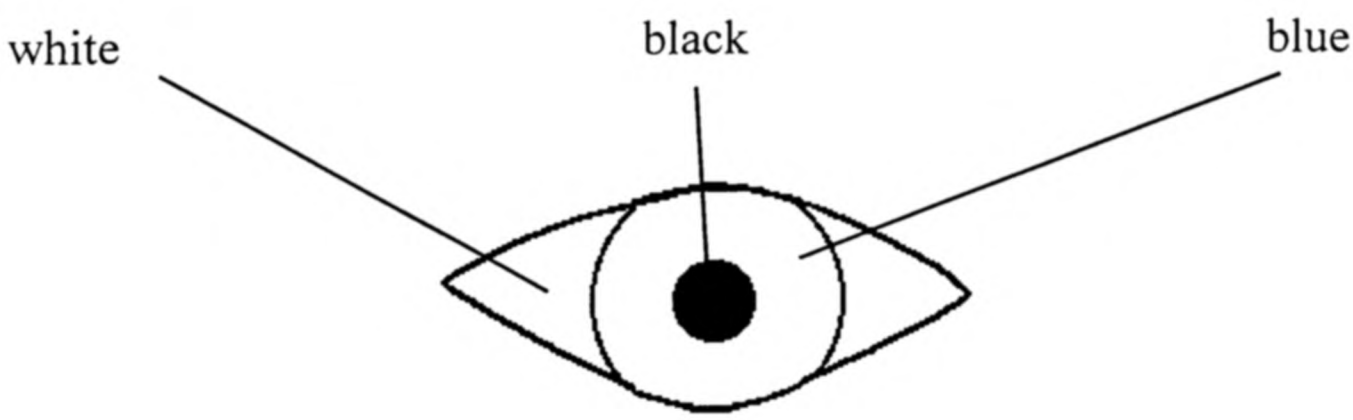
The possibility of a practice effect was investigated: **B** did 5 blocks and firstly all 5 and then the last 4 were analysed. There was virtually no difference between the results of these two analyses (515.5 ms to 515.0 ms and 12.7% to 12.5% errors). This indicated that he was performing the first block at a similar level of performance to the later blocks. Also, all blocks contained 6 trials at the start for practice, the results of which were not recorded.



Experiments E.3, E.4



Experiment E.5



Experiment E.6

Figure E.1 - Diagrammatic stimuli for some of the Experiments in Appendix E

Experiment E.3
This experiment was very similar to Experiment E.2 but the stimulus was now a blue circle on a white background. Stimuli for this and some of the following experiments are shown in Figure E.1. Also, the background was no longer a circle but a sphere and the blue circle plotted as if it were rotated around the surface of the sphere. This gave a maximum offset of 10 pixels as in Experiment E.2 but the actual blue circle was now slightly deformed at greater offsets. The subjects were given identical instructions as in the previous experiment and were not told that the stimulus was a sphere. Only **S** and **B** participated in this experiment, and only completed 120 trials each.

The results were fairly similar to those of Experiment E.2 although the RTs were slightly faster (347.0 ms to 494.0 ms). Again **S** was tested on a different computer so his RTs are not really comparable to those of **B**. The error rates were also very similar to those in Experiment E.2. Both the error rates and the RTs appear better (i.e. lower / faster) on the positive (rightwards) offset trials than the negative (leftwards) ones. Again the error rates for 2 pixels shifted leftwards were over 75%.

Experiment E.4
This experiment used exactly the same stimuli as Experiment E.3 except that the instructions differed: subjects were told that they would be shown very simple models of an eye which was either looking at them or not looking at them, and they were instructed to press the 'centred' button if it was looking at them, and the 'non-centred' button if not. Again **S** and **B** did 120 trials, and for this experiment **P** did 240 trials.

Note that there is an inherent problem, in that as **P** was the experimenter (i.e. myself) who therefore planned the experiments and decided which strategies were being investigated, the different instructions, issued by me, were not necessarily likely to produce a different (and the required) strategy. However, I did believe that in Experiment E.4 I was basing my decision on whether the rudimentary 'eye' was looking at me or not; of course, this belief was based on introspection. Testing myself on experiments where the instructions are important in the response strategy they are intended to produce is far from ideal. If these experiments had been continued for the thesis as a whole, my results would of course not be included.

The overall median RTs for **S** and **B** were not very much changed from Experiment E.3 - slightly more so for **S** (23 ms longer). **B**'s median RT for 0 offset was virtually unchanged, but **S**'s was increased by almost 50 ms. Error rates appeared marginally lower, with no RTs having to be discarded due to unacceptably high error rates. **P**'s results were noticeably smoother as he did twice as many trials, and his results were overall slightly worse than those for Experiment E.2, unlike those of the other two subjects.

Thus there does not appear to be any systematic change in the results between Experiments E.2, E.3 and E.4. However, there might be more of a variation if subjects were tested with higher offsets, as at this level of offset, there is very little difference in the stimulus between the case when a circle within a circle is displayed, and the case when a circle on a sphere is displayed. Also, relatively few trials were carried out overall, and more trials would be needed to produce more robust results.

Experiment E.5
The stimuli in this experiment were those of the previous experiment plus a black 'pupil' which was positioned in the blue 'iris', and whose diameter was slightly greater than the radius of the 'iris'. The 'iris' offset was the same as that of Experiment E.4.

All three subjects did this experiment. When all the results were combined, the median RT and error rates appeared to be in fact a little worse than for Experiment E.4 (+20 ms, +1.2% errors), although the subjects said that the stimulus looked more like an eyeball than in Experiment E.4. However, it is important to note that comparison of **S**'s results for Experiments E.2, E.3, and E.4 with Experiment E.5 is not entirely feasible due to the different programs and computer used. Thus the RTs were unaltered for **B** and lowered for **P** (20 ms) but increased by 180 ms for **S**. Reliable comparison with **S**'s data would require **S** to redo the earlier experiments on the later version of the program on the correct computer.

Again there were more errors for a leftwards looking eye than for a rightwards looking one. One interesting questions is whether this would be reversed in left-handers: this was not investigated in this thesis.

Experiment E.6

In this experiment the stimuli were now much more reminiscent of eyes, as the eyeballs were bounded by two arcs - 'eyelids'. Also, a highlight was added to the eye as if there were a light source behind and to the right of the subject - the position of this was calculated roughly and moved relative to the eye when the eye was rotated.

This experiment was carried out in two versions. In the first, the stimulus appeared in a different location (in the central area of the screen) in each trial. Both **S** and **B** showed increased RTs (medians up by 119 ms and 79 ms respectively) compared to the previous experiment and also slightly higher error rates (by 2%). **P** showed a marginally decreased RT (by 19 ms) but at the cost of a greater increase in error rate (up 4% to over 18%). **P** completed twice as many trials as the other two subjects so his results were smoother. There does not appear to be any consistent difference in RT results between leftward and rightward looking eyes, although there are more errors for leftwards looking eyes, especially at the smallest offset.

Possibly the increase in RTs arises because a 'centred' judgement may still have been used in Experiment E.5 but is now less accessible. The eye is drawn such that the iris (when looking straight ahead) is centred such that the white areas on either side are equal - this of course is not so in a real eye: eyes are not symmetrical with respect to their shape, as they are narrower on the nasal side. The fact that the eye was not displayed in the same position on each trial meant that the subjects probably found it more difficult to use a centred judgement. This was tested in the second version of this task. In this second version, the stimulus appeared in exactly the same place on the screen in each trial. This resulted in decreased RTs and error rates, down to roughly the values for Experiment E.5. This version was tried out because the subjects complained that to tell whether an eye was looking at them or not (when not in the context of a face or another eye) it was much easier if the eye were exactly facing them and therefore in the same place on each trial. The ISI was long enough to remove any after-image or iconic memory effect for comparison of stimuli from trial to trial. This suggests that the random positioning of the stimulus from trial to trial had contributed to the longer RTs and higher error rates.

Experiment E.7

In this experiment the subjects had to determine whether the stimulus displayed was a circle or an ellipse (stretched or contracted in the x direction). The y radius was 60 pixels and the x radius varied from 45 to 75 pixels in steps of 3 pixels. There were some problems with this experiment due to the fact that the screen is not flat and therefore whether a circle on the screen really looks like a circle to the human eye. An additional problem lies in the ability to alter the vertical size of the screen, thus altering the ratio of the horizontal to vertical size. This was realised some time later, and a stimulus which was programmed to be a true circle (60 pixels wide in each direction) was measured using tracing paper and a ruler. It was found to be 50 mm by 47 mm, and thus not

circular. However, it is not known whether the V-size control had been altered between original testing and this measurement and also whether the ageing and partial breakdown of the monitor had contributed to a change in the horizontal-vertical ratio. Therefore it is not possible to be sure that a programmed circular stimulus at the time of testing was in fact circular (see **S**'s results below).

P and **B** both completed 240 trials and showed similar results in that the RT increased with a decrease in offset (the distance in which the stimulus was stretched or contracted in the x direction from being circular), but **B** had a slower median RT and **P** showed a smaller increase in RT for a stretching than for a contraction. In both cases, however, there were consistently more errors made for a stretching than for a contraction.

S, however, showed different results and reported a different subjective experience. He first completed 120 trials when he responded to how it looked. He made no errors for a contraction, 5 out of 6 errors for both of the smallest stretches and over 80% errors for those trials on which circles were displayed. Thus he saw the stimulus which in fact had a y radius of 60 and an x radius of 63-66 as a circle.

He was informed of this and then instructed to respond on the basis of whether the stimulus was a circle, not whether it looked like a circle. In other words he learnt which stimulus required the response 'circle' and responded accordingly. He now made a total of 7.5% errors (down from 50%) and only 2 out of 30 errors for the circles. Also, perhaps surprisingly, his median RT decreased, although both sets of results were rather noisy as only 120 trials were done for each. Again, most of his errors were made on those trials with stretching, not contraction.

S carried out this task by learning which stimulus was in fact a circle and remembering it for the purposes of this experiment. The pattern of errors which all three subjects made together with the strategy that **S** had to use suggest that in fact the 'real' circle looks squashed and that the smallest stretching in fact looks circular. **S** also pointed out that whether a stimulus looked circular or not sometimes depended whether he was looking at the right or the left half of the circle. **S** is by profession (now, in 1997) a theatrical set designer and artist, and his visual perception and drawing skills are excellent; this may have contributed to his being able both to tell that the stimulus which was programmed to be a circle was in fact slightly contracted by the curvature of the monitor screen and possibly different horizontal and vertical ratios in the display, and to learn which stimulus required the response 'circle' with little difficulty.

Experiment E.8

This task involved the bisection of a horizontal line the same length as the diameter of the circle in Experiment E.2. This was to investigate the ability of the subjects to say whether one thing is in the middle of another using stimuli which are not in the least reminiscent of eyes. Line bisection is a widely used means of assessing visual hemi-neglect and visual distortion. The line's position was varied from trial to trial. The lines were 140 pixels long for both this and the next experiment (vertical line bisection).

All three subjects completed 240 trials. They all showed a greater error rate for a positive (rightwards) shift of the bisecting line than for a negative (leftward) one, unlike Experiment E.2. The RT data were not particularly smooth, but combining them for the three subjects showed a general increase in RT with a decrease in offset, as expected. **P**'s median RT was about 150 ms faster than either of the other two subjects, who showed similar overall medians but fairly different raw data to each other. The error rates varied from 15% to 19%, compared with 10% to 13% for Experiment E.2. All three subjects made more errors and were slower than in Experiment E.2, suggesting they found the line bisection task more difficult than the centred circle task.

One of the subjects suggested that it might be easier if the line being bisected were made longer. The effect of line length is investigated in Section E.3.

Experiment E.9
This experiment was similar to Experiment E.8, but the line being bisected was vertical rather than horizontal. It was placed slightly to the right of centre screen and (like Experiment E.8) moved between trials. This was done because one of the prosopagnosic subjects I hoped to test, **MS**, is, as previously mentioned, hemianopic and therefore fixates a few degrees to the left of what he wishes to look at. The subjects were not, however, instructed to fixate to the left of the line. In the end, **MS** was not tested.

Again all three subjects completed 240 trials each. Their error rates were very asymmetrical - many more errors were made by all three for an upwards shift than for a downwards one. The RT data were fairly similar to those in the previous experiment (**S** was a little slower, **P** was a little faster) but the error rates were higher (17% to 27%) for **P** and **B**. Note that **S**, although slower, made 2% fewer errors than in Experiment E.8, whereas the other two subjects made 9% to 12% more errors. The error rates were over 75% for the smallest two offsets upwards for all three subjects and the smallest one downwards for subjects **P** and **B**.

Overall, this was a harder experiment than Experiment E.8. This cannot readily be explained by the fact that our eyes lie side by side on the horizontal plane, not in the vertical plane, as this would improve our ability to determine horizontal distances in 3-D depth, due to disparity, but should not help in a 2-D display such as this one where the stimuli are placed frontally. The influence of binocularity in this experiment could be tested by covering one eye and seeing if there was still a difference in the results between the two tasks (horizontal and vertical line bisection). This was not done because this experiment was investigating a side issue which was not followed up.

E.2.4 - Discussion
Apart from Experiment E.1, the remainder of the tasks described in the above section were not followed up with either more controls or prosopagnosic subjects. The main problem with many of the tasks was the spatial non-linearity (in addition to the brightness non-linearity) of the computer display to the extent that when certain stimuli were presented their perceptual representations were different. This was illustrated very clearly in Experiment E.7 by subject **S** who performed markedly differently depending on whether he was responding to how the stimuli looked or how he thought they were meant to look. After investigation it was found that there was not at that time an available monitor of the advanced technology needed to show precise spatial patterns to the precise pixel with no distortion - a flat-screen monitor, for instance. Therefore it was decided at the time to continue other experiments concerned with large-scale stimuli, such as face matching, which did not rely on the absolute absence of any distortion. These new experiments took over and also it was realised that as I would have a very limited time in which to test the prosopagnosic subjects, it was best to restrict the number of experiments in which they were to participate. Therefore these experiment were not continued.

E.3 - Judgement of Line Lengths
E.3.1 - Introduction
One of the earlier experiments carried out (Experiment E.9) investigated the bisection of a vertical line as a control experiment for the bisection of a horizontal line. The same three subjects as in the previous section participated in it, **P**, **S** and **B**. All three subjects were found to make more errors and have longer reaction times when the bisecting line was displaced above the midpoint compared to the trials where the bisecting line was below the midpoint. This suggested that the perceived

midpoint was in fact above the real midpoint, i.e. that there was perceptual enlargement of the upper visual field. If this was the case, why reasons could be put forward to explain it?

People generally look below the horizontal rather than above it because it is usually the ground that is being scanned rather than the air. If a person looks at two identically sized objects which are lying in a straight line away from the viewer on the ground, fixating on the point where their ends meet, then one object falls in the upper visual field and the other in the lower visual field. The object in the upper field, being further from the eye, casts a smaller retinal image then the object in the lower field, yet the viewer perceives the two objects to be the same actual size - i.e. he shows perceptual enlargement of the upper visual field. This is a cognitive theory of the kind put forward by Richard Gregory (e.g. Gregory 1980), and relies on the idea of size constancy.

To test whether this is indeed the case, an experiment was carried out in which two vertical lines, one above and the other below a fixation point, were displayed and the subject had to say which, if either, was the longer. If there were indeed perceptual enlargement of the upper field, there would be more errors on the trials in which the lower line was slightly longer, than those in which the upper line was slightly longer.

E.3.2 - Method

In each block there were three line lengths used, the middle being 100 pixels long, and the longest being one of 120, 115, 110, 105 or 102 pixels long : the shortest was calculated such that the ratios of long:middle (l:m) were equal to the ratios for middle:short (m:s), and were thus 83, 86, 90, 95 or 98 pixels long. All possible combinations of the three lines were used giving rise to 9 trial types; in three of which the lines were the same length (s:s, m:m, l:l), in another three the upper line was longer (l:m, l:s, m:s) and in the last three the lower line was longer (m:l, s:l, s:m). There were 5 trials of each in each block, giving 45 trials in all. **P** completed 4 blocks for each set of line lengths, and **S** and **B** completed 2 blocks for each.

In each trial, a fixation point appeared in the centre of the screen for 500 ms. The lines were then presented for 200 ms. There was then a delay of 600 ms and then a warning beep occurred for 75 ms. After this the subjects were free to answer. The response was manual, using three computer keyboard keys. Thus reaction times were not collected, only error rates, and the warning beep was to stop the subjects answering until they were as sure as they could be.

E.3.3 - Results

The results were calculated for the three subjects separately.

P Forty trials for each trial type for each set of line lengths were carried out. The overall error rate was 27.4%. Generally there was a greater error rate (41%) when the lower line was longer than when the upper line was longer (23%). There was a slightly lower rate when the lines were the same length (18%). Of the errors when the lines were the same length, for 70% of them the response given was that the upper line was longer. Both these types of errors suggest that there is indeed perceptual enlargement of the upper field (and hence perceptual reduction of the lower field). Not surprisingly, as the difference in the line lengths decreased, the error rates increased from 11% errors for 120:100:83 pixel lines to 54% errors for 102:100:98 pixel lines. There were fewer errors on those trials where the lines were long and short (i.e. a larger length difference) than when they were long and middle or middle and short. For those trials where the lines were of the same length, there was little difference but fewer errors when the lines were both short than when they were both medium or long. This could be because in such cases the overall display is smaller and the whole stimulus can be seen more easily - i.e. the far ends of the lines are not at such a great eccentricity.

S Twenty trials for each trial type for each set of line lengths were carried out. In this case, however, there was a greater error rate (27%) for the trials where the upper line was longer than when it was shorter (14%). The highest error rate was for the trials where the lines were of the same length (32%). This is the opposite to **P**'s results. There were only half as many trials carried out but the pattern of results was consistent over all the sets of line lengths. Again, a smaller length difference led to a greater error rate. The error rates increased from 9% errors for 120:100:83 pixel lines to 48% errors for 102:100:98 pixel lines. Again there were fewer errors on those trials where the lines were long and short (i.e. a larger length difference) than when they were long and middle or middle and short. There was not as large a decrease in the number of errors for the 'same' trials as the lines decrease in length as for **P**. Of the errors when the lines were the same length, for 74% of them the response given was that the lower line was longer. Both these types of errors suggest that there is perceptual enlargement of the lower field.

B Twenty trials for each trial type for each set of line lengths (except 110:100:90) were carried out. This set of results is less clear. Again, as for **S**, there are fewer data but the pattern of results is not consistent. For the 102:100:98 and 105:100:95 cases there were more errors when the upper line was longer, as for **S**, but this was not so for 115:100:86, where there was no difference between the response types, or 120:100:83, where there were more errors when the lower line was longer, but here there is a ceiling effect, with no errors being made. When the data were combined, there was found to be a slightly higher error rate (40%) when the upper line was longer than when the lower line was longer (32%). Unlike **S**, **B** made fewer errors when the lines were the same length (21%). A total of 64% of the errors on 'same trials' were for responding that the lower line was longer. So this subject shows weak perceptual enlargement of the lower field.

E.3.4 - Discussion and Conclusion

Only one of the three subjects showed perceptual enlargement of the upper field, and when he completed a number of blocks on a later occasion he failed to replicate convincingly his earlier data. There are a number of possible reasons why the experiment may have failed to confirm the hypothesis, most of which are due to faults in the experimental design.

Firstly, the distance between the ends of the lines and the fixation cross was not kept constant from trial to trial but was randomly assigned between 35 and 45 pixels from the fixation cross; moreover, the distance between one line and the cross was not necessarily the same as the distance from the other to the cross. This could have been a distracting aspect of the experiment, and the subjects might unconsciously have decided that the shorter line was the one nearer the cross. A version where the lines are a constant and equal distance from the cross was to have been tested as the next step.

Secondly, the position of the screen was not kept constant, either with respect to the position of the subjects' heads or with respect to the vertical. In other words, the tilt of the screen was not taken into account. If it were tilted then one line would seem shorter and / or further away already and this would confuse the issue of whether there is a perceptual enlargement. This would have to be investigated by running several blocks where the angle of the screen was an independent variable.

Finally, it has since been discovered that the computer screen being used shows a non-linear, non-symmetrical distortion of length in itself (as shown in Experiment E.7). This is not very severe, but may again have confused the data collected for trials where there was already little difference in the line lengths. To rectify this, a better computer screen would be required.

Thus at this stage it is not possible to say whether there is in fact perceptual enlargement of the upper visual field. No more investigation was conducted on this topic.

E.4 - Posner Cueing Task

As has already been mentioned in Chapter 1 and will be covered in more detail in Chapter 8, eye gaze sensitivity is important to humans and primates for a number of reasons, including in social situations and also as an indication of the referent of a conversation: we often look at or towards whatever we are talking about to aid comprehension.

I was interested whether, when someone's eyes are being viewed, a shift in that person's eye gaze to a third object would cause a shift in the viewer's eye gaze towards the same direction - in other words, whether an eye gaze shift produces a complementary oculomotor orienting response in the viewer.

Posner and his colleagues (e.g. Posner and Cohen 1984) have showed that a peripheral cue causes an automatic shift of attention, either covert or overt (with a corresponding eye movement). The method they used involved the subject's centrally fixating and then a cue was given in a peripheral location, followed after a variable interval by a target, either in that position (the cue is termed valid) or on the opposite side (the cue is termed invalid). Reaction times were measured for detecting the target, either after a covert shift in attention, usually by means of a manual response, or after an overt shift in attention, whereby the saccade to the target was the response measured. Typically, when 80% of the trials are valid and 20% are invalid, reaction times are faster for valid trials than neutral trials (where there is a temporal cue but no spatial cue) and slower for invalid trials compared to neutral trials. The difference in reaction times suggests that this shift in attention cannot be suppressed, because if it were possible to do so, then invalidly cued trials should be no slower than neutral trials. Also Posner found inhibition-of-return - it took longer to return attention to a previously incorrectly cued location if the cue-target interval was longer than about 600 ms. This is likely to be useful in visual search and visual scene scanning, increasing its efficiency by lessening the likelihood of perseveration or returning attention to a previously inspected area immediately after leaving it.

Posner and colleagues (e.g. Jonides 1981) then repeated the procedure using, instead of a peripheral cue in the same (or opposite) position as the target, a central cue of an arrow pointing in the direction in which the target was due to appear, again valid 80% of the time, and invalid 20% of the time. The results again showed that validly cued trials were faster, but this time there was no inhibition-of return to an invalidly cued position.

My question was whether a pair of eyes would work in the same way as a central cue, facilitating an attention shift to the cued side. To test this, experiments were planned in which reaction times would be measured for the subject to respond to the presence of a visual target such as an **X** in either the right or left visual field after first seeing a pair of eyes at fixation, which are looking either forward (a neutral cue) or to one side (either a valid or an invalid cue depending on whether they are looking at the subsequent target position or not). Eventually it would be preferable to have the eyes looking at the targets rather than in their general direction so two LEDs in depth, in front of the computer monitor would be used. For the first study, **X**s on screen were to be used.

Two hypotheses were to be tested. The first was that if the eyes are looking in the direction in which the **X** occurs, then the RT should be lowered compared to the trials in which the eyes are looking in the opposite direction. This is very similar to Posner's tasks using the eyes as a central cue, assuming that the eyes would work in a similar way to the arrow.

The second hypothesis was that the eyes shift attention automatically to an extent, unlike typical central cues but like peripheral cues. This was to be tested by manipulating the percentage of valid trials and also the cue-target interval to investigate inhibition-of return.

Two types of cue stimuli were also originally planned. The first type would be a pair of eyes looking forward or to one side which would be displayed statically. The second type would be forward pointing eyes which would then move to one side - this was likely to be much harder to program, necessitating some form of video presentation. The reasoning behind this type of stimulus was that it is often the movement of someone's eyes rather than their position that causes us to move our eyes in order to see what they are looking at.

Early versions of these programs were written but no subjects were tested. A fixation cross was displayed in the centre of the screen for 750 ms, followed by a blank screen for 150 ms. Then the eyes were to be displayed in the centre and after a variable delay the target **X** displayed in one visual field. The reaction times were to be measured using a similar bimanual response to that used in Chapter 4, Experiment **4.1**. In order to prevent anticipation, 80% of the trials would be valid, with the remainder invalid or neutral. In a second experiment, in order to investigate the possible existence of inhibition-of-return, 80% would be invalid, with the remainder valid and neutral, to see whether the subjects could ignore the cues.

What was needed for this experiment was pictures of human eyes looking in three different directions, and possibly in later versions of the experiment whole heads where the heads and eyes were not necessarily facing the same directions. At this stage of the thesis I had no access to a digitising camera that would allow me to use real scenes or real photographs for computer presentation using the TurboPascal procedures, and when I did subsequently obtain such images (for the experiment in Chapter 8) there were too many other experiments to complete to return to these. However, they are still potentially of interest, especially with respect to Baron-Cohen's theories about the eye direction detector and shared attention mechanism (Baron-Cohen 1993, 1994, Baron-Cohen et al 1995).

E.5 - Wernicke's Aphasics

One thing that I hoped to do was to test a group of Wernicke's aphasics on the experiments outlined in Chapters 7 and 8, in addition to the group of prosopagnosic subjects who were tested. The reasons for this are outlined in the Introduction to Chapter 7. However, it was not possible to gain access to any Wernicke's aphasics in time and this remains a possibility for future research.