Interhemispheric Communication During Face Perception

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Abstract

It is widely acknowledged that the cerebral hemispheres do not operate in isolation during the processing of complex visual stimuli. Patterns of interhemispheric communication are believed to be integral to cognitive abilities yet despite this, both the circumstances under which communication takes and the nature of the information that can be communicated remain relatively poorly understood. The experiments in this thesis address the nature of interhemispheric communication during the processing of face and identity information using a range of divided visual field paradigms. The first line of enquiry explored the nature of identity information that can be communicated interhemispherically. Specifically, the aim was to establish whether abstract identity driven collaboration could be achieved with stimuli denoting the same concept or if cross-hemispheric communication is restricted to more low-level, stimulus driven interactions. Further studies examined the impact of task difficulty on interhemispheric communication and whether dividing identity related cognitive processing between both hemispheres was more beneficial to performance than constraining to one. The main findings indicate that both conceptual identity information and superficial image characteristics can be communicated across the hemispheres for familiar but not unfamiliar faces. Results of enquiries into the benefits of dividing processing between the hemispheres were somewhat inconclusive leading to an exploration of the impact of capacity limits for face processing on the experimental paradigm. Evidence that interhemispheric communication may occur asymmetrically in the direction of right hemisphere to left hemisphere was also obtained. Findings are discussed within the context of existing literature and theories examining the processes of interhemispheric communication.

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Declaration

I declare that this thesis is my own work carried out under the normal terms of supervision.

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Publications

Experiments 3 and 4 of this thesis have been published in the following article:

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Contents

Chapter 1

General Introduction

1.1 Introduction

It has long been established that functional asymmetries exist between the cerebral hemispheres. Broadly speaking, for most right-handed individuals, verbal and linguistic abilities are attributed to left hemisphere (LH) function, whereas non-verbal, visuo-spatial operations, in particular face processing, tend to be attributed to the control of the right hemisphere (RH). Although such laterality of function is undoubtedly fundamental to the architecture of the human brain, for many tasks, dominance of function is believed to be relative rather than absolute with significant communication occurring between the hemispheres. These dynamic interactions occur primarily through the corpus callosum and may be involved with fundamental processes such as the modulation of attention and the unification of perception, thought and action. Indeed, interhemispheric communication is thought to be central to many cognitive processes, with patterns of interaction altering over a lifespan. These changes in hemispheric function are therefore capable of providing valuable insights into both developmental (Banich, Passarotti, Nortz & Steiner, 2000; Banich, Passarotti & Janes, 2000) and ageing processes (Reuter-Lorenz & Stanczak, & Miller, 1999; Cabeza, Anderson, Locantor & McIntosh, 2002). In addition, the pivotal nature of interhemispheric communication to cognitive function has been highlighted in cases where disruptions to this process occur. For example, atypical interhemispheric communication has been associated with a number of conditions (e.g. schizophrenia) and in particular the related attentional difficulties with these disorders (David, Minne, Jones, Harvey & Ron, 1995; Mohr**,** Pűlvermuller, Rockstroh, & Endrass, 2008).

Anticipating patterns of hemispheric interaction based on the manner in which each hemisphere operates in isolation is not a straightforward process. For example, while the RH is known to play a dominant role in face processing, it has become increasingly evident that input from the LH is also crucial. Indeed, LH damage alone can be sufficient to significantly impair face-processing systems (Benton, 1980), although a complete disruption of face identification (prosopagnosia) appears to require damage to both hemispheres (Damasio, Damasio, & van Hoesen, 1982). Attempts to more clearly define this combined hemispheric input to face processing have led to the suggestion that the RH may store identity information in a relatively image-dependent manner, in contrast to a more image-independent contribution by the LH (Cooper, Harvey, Lavidor & Schweinberger, 2007). Relative functional dominance therefore appears to offer a more appropriate reflection of hemispheric function. Although the exchange of information between the cerebral hemispheres is seemingly at the heart of many congnitive processes, full understanding of the mechanism and purpose of this interaction, particularly in relation to face and identity information, has yet to be acheived. Greater insight into the underlying nature and process of interhemsispheric communication may therefore help bring about a more complete understanding of the role interhmispheric communication in cognitive processing.

1.2 METHODS OF INVESTIGATING INTERHEMISPHERIC COMMUNICATION

Numerous aspects of interhemispheric communication have been studied in recent years using a variety of different approaches. For example, some major lines of research have focused on the effectiveness of dividing cognitive processing between both hemispheres, exploring interference effects between bilaterally presented stimuli and determining how the hemispheres will process multiple copies of the same stimulus. These different research focuses have resulted in the emergence of a range of different findings and experimental paradigms.

Divided visual field methodologies provide a non-invasive and accessible means of investigating these issues of interhemispheric communication. This technique was initially adopted by Dimond & Beumont, (1971) and typically involes presenting stimuli briefly to the left visual field (LVF), right visual field (RVF) or bilaterally to both visual fields (BVF). The organisation of the human visual system provides that information presented to a given visual field will initially be processed by the contralateral hemisphere. Through comparing patterns of results produced on unilateral and bilateral trials, a measure of hemispheric interaction can be obtained along with insights into whether this is collaborative or inhibitory in nature. The application of this experimental design has since formed the basis of many explorations into interhemispheric communication.

1.3 THE MODULATION OF COGNITIVE PROCESSES THROUGH INTERHEMISPHERIC COMMUNICATION

Establishing the impact of interhemispheric communication on the processing capacity of the brain has provided the focus of several lines of investigation. Typically this issue has been researched using a paradigm devised by Banich & Belger (1990), in which subjects view triangular visual arrays of three stimuli arranged round a central fixation point. The top two items in these visual trigrams are strongly lateralised to the left and right hemispheres while the third item is presented below these items in a position still lateralised, yet closer to the midline. Participants are required to indicate whether the bottom item matches either of the top two items (See Figure 1).

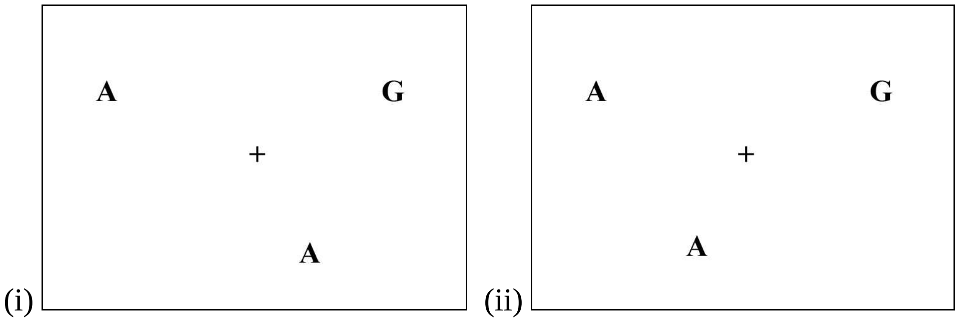

Figure 1: Example of (i) Across hemisphere match and (ii) Within hemisphere match trials.

On trials where the matching items are presented in the same visual field, within hemisphere processing is assumed while on trials where matching items are presented in opposite visual fields, interhemispheric interaction is deemed necessary in order to complete the task. No cues are given to participants to indicate whether the matching items will appear within or across hemispheres.

1.3.1 The influence of task complexity

Numerous studies have demonstrated that as task complexity increases, across field processing is advantageous to performance relative to within field (Banich & Belger, 1990; Merola & Liederman, 1990; Passarotti, Banich, Sood, & Wang, 2002; Weissman & Banich, 2000). Indeed, this finding has been shown to remain relatively stable, regardless of the extent to which a particular task is lateralised, provided that both hemispheres are capable of performing the task (Banich, 1998).

In a series of experiments, Banich & Belger (1990) explored the impact of task difficulty on interhemispheric communication. Performance on a letter-matching task demonstrated that across hemisphere processing improved performance for identity matches (e.g. A-a), yet had a detrimental effect following a less challenging physical match condition (e.g. A-A). It appears that the differing complexity of each task was responsible for this differential match-type performance on across hemisphere trials. Specifically, an analysis of letters on a perceptual level is sufficient for reaching a decision in the physical match task, yet in order to make a successful match in the identity match condition, an additional stage involving extraction of a case-sensitive letter code, must first be completed. The extension of this paradigm to explore the impact of task complexity on numeric processes corroborates these findings. It was shown that a within hemisphere advantage occurred for matching numeric digits on the basis of physical identity in comparison to an across hemisphere advantage for more complex numeric matches (Banich & Belger, 1990, Experiments 2 & 3). Numerous studies have since replicated this basic finding in which the benefits of across hemisphere processing are greater for more complex name identity tasks in comparison to those involving matching the physical identity of stimuli (e.g. Belger & Banich, 1998; Cherry, Adamson, Duclos & Hellige, 2005; Eviatar & Zaidel, 1994, Reuter-Lorenz, et al, 1999; Weissman & Banich, 2000; Weisman & Compton, 2003). Populations such as children and older adults also demonstrate benefits of across field processing, even at low levels of task complexity. Given that such individuals posses a reduced overall processing capacity, these findings provide a useful insight into the facilitative nature of interhemispheric communication to cognitive processing (Banich, et al, 2000; Reuter-Lorenz, et al, 1999).

Similar cross hemisphere processing advantages for complex tasks have since been observed for a wide range of stimuli and tasks involving letters, patterns, numbers, objects and faces (Brown, Jeeves, Dietrich, & Burnison, 1999; Koivisto, 2000; Liederman, Merola & Martinez, 1985; Weissman & Banich, 2000; Compton 2002). For example, increasing the number of letters in a display (e.g. Belger & Banich, 1998) and identifying two targets in an attentional blink paradigm (Scalf, Banich, Narechania, & Liebler, 2001) have all been shown to result in across hemisphere advantages. Moreover, when within and across hemisphere processing is manipulated to be equally possible, performance has been shown to resemble that of single hemisphere performance following simple tasks. However, as task complexity increases, a shift in performance to mirror that of both hemispheres is observed (Weissman & Banich, 2000). Such a finding offers compelling evidence in support of the flexibility of interhemispheric communication to meet the processing demands of a task.

The results of several neuroimaging studies also serve to corroborate the theory that interhemispheric communication is of particular benefit during complex tasks. Specifically, computational complexity in a task has frequently been observed to increase amounts of bilateral activity in comparison to less challenging tasks (e.g. Pollman, Zaidel, & von Cramon, 2003; Smith, Jonides, & Koeppe, 1996). There does however remain some debate regarding the issue of whether increased task complexity leads to an increase in the strength of existing bilateral activation or whether additional cortical regions are recruited (e.g. Dräger, Jansen, Bruchmann, Förster, Pleger, Zwitserlood & Knecht, 2004; Just, Carpenter, Keller, Eddy, & Thulborn, 1996).

Insight into the breadth of information that can be communicated cross hemispherically can be obtained from studies demonstrating a cross hemispheric advantage during semantic matching tasks. For example, using pictorial stimuli, Koivisto (2000) found that pictures belonging to the same category were categorised faster in bilateral, compared to unilateral, presentations. Moreover, for the less complex task of categorising visually identical stimuli, no performance advantage was observed for across hemisphere presentations. Less complex visual matching tasks were however processed more effectively within a single hemisphere. Such a finding offers further support to the idea that the processing of complex tasks benefits from the involvement of both hemispheres. In addition, evidence is also provided to suggest that non-image specific aspects of complex, higher-order stimuli can be communicated cross hemispherically.

Despite the reported performance advantages arising from interhemispheric communication, there is an associated cost with the transfer of information across the corpus callosum. Indeed, some interactions are thought to occur in the region of 100-300ms (Ringo, Doty, Demeter & Simard, 1994). It therefore appears that both the costs and benefits associated with information transfer must be assessed in relation to the computational complexity of the task in order to determine the benefit of interhemispheric communication (Banich, 1998). It has been suggested that when the capacity or resources of one hemisphere are overtaxed, additional cortical regions in the opposite hemisphere will be recruited to assist in the processing (Belger & Banich, 1992; Weissman & Banich, 2000). Consequently, the role of interhemispheric communication appears to be a dynamic one whereby the processing capacity of the brain is modulated by way of mediation from the corpus callosum (Banich, 1998). Evidence of this is reflected in the typical within hemisphere advantage observed following simple tasks. In such circumstances, the costs associated with transferring information across the hemispheres are too great to outweigh any benefits that may be received following input from both hemispheres. However, for more complex tasks, an advantage for across hemisphere processing will be observed if the associated costs of interhemispheric communication can be overcome.

While the benefits of interhemispheric communication for complex tasks may appear unambiguous, a distinction seems to exist in relation to the computational complexity of a task and the general task difficulty. For example, Weissman & Banich (2000), demonstrated that whereas low-contrast stimuli took participants longer to identify in comparison to high contrast stimuli, interhemispheric interaction was not shown to moderate this difference. It was argued that similar computational complexity between contrast conditions was responsible for this finding. Of greater importance to the benefits of interhemispheric communication appears to be the number of computational steps required to perform the task (Belger & Banich, 1998) combined with an individual’s prior experience. Indeed, patterns of interhemispheric interaction following practice appear to corroborate this theory (Liederman, et al, 1985; Weissman & Compton, 2003; Cherbuin & Brinkman, 2005). For example, Liederman et al, (1985) instructed participants to indicate whether two words presented either to the same or opposite visual fields, belonged to the same semantic category. Results revealed an across field advantage at the outset of the experiment which declined as the experiment progressed. With increased practice comes a reduction in the cognitive demands of a task. In turn, this should result in a similar decline in the requirement for additional neural recruitment. Not only does such a finding demonstrate the advantage of interhemispheric communication during complex tasks, but the dynamic nature of such interplay is also highlighted. Whether this shift in communication patterns arises as a result of a generalised practice effect or due to a change in processing strategy remains an issue for debate (Weissman & Compton, 2003; Cherbuin & Brinkman, 2005).

Instances do however exist in which cross hemispheric division of labour does not lead to processing advantages for complex tasks. For example, in an adaptation of the typical 3-item matching design described previously, Koivisto & Revonsuo (2003, Experiment 2) examined the impact of within and across field semantic categorisations of pictures, words and cross domain word-picture pairs. Results revealed that within-domain matches containing semantically related picture or word pairs were categorised faster in across field presentations. Surprisingly, no across field advantage was observed for the cross-domain matches (word-picture pairs). It was argued that such a failure to demonstrate a cross hemisphere advantage in the word-picture conditions may have arisen as a result of different cortical processing areas being utilised by these distinct stimulus types. As such, no processing overload within any one hemisphere occurred. In support of this theory, Patel & Hellige (2007), revealed a within hemisphere advantage following a complex numeric matching task in which stimuli were presented in different visual formats. They reasoned that the different visual formats of stimuli allowed for processing to occur within distinct cortical areas and without interference from competing stimuli. The mixing of stimulus formats within a hemisphere may therefore provide a means through which the overall processing capacity of the hemispheres may be increased.

The influence of task difficulty on interhemispheric communication has also been extended to the socially relevant domain of faces. For example, Compton (2002) carried out a face matching task in which participants were required to match unfamiliar faces on the basis of either emotional expression (Experiment 1) or character identity (Experiment 2). Results revealed that for both match-types, performance was superior for across field matches compared to within. In addition, the across hemisphere advantage was shown to be greater for the more difficult character identity task, a finding which offers further support to the theory that interhemispheric cooperation is most beneficial for complex tasks. Despite this, little evidence was observed to differentiate hemispheric performance within each experiment for category and physical matches. The precise reason for this lack of performance distinction was not established however certain methodological factors including the intermixing of match-types within the same experimental blocks may have played some role. In a follow-up study, Compton, Feigenson, & Widick (2005), demonstrated a greater across field advantage for the matching of what they deemed as more cognitively demanding emotional faces (e.g. happy and angry) compared with faces of neutral expression. The studies therefore offer an extension to the existing research in the field to suggest that the benefits of interhemispheric communication can encompass the highly complex stimuli of faces. It does however remain to be seen whether this processing advantage can be extended to encompass a wider range of social stimuli including familiar faces. Given that the mechanisms through which familiar and unfamiliar faces are processed are known to differ (e.g. Burton, Jenkins, Hancock & White, 2005), it may be the case that the benefits of dividing information across the hemispheres will follow different pattern as a factor of the familiarity of the face.

It should also be noted that unlike many other paradigms used to investigate interhemispheric communication, the majority of cross hemispheric matching paradigms generally equate the perceptual load of trials, regardless of whether they assess within or across hemisphere processing. However, little consideration is generally given to the impact of distracter items in unattended visual fields on results, despite evidence this should be a consideration (Boles, 1983, 1987, 1990, 1994). For within field matches, distracter items appear in the opposite visual field to the matching item while for across field matches, such distracters appear within the same visual field as the target item. If the impact of distracter items is different on within and across field trials there is the risk that this could confound results. One factor which may be instrumental is the similarity between target and distracter items. Specifically, hemispheric asymmetry for words has been shown to be influenced less by pseudoword distracters than by word distracters (Boles, 1990; Iacoboni and Zaidel, 1996).

1.4 INTERHEMISPHERIC COMMUNICATION DURING BILATERAL REDUNDANT STUDIES

A further line of investigation into interhemispheric communication has focused on the outcome of presenting critical stimulus information simultaneously to both visual fields in what is known as a bilateral redundant trial. In contrast to the designs outlined above, the aim of this paradigm is to establish how the hemispheres will process identical information. Through comparing performance of bilateral trials with that of unilateral trials, it is possible to gain insights into whether collaboration occurs and indeed whether it is facilitative or inhibitory in nature (see Banich, 1998; Hasbrooke & Chiarello, 1998). Where the bilateral redundant paradigm differs from that of many other investigations into hemispheric communication is that it does not necessarily require interhemispheric interaction in order to perform the task successfully. As a result, improved performance on bilateral trials can be seen as supporting theories of cooperation rather than hemispheric inhibition or independence. Using this technique, a wide range of studies have demonstrated superior performance in the bilateral condition in comparison to either of the unilateral conditions. These include studies involving simple visual patterns (Miller, 1982), colours (Roser & Corballis, 2003), and consonant–vowel–consonant syllables (Hellige & Adamson, 2007; Marks & Hellige, 1999, 2003). This effect has become known as the bilateral advantage or bilateral gain (Mohr, Pulvermüller, & Zaidel, 1994).

A robust bilateral advantage for words, but not for pseudo-words, has been demonstrated in a lexical decision task and interpreted as evidence of interhemispheric communication (Mohr, Pulvermüller, & Zaidel, 1994; Mohr & Pulvermüller, 2002). Evidence suggests that this performance advantage is greater for high frequency words compared to low (Mohr, Pulvermüller, Mittelstädt & Rayman, 1996) and for Japanese Kana presented in familiar script compared with less familiar characters (Yoshizaki, 2001). The results of these and several other studies appear to indicate that the familiarity of stimuli may impact significantly on patterns of interhemispheric communication involving complex stimuli. For example, the results of an EEG study revealed that whilst bilateral word presentation resulted in an increase in cortical activation that was not seen following unilateral word presentation, no similar distinction was observed for pseudowords (Mohr, Endrass, Hauk, & Pulvermüller, 2007).

Further distinctions between stimuli-type and patterns of interhemispheric communication have been reported by Zaidel and Rayman (1994) during a lexical decision task. They presented participants with one to four identical copies of words or pseudowords to the LVF, RVF or divided between both. When one word was presented in each visual field, a bilateral advantage was obtained for words but not pseudowords. Multiple stimulation with two copies of a word within a single visual field also increased accuracy relative to single presentation. Of interest however was the finding that the bilateral condition was superior to LVF stimulation with two copies. Increasing the number of presentations above two did not result in any further increases in performance. In addition to supporting the notion that interhemispheric communication is influenced by the familiarity of complex stimuli, this differentiation between word and pseudoword performance can also be interpreted as evidence that such communication occurs at a relatively deep, lexical stage of processing (Zaidel & Rayman, 1994).

Studies examining the bilateral advantage and interhemispheric communication have since been extended from the verbal to the non-verbal domain. The results of these investigations indicate that the bilateral advantage is a relatively global phenomenon applicable to a wide range of both complex and simple stimuli. In the face-domain, a significant bilateral advantage has been found for the recognition of famous but not unfamiliar faces (Mohr, Landgrebe & Schweinberger, 2002; Schweinberger, Baird, Blümler, Kaufmann, & Mohr, 2003; Baird & Burton, 2008).

Taken together, the above results indicate that at least for complex stimuli, bilaterally redundant information has a facilitative effect on processing. However, this is not a generalisable advantage and a necessary requirement of this performance benefit appears to be that stimuli have been previously learned, as in the case of words and famous faces but not pseudo-words or unfamiliar faces.

1.5 MODELS OF COOPERATION

The exact mechanism underlying the bilateral advantage using a bilateral redundant paradigm still remains unclear in that stimulation of both hemispheres in this manner may result in a number of different processing possibilities. Consequently, various models of hemispheric interaction have evolved. These can be classified broadly into unilateral specialisation, parallel processing and cooperation models.

1.5.1 Metacontrol

Levy and Trevarthen (1976) proposed a unilateral specialisation model based on the idea of metacontrol in which a single hemisphere always exerts control during a given task. Accordingly, this theory suggests that performance on bilateral trials should always mirror the pattern of performance displayed by the dominant hemisphere.

Tests carried out on split-brain patients after the simultaneous tachistoscopic presentation of stimuli to both visual fields provide much of the basis behind this theory. Results from these patients revealed that the requirements of the task dictated which hemisphere would exert control over processing. Further support for a theory of metacontrol has come from Hellige (1993) following studies involving healthy participants. Specifically, right hemispheric metacontrol was observed for error patterns during a consonant-vowel-consonant (CVC) identification task. Despite such displays of apparent unilateral control, a major weakness of this model lies with the assumption that bilateral performance will never exceed that of unilateral. Several instances exist whereby this assumption is violated (e.g. Mohr et al, 1994; 2002) and as such it appears a more comprehensive model is required.

1.5.2 Race Models

Unlike unilateral specialisation models, an alternative approach has been to consider the involvement of both hemispheres in a parallel processing model. One interpretation of the bilateral advantage is that it reflects a race between the processing of two competing stimuli (Raab, 1962; Miller, 1982). Facilitation after redundant stimulation is then considered to be a result of statistical probability. Specifically, if both stimuli are processed independently and in parallel, the hemisphere that is most efficient for a particular task normally completes it first. However, if the less specialised hemisphere occasionally completes the task fastest, the overall average processing speed will be faster than unilateral presentation to the specialised hemisphere. A bilateral redundant advantage will be observed in such a case. The application of a race model of this nature could be applied to processing of pairs of stimuli anywhere in the visual field. Specifically, if increasing the number of stimuli results in faster detection, then improved performance might be predicted for a wide range of stimuli, both crossing visual fields and lying within them (Marks & Hellige, 1999).

Several bilateral advantage phenomena exist in the literature which can easily be accounted for by a race model. However, these tend to be tasks involving the detection of simple, meaningless stimuli (Iacoboni & Zaidel, 2003; Reuter-Lorenz, Nozawa, Gazzaniga & Highes, 1995). Corballis (1998) examined redundancy gains in split-brain patients and healthy controls through the use of a simple reaction time task involving changes in luminance between stimuli and background. Redundancy gains were compared to the probability summation predicted by a race model. While all participants were shown to have faster bilateral reactions compared with unilateral, it was observed that redundancy gains in controls did not exceed the probability prediction. There are however further instances in which a race account of the bilateral advantage is less compelling. For example, in a simple signal detection task, Miniussi, Girelli, & Marzi, (1998) presented checkerboards either unilaterally to the LVF or RVF or simultaneously to both visual fields. Results revealed faster responses for bilateral presentations in comparison to unilateral, at a level beyond that predicted by race-model probability. Of greater concern for race model theories is the finding that a bilateral advantage has been observed for familiar but not unfamiliar stimuli. Specifically, it is difficult to reconcile this finding in ‘race’ terms for which differentiation between the familiarity of stimuli should not occur.

1.5.3 Neurocognitive Models

A neurocognitive model based on Hebb's theory of learning and cell assemblies (Hebb, 1949) does however seem to offer a more satisfactory account of the underlying process through which the bilateral advantage occurs. Such a model proposes that through the process of neurophysiological learning mechanisms, familiar stimuli become cortically represented by strongly connected cell assemblies (CAs). As concepts located in different regions of the brain become associated, the CAs may become distributed across both hemispheres, with connections through the corpus calosum, to form transcortical cell assemblies (TCAs) (see Figure 2).

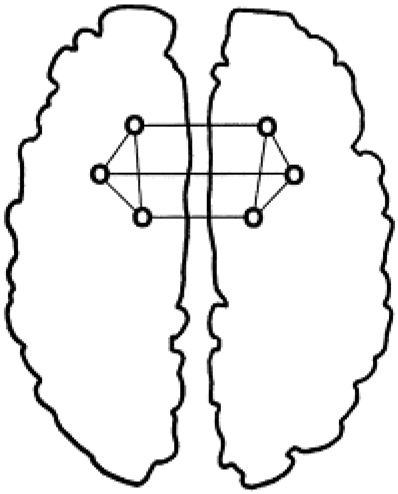

Figure 2: Illustration of a transcortical cell assembly (from Pulvermuller & Mohr, 1996). Small circles represent local clusters of neurons with lines representing connections between these clusters.

TCAs may be involved with the processing of certain stimuli or represent mental concepts such as words or faces. If stimulated once through input to a single hemisphere, the CA activation will be less efficient than if both hemispheres are stimulated simultaneously (Pulvermüller & Mohr, 1996). Increasing the number of stimulus copies presented unilaterally or bilaterally has also been shown to improve performance for words but not for pseudowords (Mohr et al, 1996). A neurocognitive model may be able to account for the relative hemispheric specialisations frequently observed for certain tasks if distribution of cortical networks is considered to be asymmetrical across both hemispheres. In addition, this model also offers an explanation for the observed distinction between a bilateral advantage for familiar and lack of for unfamiliar stimuli. Specifically, as CAs should only exist for concepts that are known, bilateral stimulation should have no subsequent facilitation on unlearned stimuli.

Further support for such a theory comes from the facilitative effect found when a CA is stimulated twice in the same visual field (Mohr, et al, 1996). Unilateral and bilateral redundant performance was compared through the presentation of one or two stimuli unilaterally in either the LVF or RVF and the presentation of either one or two redundant stimuli bilaterally to each visual field. Results revealed that the presentation of two-word stimuli lead to no differentiation between RVF and bilateral conditions. However, maximum performance was achieved following the presentation of four stimuli. This finding appears to offer support to the idea that summation in interhemispheric networks can occur within or across hemispheres following the presentation of multiple stimuli.

Examination of a split-brain patient using a bilateral redundant design with a lexical decision task revealed no evidence of improved performance after bilateral stimulus presentation in comparison to the best unilateral performance (Mohr et al, 1994a). This finding is in contrast to the superior performance on bilateral trials compared with unilateral trials for words but not pseudowords displayed by healthy controls (Mohr et al, 1994b). It appears clear from these results that an intact corpus callosum is necessary for the production of a bilateral advantage in lexical processing. A lack of bilateral advantage for words has also been observed in schizophrenic patients (Mohr et al, 2000), a further patient population believed to demonstrate atypical patterns of interhemispheric communication. However, while a neurocognitive explanation of the bilateral advantage appears to offer an account for the lack of bilateral advantage observed in some split-brain patients (Mohr, Pulvermuller, & Zaidel, 1994; Mohr, Pulvermuller, Rayman, et al., 1994), it should be noted that other results with acallosal patients are more variable. As stated previously, there are instances in which enhanced bilateral redundancy gains have been demonstrated, particularly in the case of basic stimuli (e.g. Corballis, 1998). What appears to differentiate these conflicting findings is the complexity of the stimuli and task. For example, redundancy gains in simple reaction time tasks do not appear to require interhemispheric communication mediated by the corpus callosum, while more complex comparison tasks or the use of more complex stimuli such as words appears reliant on communication from both hemispheres.

Although explaining the differential aspect of the bilateral advantage in terms of cell assemblies is useful, the bilateral advantage observed during simple stimulus detection tasks does on the other hand indicate that communication may occur instead at an earlier perceptual processing level. The assumption that only meaningful stimuli gain from bilateral stimulation is then violated by findings from simple reaction tasks. For example, a bilateral advantage has been observed for both pattern (Minussi et al., 1998) and letter detection tasks (Miller, 1982). Moreover, while Zaidel and Rayman

(1994) observed no bilateral advantage for pseudowords during a lexical decision task, a bilateral advantage was reported for pseudowords during a go-/no-go task. Specific task requirements may then be influential in relation to the bilateral advantage. Indeed, it has been shown previously that the involvement of each hemisphere in face processing can vary as a function of the specific demands of a task (Sergent, 1985). Tasks resulting in a bilateral advantage from meaningful stimuli seem to require that full stimulus identification occurs. Specifically, lexical decision, familiarity decision and object decision tasks all require some degree of stimulus selection and this may be at the root of differences between stimuli types. In contrast, simple reaction time paradigms do not necessitate this. It may therefore be that different processing mechanisms are utilised following simple reaction time and decision-making processes and that a differential bilateral advantage as observed with meaningful stimuli may only occur in tasks in which full stimulus processing is required. For simple reaction time studies requiring fast visual detection, activation of activity within cell assemblies will not occur, yet may benefit from bilateral presentation due to higher overall cortical activation relative to unilateral presentation. No further stimulus processing is required following stimulus detection in such cases. In contrast, decision tasks in which full stimulus identification is required will only result in improved performance when stimuli are represented in neuronal networks to allow for summation of activation in cortical cell assemblies.

Interhemispheric cooperation has however been shown to be absent for the recognition of facial expressions (Schweinberger, et al, 2003). Participants were required to classify facial expressions of unfamiliar faces as either positive or neutral. Results revealed that bilateral presentation did not facilitate performance for either facial expression type. This finding seems to suggest that it is not how meaningful a stimulus is *per se* that will yield bilateral activation of TCAs, but rather it must be the activation of concepts acquired through learning. Expression recognition is proposed to be an innate process (Ekman & Friesen, 1971), and if so, it could be assumed that this process would require no activation of acquired cortical representations. As such, a lack of bilateral advantage for the recognition of expression could be seen as evidence in support of a neurocognitive theory.

While many aspectS of a neurocognitive model are compelling, it should also be remembered that unilateral and bilateral trials differ in both the number of locations stimulated and number of redundant copies, variables which may influence efficiency. In an attempt to establish the extent performance on bilateral trials might be due to target redundancy rather than to stimulation of both hemispheres, Marks and Hellige (1999), used a paradigm in which two copies of identical nonword letter trigrams were always presented on each trial for participants to identify. On unilateral trials both copies of the stimulus were presented to the same visual field while on bilateral trials, one copy of the stimuli was shown simultaneously to each visual field. Results revealed that the best performance occurred when stimuli were presented to the RVF, worst for stimuli to the LVF, with intermediate performance on bilateral trials. Such a finding indicates that for CVC identification, redundancy gain is not restricted to bihemispheric presentations. However, it is quite possible that interhemispheric processing confers an advantage only for complex stimuli and as such remains an issue for investigation.

1.6 STRUCTURE OF THIS THESIS

The aim of this thesis is to use a variety of methodologies to explore patterns of interhemispheric communication during the processing of face and identity information. Moreover, the scope and purpose of such communication will be under investigation, with a focus on how patterns of interhemispheric communication may differ for familiar and unfamiliar faces. While evidence exists to show that interhemispheric communication can occur for familiar faces, it remains unclear whether this collaboration is restricted to a superficial image level or whether more abstract information can also be combined, perhaps as part of a larger face processing mechanism (e.g. Bruce & Young, 1986). A final aim will be to determine how observed patterns of interhemispheric communication can be applied to existing theoretical models of interhemispheric communication.

Chapter 2 focuses on the scope of the bilateral advantage in relation to faces and whether collaboration between the hemispheres can occur when different, but complimentary, facial information is presented to each hemisphere. Until now, the bilateral advantage for faces has only been obtained through presenting identical images of faces to each hemisphere. Therefore, if collaboration can also be obtained through the presentation of disparate yet related information, this may help elucidate the nature of the information stored in the memory representations responsible for such an effect. Specifically, insights into whether communication is of a pictorial or more abstractive nature might be achieved. This issue was investigated using faces divided both vertically (Experiment 1) and horizontally (Experiment 2).

Further exploration of the nature of interhemispheric communication forms the basis of Chapter 3 in an attempt to determine whether identity information denoting the same concept can be communicated cross hemispherically. The purpose of this focus is to investigate whether communication occurs at a low sensory or more abstract level of information transfer. Firstly, Experiment 3 attempts to establish whether interhemispheric communication can provide a suitable explanation for the bilateral advantage observed for famous faces or whether a race model explanation may be more appropriate. Experiment 4 presents different images of the same identity to each hemisphere. The aim of this manipulation is to establish if the bilateral advantage for faces is an image-specific effect or whether as with other experimental domains, (e.g. Marks & Hellige, 2003) communication can also occur at a more abstract level of processing, perhaps related to identity. The final experiments in Chapter 2 examine the impact of presenting additional name information (Experiment 5) along with exploring differences between face and name presentations (Experiment 6). The purpose of these experiments is to explore the impact of cross domain presentations on hemispheric communication and to determine how different identity modalities differ from performance obtained for faces.

Through adopting a divided visual field priming paradigm, Chapter 4 explores the nature of identity information capable of being communicated cross hemispherically. Specifically, Experiments 7 and 8 aim to extend the findings of Bourne & Hole (2006), in which evidence for asymmetric interhemispheric cooperation for familiar faces was provided within a repetition priming framework. The use of the same image at prime and test within Bourne & Hole’s (2006) study leaves open the possibility that the priming effect observed reflects image-specific rather than face-specific identity priming. Experiment 7 therefore presents different images of the same identity at prime and target phases to examine if abstractive priming can occur within and across the hemispheres. In addition, the existence of similar asymmetries in cooperation is also investigated. Experiment 8 focuses further on the asymmetrical cooperation observed by Bourne & Hole (2006), and seeks to establish if such asymmetry is a generalisable effect which can be achieved under different experimental constraints.

The final experimental chapter (Chapter 5) aims to determine the purpose of interhemispheric communication during face processing. Previous studies have demonstrated that task difficulty increases the benefits of interhemispheric communication. Establishing the impact of manipulating the difficulty of decisions associated with faces was seen as a further means through which to study this effect and ascertain the basis of any shift in processing style. Experiment 9 therefore seeks to establish whether altering the cognitive demands of a task through the division of task relevant and task irrelevant identity information, within or across the hemispheres, will impact upon performance. Experiments 10 and 11 go on to adopt a more frequently utilised divided visual field matching methodology to assess the impact of task difficulty on interhemispheric communication during face processing. Both physical and identity matches for famous and unfamiliar faces are examined; a manipulation intended to alter the degree of difficulty for which matches can be made. Finally, it has been proposed that the visual system is only capable of processing one face at a time (Bindeman, Burton & Jenkins, 2005). Experiments 12 & 13 therefore aim to establish how varying the number of faces in a divided visual field semantic matching task impact upon patterns of interhemispheric communication.

Chapter 2

Interhemispheric Communication With Divided Faces

Introduction

Investigations into interhemispheric communication (IHC) have provided numerous instances in which dividing information between the hemispheres can improve performance for complex tasks compared to when processing is restricted to a single hemisphere (Compton, 2002; Koivisto, 2000; Liederman, et al, 1985; Weissman & Banich, 2000). For example, the bilateral advantage in which simultaneous presentation of identical stimuli to both visual fields improves performance over presentation to either hemisphere alone has been demonstrated for a wide range of stimuli, including simple visual patterns (Miller, 1982), colours (Roser & Corballis, 2003), and consonant–vowel–consonant syllables (Hellige & Adamson, 2007; Marks & Hellige, 1999, 2003). More recently the bilateral advantage has also been extended to include the more complex visual stimuli of famous faces (Mohr, et al, 2002; Schweinberger, et al, 2003).

While such studies provide evidence that bilaterally redundant information can have a facilitative effect on processing, it remains unclear where the limitations of this effect lie. Specifically, previous studies investigating hemispheric communication using the divided visual field paradigm with faces have always presented identical stimuli to both visual fields. This therefore raises the question of whether collaboration between the hemispheres would still occur if different but related information were presented to each hemisphere. Specifically, can information be shared between the hemispheres?

Studies investigating the issue of interhemispheric communication in the face domain have revealed that a bilateral advantage occurs for redundant famous faces (Mohr, et al, 2002; Schweinberger, et al, 2003). However, such a facilitative effect on processing appears only to occur for stimuli that have been previously learned such as words and famous faces but not pseudo-words or unfamiliar faces. If the claim of interhemispheric collaboration is to be accepted in these studies then it is proposed that this communication may occur via learned cell assemblies spanning both hemispheres via the corpus callosum (Pulvermüler & Mohr, 1996). As described in detail in the introduction, this explanation of the bilateral advantage postulates that if a given cell assembly existing for a particular learned concept is stimulated once through input to a single hemisphere, then that cell assembly activation will be less efficient than if both hemispheres are stimulated simultaneously. This being the case, then the question of how such concepts are represented in these proposed cell assemblies also arises.

One way in which such cooperative abilities may be investigated further is through the presentation of partial, but complimentary information, to each hemisphere such as divided faces. It would seem plausible that if interhemispheric collaboration can occur then presenting each hemisphere with one half of a divided face may contrive a situation in which this information may be recombined through cross-hemispheric collaboration. If indeed disparate information such as divided faces can be successfully combined, then this would expand our understating of the scope of interhemispheric communication in addition to providing an insight into the means by which such information can be communicated. Specifically, to date the bilateral advantage for famous faces has only been demonstrated using identical images of the same identity. Therefore, if evidence of collaboration can be found using divided faces then this may help elucidate the nature of the information stored in the memory representations responsible for such an effect and whether this is of a pictorial or more abstractive nature. Insights relating to this can be seen from a bilateral advantage previously demonstrated using perceptually different stimuli of the same value (Marks & Hellige, 2003). Whilst such a finding indicates that a great deal of abstract aspects of information processing contribute to the bilateral advantage, the results of this study also showed that when stimuli became too distinct the bilateral advantage was diminished, thus making clear that physical characteristics of the stimulus may also play an important role.

Although the collaboration of faces divided cross-hemispherically has not been investigated previously, the integration of faces divided through other means has been. Several behavioural studies investigating the nature of face processing have revealed that strong integrative mechanisms are at work during facial processing. For example, Tanaka & Farah (1993) demonstrated in their isolated parts test that participants are better able to recognise a feature within a previously learned face than when that feature is presented in isolation. As this effect does not occur for scrambled faces, inverted faces or houses, it suggests that the features in upright faces, but not other stimuli are represented interactively. In addition, Young, Hellawell & Hay (1987) have demonstrated in their composite face paradigm that participants are poorer at recognising an upper half or lower half of two different faces when the two halves are fused to make a composite upright face than when the two halves are misaligned or when the fused faces are inverted. Such findings therefore indicate that whilst individual facial parts can be identified accurately in isolation, unifying these elements to form a whole acts to aid recognition. However, this predisposition to integrate can also lead to interference with recognition when the parts do not belong to the same identity.

Nonetheless, despite such strong integrative tendencies that occur when viewing whole faces, faces can be divided and accurately recombined in an individuals mental representation. For example, in a series of studies investigating the temporal division of faces, Anaki, Boyd & Moscovitch (2007) presented participants with famous and non-famous faces which had been separated into segments consisting of the top, middle or bottom section of each face. These segments for which participants were required to make familiarity judgements to were presented in varying order and with altering time lags between the face part segments. Findings from these studies showed that inversion and misalignment effects could be found when the interval between the face segments was short. Moreover the size of the observed effect was comparable to that of whole-face presentations. The inversion effect (Yin, 1969; Diamond & Carey, 1986) is a frequently observed phenomenon in which upright faces are recognised more easily and accurately than inverted ones, presumably as a result of the configural information in the face being disrupted when a face is inverted. It would appear that these temporally divided face parts had been accurately integrated into a complete facial representation given that an inversion effect was observed on the scale found for whole-face presentations.

The interactive processing of faces in the spatial domain has also been previously observed. Yovel, Paller & Levy, (2005) investigated the interactive processing of complete faces rather than face parts using a match-to-sample task in which centrally presented face stimuli were comprised of unilateral facial information or bilateral facial information from one face or two different faces. It was demonstrated that accuracy for hemifaces from the same face was greater than the summed accuracy for left and right hemifaces presented in isolation. Such a finding has been interpreted as evidence of interactive processing as each half of the centrally presented face stimuli is projected to a different hemisphere and so requires interhemispheric integration. However, as processing differences exist between the processing of parafoveal and centrally presented stimuli, it remains unclear whether similar findings would also be found if such stimuli were presented in the manner of previous studies demonstrating interhemispheric collaboration (e.g. Mohr et al, 2002).

Whilst it has been demonstrated that faces can be divided and successfully recombined in our mental representation, studies using chimeric face stimuli also make clear that certain aspects of a face dominate in our mental representation. Chimeric face tests are a widely used as a test of cerebral lateralisation for face processing in which participants are asked to match centrally presented chimeric faces, comprised of left and right halves of two different faces (e.g. Levy, Trevarthen & Sperry, 1972). Typical results demonstrate that not only do participants perceive a coherent face but LVF facial information dominates in the mental representation of the complete face. Such a left visual field/right hemisphere bias has been demonstrated for a range of variations to the chimeric faces test including judgements of emotion, sex, age and attractiveness (Burt & Perrett, 1997; Chiang, Ballantyne & Trauner, 2000, Christman & Hackworth, 1993).

A great deal of research into face recognition has focused on the areas of the face that may be of greatest importance for recognition. Undoubtedly, facial features differ considerably in terms of their saliency and perhaps consequently their importance for recognition purposes. For example, the internal features are thought to be more beneficial for familiar face recognition than the external features (Ellis, Shepherd & Davies, 1979; Young, Hay, McWeeny, Flude & Ellis, 1985). Moreover, the internal features also differ in their saliency with the ocular region appearing to be of greater importance than the nose or mouth (Shepherd, Davies, & Ellis,1981; Schyns, Bonnar & Gosselin, 2002). Whether this is as a result of saliency of features or a top-down scanning processing of faces remains under discussion (Bruyer & Coget, 1987; Schwarzer, Huber & Dummler, 2005). It has been suggested that hemispheric asymmetries in face processing strategies may also exist. Sergent (1982a) investigated this issue in a series of experiments in which participants were required to make same-different responses to face drawings presented in either the LVF or RVF following a centrally presented face. Faces differed only on the particular region being tested on a given trial (e.g. eyes and mouths). Results revealed a top-bottom strategy for RVF/LH faces and the use of the most salient feature for LVF/RH faces. Despite the existence of such apparent processing asymmetries, later studies have found no such evidence of differences in processing strategy between the hemispheres with both always using a top-down strategy (e.g. Hines, Jordan-Brown & Juzwin, 1987).

These studies combine to demonstrate that whilst there are indeed elements of a face that are particularly important for identification, recognition can nonetheless still be achieved through the use of partial and less salient facial components. In addition, ability exists through which centrally presented faces can be divided and recombined to create accurate depictions of these faces in an individual's mental representation. Therefore, the present studies aim to bring together this knowledge and apply it to the field of interhemispheric communication in an attempt to better understand the confines of cross-hemispheric collaboration and the means through which communication may occur. Specifically, given the successful integration of divided faces both spatially and temporally it is of interest to investigate this issue cross-hemispherically through presenting partial but complimentary face parts to each hemisphere. Successful integration of such divided images will not only add to our understanding of the limits of interhemispheric collaboration but findings may also help elucidate the mechanism driving the effect.

Experiment 1: Interhemispheric Communication Investigated With Left and Right Face Halves

In Experiment 1, participants were required to perform a familiarity decision on partial but complementary face halves presented to the left and right hemispheres in order to determine whether interhemispheric communication would occur.

As stated above, previous research has demonstrated that identity can successfully be obtained from a single face-half with LVF facial information predominating in the mental representation of the complete face for the perception of both identity and emotion (Heller & Levy, 1981; Campbell, 1978; Yovel, Levy, Grabowecky & Paller, 2003). Nonetheless, this process is not as proficient as when viewing a complete face (Yovel, Paller & Levy, 2005).

If cooperation is occurring between the hemispheres then we would expect to see improved performance on conditions in which complimentary face-halves are presented to each hemisphere in comparison to conditions in which a single face-half is presented to either visual field or indeed when two identical halves are shown in both visual fields.

Method

Participants

36 participants (24 females) were paid for their participation in the study. Participants ranged in age from 17 to 28 years (*M* = 20.9 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 95.6) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli comprised 16 familiar and 16 unfamiliar faces (8 men and 8 women of each category). Famous faces consisted of well-known actors, singers, politicians and sport stars and were obtained from the Internet. Unfamiliar faces were matched to famous faces with respect to gender, approximate age and any distinguishing features. All faces were of neutral expression and were presented in greyscale on a black background. Faces were edited in Adobe Photoshop and split down the vertical meridian to produce 2 face halves (left and right). The on screen image size of each face-half was 2.2cm wide x 3.2cm high or 2.2 by 3.2 ° of visual angle. Stimuli eccentricity (centre to fixation) was 3.0cm corresponding to a visual angle of about 3 º. Figure 3 shows examples of left and right face-half stimuli.

Figure 3. Example of left & right-hemiface stimuli.

Procedure

Participants were seated at a fixed distance of 57cm from a 16inch monitor of an Apple Macintosh G5 Workstation and used a chin-rest with a forehead restraint bar centred relative to the viewing screen. Participants were instructed that they would be presented with faces for which they must perform a familiarity decision task. In addition, they were instructed not to move their eyes from the fixation cross, and to perform as fast and as accurately as possible. Due to the difficult nature of the task, prior to starting the experiment subjects were shown a list containing the names of the famous faces that would be seen during the trials.

Each trial began with the presentation of a central fixation cross for 1500ms followed by the presentation of a face half for 150ms in one of 8 presentation conditions. The fixation cross remained on screen during stimulus presentation to ensure proper fixation. The inter-trial duration was 500ms in which a blank screen was shown. The presentation conditions which were comprised of 4 unilateral presentations and 4 bilateral were as follows:

1. Left hemiface to LVF (L_LVF)
2. Left hemiface to RVF (L_RVF)
3. Right hemiface to LVF (R_LVF)
4. Right hemiface to RVF (R_RVF)
5. Left hemiface to LVF & RVF (L_BVF)
6. Right hemiface to LVF & RVF (R_BVF)
7. Left hemiface to LVF & complimentary right hemiface to RVF (LR_BVF)
8. Right hemiface to LVF & complimentary left hemiface to RVF (RL_BVF)

Each identity was shown once in each of the eight presentation conditions, comprising 4 experimental blocks with 256 trials in total. Trial order was independently randomised for each participant. A short practice session consisting of all experimental conditions preceded the experimental session. Practice faces were not shown subsequently.

Manual responses were made by computer keyboard. All responses were made bimanually by pressing two “familiar” keys with the middle fingers of the left and right hands and two “unfamiliar” keys with the index fingers of both hands. Key assignment was counter-balanced between participants. Although bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used. The experiment was controlled using Psyscope version 10.

At the end of the experiment, participants were required to rate their degree of familiarity with each face seen in the experiment on a 3-point scale. Only participants who had high familiarity ratings for at least 85% of the famous faces were included in the analyses. No participants were excluded on this basis.

Results and Discussion

Accuracy

Mean correct response rates for familiar and unfamiliar faces in each of the 8 presentation conditions are shown in Figure 4.

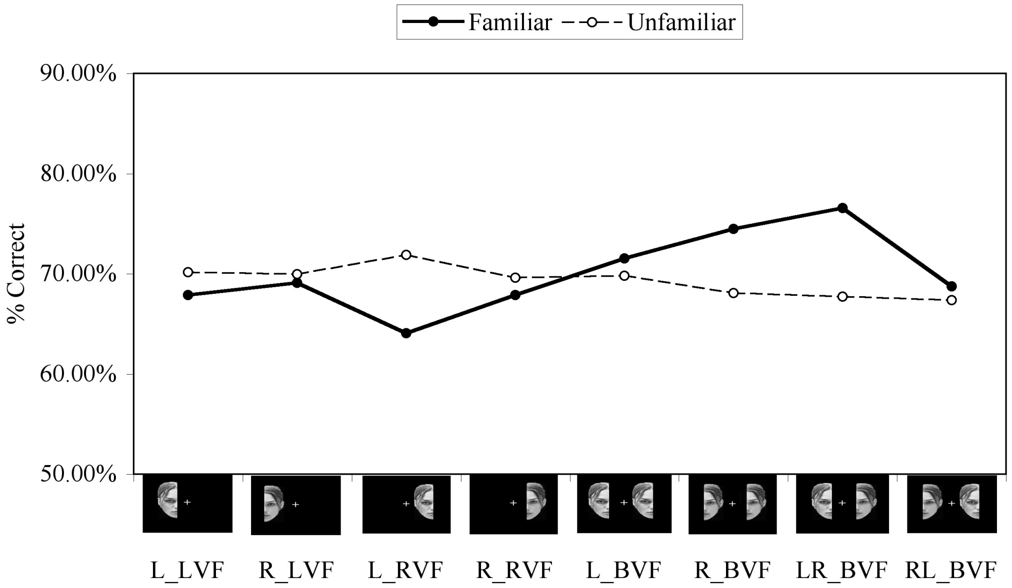

Figure 4. Percentage of correct responses across each of the 8 presentation conditions for familiar and unfamiliar faces.

A two-way within subjects Analysis of Variance was carried out with factors familiarity (familiar / unfamiliar) and presentation condition (L_LVF / R_LVF / L_RVF / R_RVF / L_BVF / R_BVF / LR_BVF / RL_BVF). Results revealed no significant main effect of familiarity, $F(1,35) = 0.045$, $MSE = 0.165$, or of presentation condition $F(7, 245) = 1.693$, $MSE = 0.01$. There was however a significant familiarity x presentation condition interaction, $F(7, 245) = 4.017$, $MSE = 0.012$, $p < 0.01$. Analysis of the simple main effects revealed a significant effect of presentation condition for familiar faces only, $F(7,245) = 5.779$, $MSE = 0.010$, $p < 0.01$. Comparing means using the Bonferroni adjustment indicated that responses were significantly more accurate for presentations to the LR_BVF conditions compared to any of the unilateral field conditions (LR_BVF vs L_LVF, R_LVF, L_RVF, R_RVF, $p < 0.01$). This finding therefore reflects a bilateral advantage for the LR_BVF presentation condition in terms of accuracy. Importantly, there was also a significant difference between the LR_BVF and RL_BVF presentation conditions, $p < 0.01$, demonstrating that it is not merely the presentation of two complimentary hemifaces that is responsible for producing the effect but rather the orientation of the hemifaces is also being encoded. In line with this finding, there were also significant differences between the LR_BVF vs L_BVF presentation conditions, $p < 0.05$, suggesting that it is not just additional stimulus information in each visual field that is responsible for this effect.

Whilst the accuracy data depicts somewhat low participant performance on the task, it should be noted that previous studies using brief presentation of familiar faces in the periphery of vision demonstrate similarly low overall hit rates (Compton, 2002; Mohr et al., 2002). Given that these studies used complete faces then such low accuracy results for half faces is perhaps not surprising.

Reaction Times

Means of median reaction times for familiar and unfamiliar faces across the 8 presentation conditions are shown below in Figure 5.

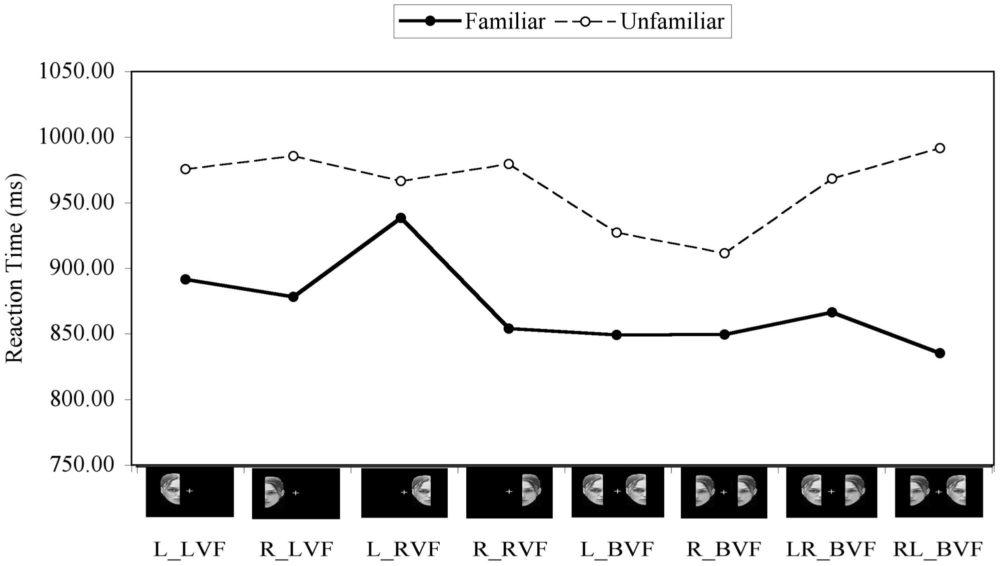

Figure 5. Means of median reaction times across each of the 6 presentation conditions for familiar and unfamiliar faces.

A two-way within subjects Analysis of Variance was carried with factors as for the accuracy analysis. Results revealed a significant main effects of familiarity, $F(1,35) = 31.119$, $MSE = 39890$, $p < 0.01$, with familiar faces being responded to faster than unfamiliar faces (870.4ms vs 963.2ms) and also a significant main effect of presentation condition, $F(7, 245) = 4.978$, $MSE = 8105$, $p < 0.01$. The familiarity x presentation condition interaction was also a significant, *F*(7, 245) = 4.073, *MSE* = 6840, $p < 0.01$. Analysis of the simple main effects revealed there was a significant effect of familiarity, with familiar faces being responded to faster than unfamiliar at the R_LVF, R_RVF, LR_BVF and RL_BVF conditions, *F*(35) > 4.688, *MSE* = 39890.7, $p < 0.5$. There was also a significant effect of presentation condition for both familiar, *F*(7, 245) = 4.768, *MSE* = 8105, p < 0.01, and unfamiliar faces, *F*(7, 245) = 3.648, *MSE* = 8105, p < 0.01.

Comparison of means using the Bonferroni adjustment revealed that for familiar faces the LR_BVF was only significantly faster than the L_RVF presentation condition, $p < 0.01$, thus failing to demonstrate any evidence of collaboration between the hemispheres. Analysis of the unfamiliar faces revealed that the LR_BVF presentation condition was significantly slower than only the R_BVF condition, $p < 0.01$, therefore also suggesting no evidence of collaboration between the hemispheres for unfamiliar faces either.

Despite a failure to demonstrate evidence of IHC from the reaction time data, the accuracy results from Experiment 1 do however appear to provide evidence that left and right face-halves can be successfully combined through interhemispheric collaboration. This is indicated by the performance advantage for the bilateral LR_BVF presentation condition in the accuracy results. Moreover, this effect has been shown to be sensitive to image orientation. Whilst it could be argued that this finding merely arises as a result of additional stimulus information being available on bilateral trials, the fact that performance is greatest in the LR_BVF compared to the RL_BVF in which the same amount of visual information is available suggests this may not be the case and that characteristics of the image such as image orientation are also being encoded. Again, as with previous research, this effect is only apparent for familiar faces a finding that is in line with previous research (Mohr, et al, 2002: Schweinberger, et al, 2003).

Given the suggestion that identity information from divided faces can be transferred interhemispherically, it raises the question of whether a face may be divided by other means so as to reproduce this effect.

Experiment 2: Interhemispheric Collaboration Investigated With Upper & Lower Face Halves

The results of Experiment 1 lend support to the hypotheses that divided facial information can be recombined through interhemispheric communication. Given these findings, the aim of Experiment 2 was again to investigate whether a divided face could be successfully combined across the cerebral hemispheres through interhemispheric collaboration. Faces were this time divided horizontally to create top and bottom face halves. As stated previously, prior research has suggested that the features contained within the upper face, such as the eyes, are inherently more salient than those in the lower half such as the nose and mouth (Bruyer & Coget, 1987). Consequently, identification of the upper face halves may be intrinsically easier than that of the lower halves. Indeed, it has been shown that a general upper over lower features advantage exists irrespective of hemisphere (Hines, et al, 1987). As in Experiment 1, it would be expected that if collaboration between the hemispheres occurs then this will be signalled by improved performance on conditions in which complimentary upper and lower face halves are presented to opposite hemispheres relative to performance when only a single face-half is presented to one visual field.

Method

Participants

16 participants (6 males and 10 females) were paid for their participation in this study. Participants ranged in age from 18 to 25 years (M = 20.9 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 96.1) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli were again comprised of 16 familiar and 16 unfamiliar faces. Faces were edited in Adobe Photoshop and divided into upper and lower segments by cropping them along a horizontal line below the eyes. The resulting face halves (2 for each identity) had an on screen image size of approximately 3.8cm high x 6cm wide corresponding to 3.8 ^{o} x 6^{o} visual angle. The exact size of each half-face did however vary depending on the position of the internal features. Stimuli eccentricity (centre to fixation) was 3.0cm corresponding to a visual angle of 3^{o}. Figure 6 shows examples of upper and lower half-face stimuli.

Figure 6: Examples of upper and lower half- face stimuli

Procedure

The experimental procedure was identical to Experiment 2 with only the presentation conditions altering. These were as follows:

1. upper half to LVF (upper_LVF)
2. upper half to RVF (upper_RVF)
3. lower half to LVF (lower_LVF)
4. lower half to RVF (lower_RVF)
5. upper half to LVF & RVF (upper_BVF)
6. lower half to LVF & RVF (lower_BVF)
7. upper half to LVF & complimentary lower half to RVF (up/low_BVF)
8. lower half to LVF & complimentary upper half to RVF (low/up_BVF)

Results and Discussion

Accuracy

Mean correct response rates for familiar and unfamiliar faces in the 8 presentation conditions are shown in Figure 7.

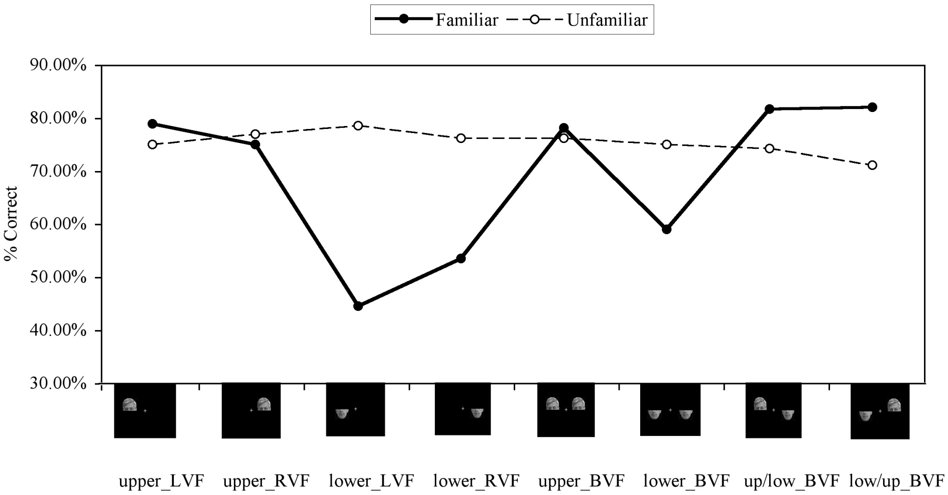

Figure 7. Percentage of correct responses across each of the 8 presentation conditions for familiar and unfamiliar faces.

A two-way within subjects ANOVA was carried out with factors familiarity (familiar / unfamiliar) and presentation condition (upper_LVF / upper_RVF / lower_LVF / lower_RVF / upper_BVF / lower_BVF / up/low_BVF & low/up_BVF). Results revealed no significant main effect of familiarity, *F*(1, 15) = 3.788, *MSE* = 0.067, and a significant main effect of presentation condition, *F*(7, 105) = 13.95, *MSE* = 0.010, *p*

< 0.01. In addition, there was also a significant familiarity x presentation condition interaction, $F(7, 105) = 17.305$, $p < 0.01$.

Analysis of the simple main effects revealed that there was a significant effect of familiarity at the lower_LVF, $F(15) = 13.782$, $MSE = 0.067$, $p < 0.01$, and lower_RVF conditions, $F(15) = 6.125$, $MSE = 0.067$, $p < 0.01$, with familiar faces being responded to less accurately than unfamiliar faces. It appears that participants may have developed a response bias to respond “unfamiliar” in these conditions. This strategy may well have arisen as a result of the difficult nature of the task, specifically, face halves containing low levels of identity information appearing in the periphery of vision. In addition, there was also a significant effect of presentation condition for familiar faces. Comparison of means using the Bonferroni adjustment revealed that responses to the up/low_BVF and low/up_BVF conditions in which it was hypothesised that interhemispheric cooperation may occur, were significantly more accurate than the presentation conditions containing just the lower halves of the face (up/low_BVF vs lower_LVF, lower_RVF, lower_BVF, $p < 0.05$ and low/up_BVF vs lower_LVF, lower_RVF, lower_BVF, $p < 0.05$). In addition, conditions containing just the lower face halves were significantly less accurate than those containing upper-face halves (upper_LVF vs lower_RVF, upper_LVF vs lower_LVF, $p < 0.05$; upper_RVF v lower_RVF, upper_RVF vs lower_LVF, $p < 0.05$). These findings indicate that participants may well have found these specific unilateral and bilateral lower-face conditions contained too little identity information to be able to carry out the task successfully.

Consequently, the very low accuracy scores on conditions in which just the lower-half of the face was presented in comparison to the very high accuracy for conditions in which the upper-half of the face was presented would suggest that the lower-half of the face does not contain enough information for participants to make successful familiarity judgements and consequently has led to the formation of near ceiling and floor effects.

Reaction Times

Means of median reaction times for familiar and unfamiliar faces in each of the 6 presentation conditions are shown below in Figure 8.

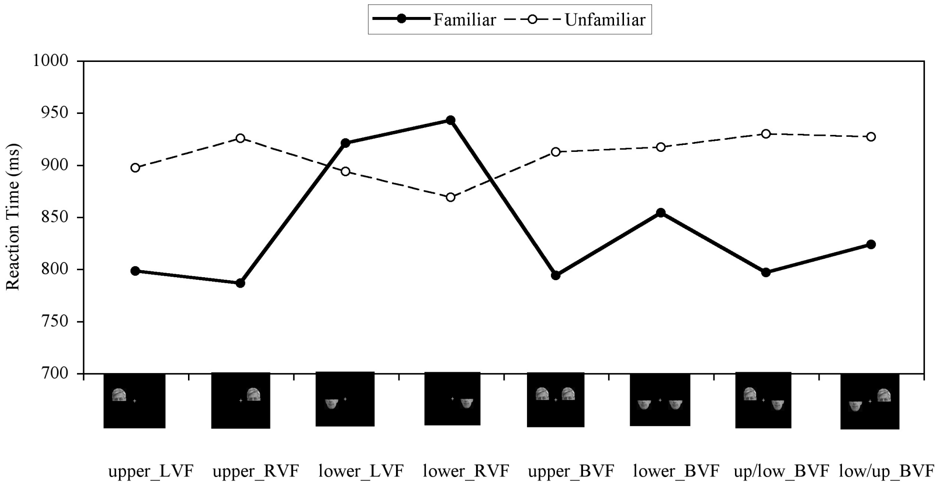

Figure 8. Median reaction times across each of the 8 presentation conditions for familiar and unfamiliar faces.

A 2-way within subjects ANOVA was carried out with factors as in the accuracy analysis. Results revealed a significant main effect of familiarity, *F*(1, 15) = 9.719, *MSE* = 31683, *p* < .01, with familiar faces being responded to faster overall than unfamiliar faces (839ms vs 909ms). There was no main effect of presentation condition, *F*(7, 105) = 1.985, *MSE* = 8836, however, there was a significant familiarity x presentation condition interaction, *F*(7, 105) = 6.597, *MSE* = 7484, $p < 0.01$.

Analysis of the simple main effects revealed that there was a significant effect of familiarity at the upper_RVF presentation condition, *F*(15) = 4.883, *MSE* = 31683.6, $p < 0.05$, with familiar faces being responded to faster than unfamiliar. This result reflects a difference only between the fastest and one of the slowest response times. In addition, there was also a significant effect of presentation condition for familiar faces. Comparison of means using the Bonferroni adjustment revealed that as with the accuracy results, responses to the up/low_BVF condition and low/up_BVF condition were significantly faster only than those conditions containing just the lower half of the face (up/low_BVF vs low_LVF, low/up_BVF vs low_LVF, up/low_BVF vs low_RVF, low/up_BVF vs low_RVF, up/low_BVF vs low_BVF, $p < 0.05$).

These findings based on analysis of reaction times are in line with the findings of the accuracy data. Specifically, it would appear that familiarity decisions using solely the lower-half of the face are too difficult for participants to carry out the task successfully and have led to the formation of near floor and ceiling effects.

Therefore, both performance measures demonstrate that the limited identity information in the lower-face half in contrast with the ease of recognition for the upper face halves has lead to a response bias to respond ‘unfamiliar’ in these difficult conditions. As a result, this appears to have led to the production of ceiling and floor effects that act in obscuring any possible interhemispheric collaboration that may have occurred. Despite failing to gain any real insight into any interhemispheric collaboration, the results of Experiment 2 do however serve to provide further evidence relating to the amount of facial information that is necessary in order for successful face recognition to occur.

Chapter Summary

Both Experiments 1 and 2 sought to further elucidate the types of information that can be communicated interhemispherically through presenting partial but complementary face parts to each hemisphere. The results of Experiment 1 in which left and right face halves were presented to each hemisphere, demonstrated that such partial face information can indeed be combined cross hemispherically. This was indicated by improved performance for familiar faces when complimentary left and right half-faces were presented to each hemisphere. Such a finding lends support to the notion that just as faces can be divided and recombined through other mediums, divided facial information can also be combined cross-hemispherically. Moreover, these results also indicate that in order for interhemispheric collaboration to occur with faces, the information presented to each hemisphere need not be identical.

The results of Experiment 2 in which upper and lower face halves were used as stimuli were however less conclusive. Specifically, whilst there was some suggestion that performance was improved for conditions in which complementary familiar upper and lower face halves were presented to each hemisphere, it seems apparent that the quality of identity information contained in the lower face halves, combined with brief exposure in the visual periphery, resulted in a task too complex for participants to carry out successfully. Consequently, participants appeared to develop a response bias to respond unfamiliar in conditions containing only the lower face half so that any possible IHC may have been obscured.

Despite the inconclusive findings of Experiment 2, the results from Experiment 1 have made clear that different facial information can be combined successfully between the cerebral hemispheres. As a result, this lends support to the idea that the information being communicated cross-hemispherically may take the form of some abstract identity code, rather than consisting of low level visual information. Support for this finding can be found from other studies in the field examining the nature of information communicated interhemispherically which have presented related yet distinct information to each hemisphere (eg. Marks & Hellige 2003, Patel & Hellige, 2007).

As with previous studies investigating interhemispheric collaboration in the face domain (Mohr et al., 2002; Schweinberger et al., 2003), interhemispheric collaboration appeared only to occur for familiar faces. This finding adds further support to a model of hemispheric communication dependent upon transcortical cell assemblies acquired for learned stimuli only. Given that no cell assemblies should exist for unknown concepts, bilateral presentation should produce no facilitation for such previously unlearned face stimuli.

However, an alternative explanation for the findings in Experiment 1 could be that the advantage arises merely as an artifact of additional stimulus information being available on bilateral compared with unilateral trials. Such an account may also be applicable to other experiments displaying a bilateral advantage for redundant faces. Specifically, as outlined in the introduction, it may simply be that two stimuli presented anywhere in the visual system will always give rise to faster performance than one. Consequently, performance on bilateral trials may not be a product of the stimulation of both hemispheres. Increasing the number of stimuli in a visual array could simply result in faster detection as a result of a race occurring between stimuli or between hemispheres, and consequently improved performance might be therefore be predicted for numerous instances in which multiple stimuli are presented both crossing visual field and lying within them (Marks & Hellige, 1999). Whilst it is difficult to entirely refute this possibility with the current experiments, the finding that improved performance was only observed for bilateral trials containing famous faces is difficult to reconcile within such a theory of a race between two competing stimuli and does lend some support to a theory based on interhemispheric communication. Further exploration into this issue would be of benefit to help clarify the basis of the bilateral advantage.

Moreover, whilst recognition can accurately be obtained from one hemiface alone, it is perhaps not surprising that performance on trials containing complimentary face parts produced better performance than unilateral trials containing a single face half. This may be due to the fact participants receive a complete representation of the face in these LR_BVF and RL_BVF trials. In addition, the finding that performance is better when complimentary face parts are presented in their original orientation

(LR_BVF) compared to the reverse orientation (RL_BVF) provides some evidence that certain pictorial aspects of the stimuli are being encoded that act in facilitating integration of the face halves.

Therefore, evidence of interhemispheric collaboration for divided faces was obtained from Experiment 1 along with the possibility that interhemispheric collaboration is reliant largely on late processing stages at which visual stimuli are recognised and categorised as familiar. This possibility that rather high level representations could be the locus of this effect might be explored further through attempting to establish in greater detail the nature of the information that may be stored in the representations thought responsible for the effect. One possibility is exploring the effects of dividing other aspects of identity such as personal names or semantic information. This idea will be examined in the next chapter, along with the possibility that a race between the hemispheres rather than interhemispheric collaboration is responsible for the effects described in this chapter and other experiments examining interhemispheric communication with faces.

Chapter 3

Interhemispheric Communication With Different Identity Formats

Introduction

In the preceding chapter, the scope of interhemispheric collaboration was investigated through presenting partial but complimentary face parts to each hemisphere. Results revealed that interhemispheric collaboration of left and right face halves could be achieved. This finding therefore provides some indication that the information being combined during this process may not lie at low pictorial levels but rather could be dependent upon more abstract information perhaps related to identity. Exploring the nature of this information transfer during interhemispheric collaboration will form the basis of this next chapter. The results of Experiments 3 and 4 have recently been published (Baird & Burton, 2008).

As outlined in Chapter 2, initial studies investigating the bilateral advantage with faces have always presented identical images to both hemispheres, leaving open the question of whether the bilateral advantage for complex stimuli might also be extended to include stimuli denoting the same concept. Given the findings from Experiment 1, in which interhemispheric cooperation appeared to occur for non-identical complimentary face parts, it appears that abstract identity information may be transferred cross-hemispherically. This being the case, it might also be that interhemispheric cooperation is possible for different images of the same familiar face. Indeed, it has been suggested that the cortical representations proposed to be responsible for the bilateral advantage may be neurobiological equivalents of face recognition units (FRUs) as proposed in Bruce and Young’s model of face recognition (Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999; Burton, et al, 2005). Such FRUs are said to be structural codes that allow for the identification of a face independently of variations in image. Exploring whether interhemispheric cooperation can occur with different images of the same identity will therefore provide a means of gaining insight into the likelihood of such a claim. Evidence in support of this idea can already be seen in the demonstration of a bilateral advantage for perceptually different stimuli of the same value (Marks & Hellige, 2003; Patel & Hellige, 2007), suggesting that at least in the case of non-complex visual stimuli, the bilateral advantage is not reliant on identical information.

If identity information such as that contained within FRU like structures does form the basis of the neuronal constructs involved in cross-hemispheric information transfer, then the possibility that other forms of identity information may also be contained within such cortical representations also exists. For example, according to the interactive activation and competition (IAC) model of person recognition (Burton, Bruce & Johnston, 1990), activation of the appropriate cross-domain, modality–free Person Identity Nodes (PINS) can allow FRUs to access semantic information that is specific to an individual. This biographical information is said to be stored in Semantic Information Units (SIUs), with access to an individual's name being achieved through their activation. It is therefore of interest to establish whether similar patterns of interhemispheric communication might be achieved with identity information other than faces, such as through the presentation of personal names or alternatively through cross-domain pairings of faces and names. This possibility that alternate identity information may be combined through interhemispheric cooperation will be explored in the proceeding experiments.

However, as stated in Chapter 2, the possibility does exist that the presumed collaboration occurring between the hemispheres may in fact be an artefact of additional stimulus information being available on unilateral as opposed to bilateral trials. Therefore, in addition to exploring the nature of any hemispheric collaboration, this chapter will first examine the issue of whether the bilateral advantage reflects interhemispheric cooperation or a race between competing stimuli.

As described in the introduction, one interpretation of the bilateral advantage is that it reflects a race between the processing of two competing stimuli and facilitation after redundant stimulation is a result of statistical probability. Specifically, if both stimuli are processed independently and in parallel, the hemisphere that is most efficient for a particular task normally completes it first and initiates a response. However, if the less specialised hemisphere occasionally completes the task fastest, the overall average processing speed will be faster than unilateral presentation to the specialised hemisphere. Hence a bilateral redundant advantage will be observed. If indeed such an account is accurate then this race model of the bilateral advantage may also be applied to processing of pairs of stimuli anywhere in the visual field. In addition, as suggested by Marks & Hellige (1999), if increasing the number of stimuli results in faster detection, then improved performance might be predicted for a wide range of stimuli, both crossing visual fields and lying within them.

Whilst there are several bilateral-advantage phenomena in the literature which can easily be accounted for by the race model (Corballis, 1998; Iacoboni & Zaidel, 2003), there are others for which such an account is harder to explain (Miniussi, Girelli, & Marzi, 1998). For example, a race model struggles to explain the differential bilateral advantage observed for familiar and unfamiliar stimuli. An alternate model based upon hemispheric collaboration and Hebbian learning mechanisms has therefore been proposed (Pulvermüller & Mohr, 1996). This account, which is described in detail in the introduction, seems to provide a comprehensive account of the observed distinction between a bilateral advantage for familiar and unfamiliar stimuli and also certain observed relative hemispheric specialisations.

One means through which these two competing theories of the bilateral advantage for familiar faces might be compared is to establish whether a similar performance advantage can be achieved when two identical stimuli are presented anywhere in the visual field. This issue was explored in a paradigm by Marks and Hellige (1999) in which two copies of identical nonword letter trigrams were always presented on each trial for participants to identify. On unilateral trials both copies of the stimulus were presented to the same visual field whilst on bilateral trials one copy of the stimuli was shown simultaneously to each visual field. Results revealed that the best performance occurred when stimuli were presented to the RVF, worst for stimuli to the LVF, with intermediate performance on bilateral trials. Whilst this finding indicates that for CVC identification, redundancy gain is not restricted to bihemispheric presentations it may be the case that for more complex and meaningful stimuli such as faces, a different pattern of results emerges.

Experiment 3: Race Or Interhemispheric Cooperation?

In Experiment 3, participants were required to perform familiarity judgments to pairs of faces presented both centrally and bilaterally to both visual fields in an attempt to distinguish whether the bilateral advantage for famous faces can be attributed to interhemispheric communication or a race between two competing stimuli in the visual field. It is hypothesised that if two (redundant) stimuli always give rise to faster performance than one, this would lend support to a race model that does not depend on differential processing across hemispheres. In contrast, interhemispheric cooperation accounts predict a redundancy advantage only when the stimulus is presented separately to each hemisphere. More specifically, such an advantage would only be expected to occur after the presentation of familiar stimuli for which learned TCAs already exist.

Method

Participants

26 participants (16 females) were paid for their participation in the study. Ages ranged from 18 to 24 years (*M*= 20.2 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 94.78) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli comprised 16 familiar and 16 unfamiliar faces (eight men and eight women of each category) in greyscale. Famous faces comprised well-known politicians, actors, singers and sports stars and were obtained from the Internet. All were high-resolution photographs, showing full-face views in greyscale. Unknown faces were matched to famous faces with respect to gender and any distinguishing features. All faces had previously been rated for familiarity by a comparable group (i.e. students from the same source, but not those who took part in this experiment). Faces were rated ‘definitely familiar’, ‘possibly familiar’, or ‘definitely unfamiliar’. Only stimuli were used which attracted ‘definitely familiar’ or ‘definitely unfamiliar’ ratings from all subjects in this exercise. On screen image size was approximately 3.5 cm high × 2.5 cm wide corresponding to a visual angle of 3.5◦ × 2.5◦ shown at distance of 57 cm. Stimuli eccentricity was 3.0 cm (centre to fixation) corresponding to 3◦ visual angle and resulting in an inner visual angle of approximately 1.75◦.

Procedure

Participants were seated at a fixed distance of 57 cm from the 16 inch monitor of an Apple Macintosh G5 Workstation, using a chin-rest with forehead restraint bar. Participants were instructed that they would be presented with faces for which they must perform a familiarity decision task. They were instructed not to move their eyes from the fixation cross, and to perform as fast and accurately as possible.

Trials began with the presentation of a central fixation cross for 1500 ms followed by a face for 150 ms in one of six presentation conditions. The fixation cross remained on screen during stimulus presentation. The inter-trial duration was 500 ms in which a blank screen was shown. In single-stimulus conditions faces were presented to the left right, above or below fixation cross. In dual stimulus conditions, stimuli were to the left and right of the fixation cross, or above and below it. Examples are given in Figure 9.

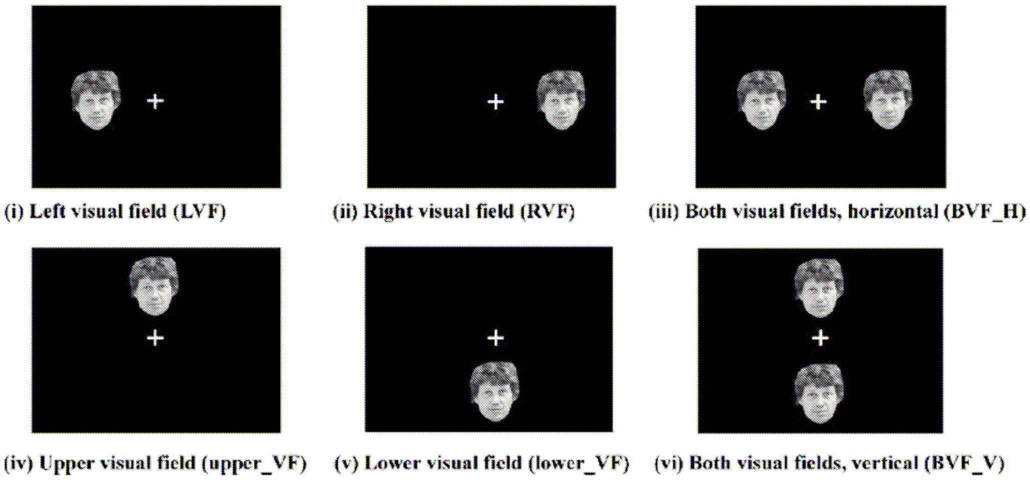

***Figure 9**:* Presentation conditions of stimuli in Experiment 3.

Each identity was shown once in each of the six presentation conditions, comprising four experimental blocks with 192 trials in total. Order of trials was independently randomised for each participant. A short practice session consisting of all experimental conditions preceded the experimental session. Practice faces were not shown subsequently.

Manual responses were made by computer keyboard. All responses were made bimanually by pressing two “familiar” keys with the middle fingers of the left and right hands and two “unfamiliar” keys with the index fingers of both hands. Key assignment was counter-balanced between participants. Though bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used. The experiment was controlled using PsyScope version 10.

Results and discussion

Reaction Times

Means of median reaction times for familiar and unfamiliar faces across the six presentation conditions are shown in Figure. 10.

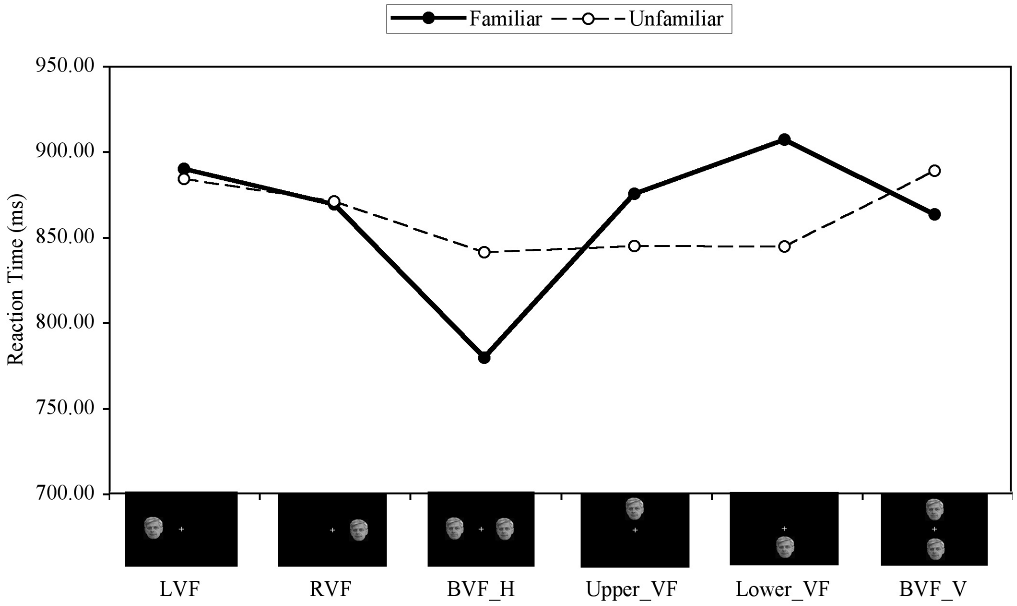

***Figure 10**:* Means of median reaction times across each of the six presentation conditions for familiar and unfamiliar faces.

A two-way within subjects ANOVA was carried out with factors familiarity (familiar/unfamiliar) and presentation condition (LVF/RVF/upper VF/lower VF/BVF H/BVF V). Results revealed a significant main effect of presentation condition, *F*(5,125) = 4.46, MSE= 8708, $p < 0.05$, but not of familiarity, *F*(1,25) < 1. The familiarity×presentation interaction was significant, $F(5,125) = 2.58$, MSE= 9345, $p < 0.05$.

Analysis of simple main effects revealed a significant effect of presentation condition for familiar faces only, $F(5,125) = 5.85$, MSE= 8708, $p < 0.05$. Comparing means using the Bonferonni adjustment indicated that responses to the BVF H condition were significantly faster than either the LVF or the RVF ($p < 0.05$) reflecting a bilateral advantage. Importantly, reaction times to the BVF V did not show a significant advantage over any of the unilateral conditions.

Accuracy

Mean accuracy across conditions is shown in Figure. 11.

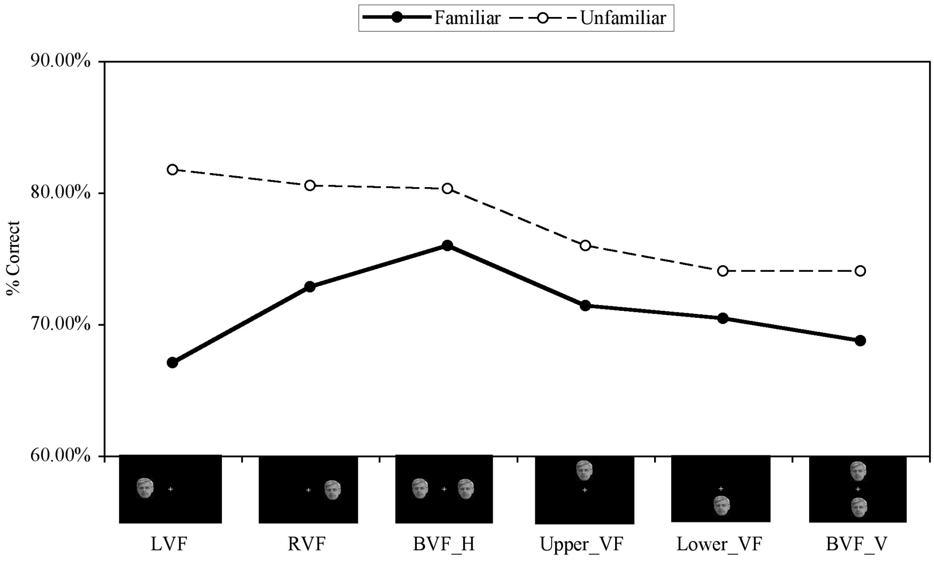

Figure 11: Correct responses across each of the six presentation conditions for familiar and unfamiliar faces.

A two-way within subjects ANOVA was carried out with factors as for the RTs. Analysis revealed a main effect of familiarity, $F(1,25) = 9.9$, MSE= 0.035, $p < 0.01$, with unfamiliar faces being recognised more accurately than familiar faces, possibly reflecting a bias to respond “unfamiliar”. Indeed, the hit and false alarm rates presented in Table 1 appear to confirm this suggestion.

Condition	Hits (%)	False Alarms (%)
LVF	67.1	18.3
RVF	72.8	19.6
BVF_H	76.0	19.8
Upper_VF	71.4	24.0
Lower_VF	66.6	26.0
BVF_V	68.8	26.0

Table 1: Percentage of hits and false alarms across each of the 6 presentation conditions in Experiment 3.

This bias may be occurring because of the difficult nature of the task, involving fast presentations in the periphery of vision, rather than because of a general unfamiliarity with the faces. Indeed, previous studies using brief presentation of familiar faces in the periphery of vision demonstrate similarly low overall hit rates (Compton, 2002; Mohr et al., 2002). There was also a significant main effect of presentation condition, $F(5,125) = 3.763$, MSE = 0.009, $p < 0.01$, however no significant familiarity×presentation condition interaction, $F(5,125) = 1.58$, MSE= 0.014. Comparisons between means for familiar faces revealed only that the BVF H condition was significantly more accurate than the LVF condition, $F(1,125) = 3.92$, $p < 0.05$. As with the reaction time analysis, the BVF V condition did not show any performance advantage over any unilateral condition.

These results show quite clearly that an advantage for presenting two face stimuli occurs only when they are horizontally aligned (i.e. one to each visual field), and not when they are vertically aligned (above and below fixation). Whilst stimuli presented in the vertically aligned condition were presented to both hemispheres, this information was complementary (the left and right halves of the faces) and did not prove sufficient to produce any form of performance advantage. Only when redundant information was presented simultaneously to both hemispheres was an effect observed. Such a finding supports the interhemispheric communication account of the bilateral advantage for face stimuli, and suggests that race accounts (at least those depending on competition between stimulus processing which is independent of hemisphere), will not suffice for these stimuli. A more subtle aspect of the data concerns the familiarity by condition interactions in RTs and accuracy. There appears to be some evidence for a speed-accuracy trade-off here. When single familiar faces were lateralised to either the left of right visual fields they were responded to as quickly yet less accurately than unfamiliar faces. When the faces were presented to upper or lower fields, the familiar faces were responded to as accurately yet slower than unfamiliar faces. The overall bias to respond ‘unfamiliar’ is evident in both these patterns, though why it should be manifested differently in vertical than in horizontal presentation planes is not clear.

Whilst certain aspects of these results remain unclear, it would appear that the evidence does however point towards an explanation of the bilateral advantage that is based upon interhemispheric communication rather than a race between competing stimuli. This being the case, it is of interest to establish in greater detail the nature and quality of such collaboration.

Experiment 4: Different Image Of Same Identity

Experiment 3 lends support to an interhemispheric account of the bilateral advantage phenomenon and so it is of interest to investigate further the precise nature of this communication. As stated above, initial studies investigating the phenomenon with faces have used identical copies of a stimulus presented to both hemispheres leaving it open to speculation whether the bilateral advantage reflects co-operation at either a pictorial or more abstractive representation of the stimulus. Experiment 4 aims to investigate this issue. In addition, it is hoped that results may also help elucidate whether the cortical representations responsible for the bilateral advantage can indeed be likened to neurobiological equivalents of face recognition units (FRUs) as suggested previously. In order to ascertain whether these abstract structures might underlie the bilateral advantage, Experiment 4 presents two different images of the same identity simultaneously to both hemispheres. If such a manipulation leads to a bilateral advantage, this would suggest co-operation at an FRU-like level. Alternatively, a reduction in the bilateral advantage in such circumstances may imply a more image-based cooperation mechanism.

Method

Participants

28 participants (16 females) were paid to take part in this study. Ages ranged from 18 to 25 years (*M*= 20.3 years). Each participant had normal or corrected-to normal vision, and all were strongly right-handed (mean laterality quotient = 96.5) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) with no left-handed first-degree relatives. Participants were recruited on the basis they be able to recognise British and American celebrities.

Stimuli

Stimuli comprised two different images of 16 familiar and 16 unfamiliar identities (eight men and eight women) in greyscale. Familiar stimuli were again well-known politicians, actors, singers and sports stars, but different from those used in Experiment 3. Face images were obtained from the Internet. Again, unknown faces were matched to famous faces with respect to gender and any distinguishing features. All faces had previously been rated for familiarity. Differences between pictures of each identity were obtained by selecting images that had been taken using different cameras or at different time periods. On screen image size was approximately 3.5 cm high×2.5 cm wide, corresponding to a visual angle of 3.5◦ ×2.5◦ shown at distance of 57 cm. Stimuli eccentricity was 3.0 cm (centre to fixation) corresponding to 3◦ visual angle and resulting in an inner visual angle of approximately 1.75◦.

Procedure

The experimental procedure was the same as for Experiment 1. Presentation conditions were as follows:

(1) Left visual field only (LVF).

(2) Right visual field only (RVF).

(3) Identical images to both visual fields (BVF same).

(4) Different images of the same identity to both visual fields (BVF diff).

Examples of stimuli used in the bilateral same and different trials can be seen in Figure 12.

Figure 12: Example of stimuli. The left hand figure shows stimuli used in Bilateral Same trials and the right hand figure shows stimuli used in the Bilateral Different trials.

Each identity was shown once in each of the four presentation conditions, giving 16 pictures per category and 128 trials in total. Breaks were allowed every 32 trials. As before, a short practice session preceded the experiment proper, but practice faces were not shown subsequently.

Results and Discussion

Reaction Times

Means of median reaction times for familiar and unfamiliar faces across the four presentation conditions are shown below in Figure 13.

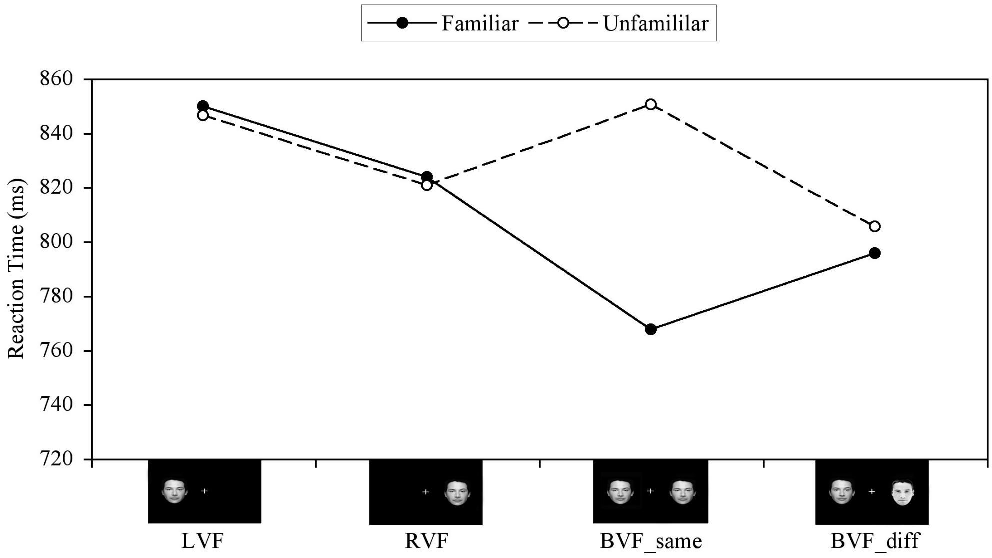

Figure 13. Means of median reaction times across each of the four presentation conditions for familiar and unfamiliar faces.

A two-way within subjects ANOVA was carried out with factors familiarity (familiar/unfamiliar) and presentation condition (LVF/RVR/BVF same/BVF diff). Results revealed a significant main effect of presentation condition, $F(3,81) = 5.572$, MSE = 4335, $p < 0.01$, but not of familiarity, $F(1,27) = 1.596$, MSE = 16,367. The familiarity×presentation condition interaction was also significant, $F(3,81) = 3.604$, MSE = 6617.626, $p < 0.05$.

Simple main effects revealed that familiar faces were responded to significantly faster than unfamiliar faces however only at the BVF same condition, $F(1,27) = 5.870$, MSE = 16,367, $p < 0.05$. More importantly, there was a significant effect of presentation condition for both familiar ($F(3,87) = 8.121$, MSE = 4335, $p < 0.01$) and unfamiliar faces ($F(3,87) = 2.952$, MSE = 4335, $p < 0.01$). Comparison of means for familiar faces, using the Bonferroni correction, revealed a bilateral advantage for the BVF same condition (BVF_same vs. LVF, BVF same vs. RVF, $p < 0.01$). The BVF_ diff condition produced significantly faster responses than the LVF presentation condition, $p < 0.01$, and a ns trend for an advantage over the RVF condition, $t(81) = 1.591$, $p = 0.11$. There was no significant difference between the two bilateral conditions. For the unfamiliar faces, further analysis revealed no systematic pattern of results, with significant differences occurring between the LVF and BVF diff conditions, $p < 0.01$, RVF and BVF same conditions, $p < 0.01$and between the BVF same and BVF diff conditions, $p < 0.01$.

Accuracy

Mean correct response rates for familiar and unfamiliar faces in the four presentation conditions are shown in Figure 14.

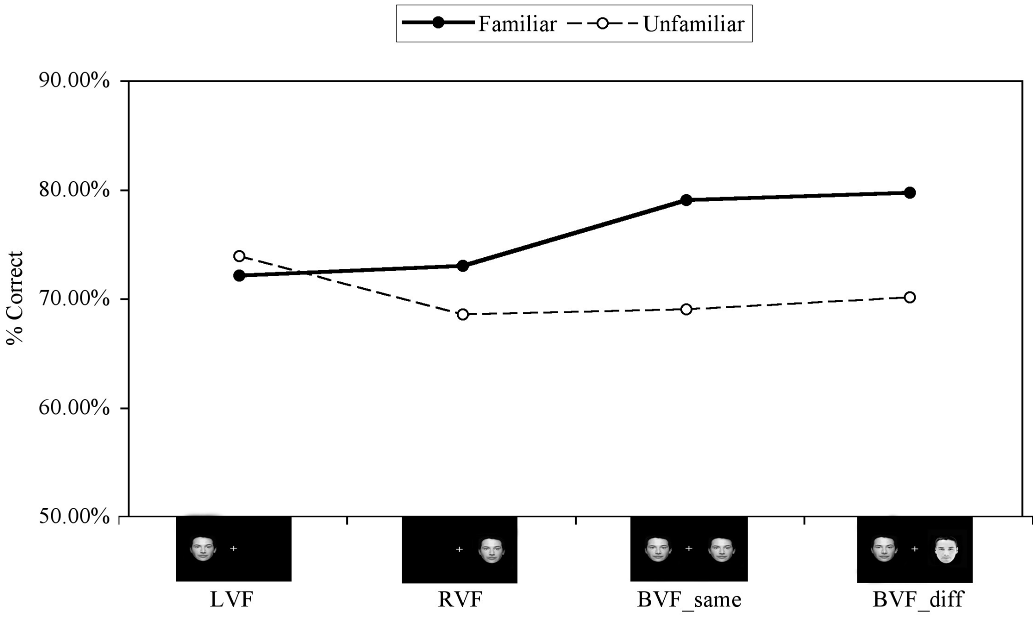

Figure 14: Percentage of correct responses across each of the four presentation conditions for familiar and unfamiliar faces.

A two-way within subjects ANOVA was carried out with factors as in the RT analysis. This revealed a significant main effect of presentation condition, *F*(3,81) = 3.02, MSE = 0.006, *p* < 0.05, but no main effect of familiarity, *F*(1,27), = 3.69, MSE = 0.047. There was, however, a significant familiarity x presentation condition interaction, *F*(3,81) = 4.15, MSE = 0.01, *p* < 0.01.

Simple main effects showed a significant effect of presentation condition for both familiar, *F*(3,81) = 7.47, MSE= 0.006, *p* < 0.01, and unfamiliar faces, *F*(3,81) = 2.83, MSE= 0.006, *p* < 0.01. Comparison of means using the Bonferroni adjustment revealed that for familiar faces there was no difference between the two unilateral conditions, and no difference between the two bilateral conditions. However, both bilateral conditions produced significantly higher accuracy than either unilateral condition (*p* < 0.01 in all cases). Analysis of the unfamiliar stimuli revealed only that

LVF was significantly more accurate than either of the bilateral presentation conditions, $p < 0.05$.

Table 2 shows a breakdown of the accuracy scores into hits and false positives. Unlike the previous experiment, there is no evidence this time for a bias towards ‘unfamiliar’ responses, and no evidence of a speed-accuracy trade-off.

Condition	Hits (%)	False alarms (%)
LVF	72.1	26.1
RVF	73.0	31.5
BVF_same	79.0	31.0
BVF_diff	79.7	29.9

***Table 2**:* Percentage of hits and false alarms across each of the six presentation conditions in experiment 1

Experiment 4 replicates the standard bilateral advantage previously observed for pictures of identical familiar faces, and this pattern is observed in both RT and accuracy. However, there is also evidence for collaboration at a more abstract level. There is a clear bilateral advantage for different images of the same familiar face in the accuracy data, where performance is indistinguishable from the standard effect using identical images. The RT data is however less clear, showing only a trend in the direction of an advantage across different images. Taken together, these results demonstrate that interhemispheric collaboration effects can operate at an abstract level, such as that corresponding to an FRU in theories of face recognition. However, as with several other explorations into face recognition, there appears to be an extra advantage for co-operation at the image level. For example, repetition priming for identities survives a change of image between prime and test, though priming is largest when identical images are used (e.g. Ellis, Flude, Young, & Burton, 1996).

The results of Experiment 4 lend support to the idea that interhemispheric cooperation is not dependent on the presentation of identical information to each hemisphere but rather occurs as a result of the communication of more abstract identity information. It therefore seems possible that other aspects of identity such as names or semantic information may also be contained within such cross-hemispheric communications. This being the case, it should be possible to observe evidence of interhemispheric communication using identity information that crosses stimulus domains, such as the presentation of a face and complimentary name to each hemisphere. This possibility will be explored in the next experiments.

Experiment 5: The Effect Of Additional Name Information On The Bilateral Advantage For Famous Faces.

Given that the presumed hemispheric cooperation observed in Experiment 4 occurred at a non-image specific level, it is of interest to establish whether identity can also be combined across domain through the presentation of face and name combinations.

Whilst personal names are obviously lexical items, their unique association with an individual and linked semantic knowledge results in them differing from common nouns. Nonetheless, although controversy does exist as to whether or not personal names are represented in the left or right hemispheres, it seems likely that as with other lexical information the left hemisphere is also dominant in the processing of personal names (Schweinberger, Langrebe, Mohr & Kaufmann, 2002). Therefore, given the respective left and right hemispheric dominances for names and faces it will be of interest not only to establish whether evidence of interhemispheric cooperation can be found for the collaboration of personal names and complimentary faces but also whether there will be additional advantage when each hemisphere receives its preferred stimulus input compared to the presentation of faces alone.

Method

Participants

30 participants (20 females) were paid for their participation in the study. Ages ranged from 18 to 23 years (M = 20.1years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 93.26) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first–degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli comprised 16 familiar and 16 unfamiliar faces (eight men and eight women of each category) in greyscale. Famous faces were again well-known politicians, actors, singers and sports stars and were obtained from the Internet. All were high-resolution photographs, showing full-face views. Unknown faces were matched to famous faces with respect to gender and any distinguishing features. On screen image size was approximately 3.5cm high by 2.5cm wide corresponding to a visual angle of approximately 3.5°x 2.5° shown at a distance of 57cm.

In addition, 16 familiar and 16 unfamiliar names were used as stimuli. Familiar names corresponded to the familiar faces whilst unfamiliar names were constructed and matched to familiar names on the basis of gender, number of syllables, number of letters and nationality before being paired with an unfamiliar face. For example, HUGH GRANT was matched with DAVE BRENT. Names were shown in capital letters with the first name presented over the second name so as to avoid any confounding of acuity resulting from the surname being closer or further away from fixation. All names were between 4 and 7 letters long with a mean length of 5.5 letters. Names were presented in white font Arial, 24 pt size, corresponding to an onscreen size of 0.5 cm or approximately 0.5° of visual angle. All stimuli were presented on a black background at an eccentricity of 3cm corresponding to 3 degrees visual angle (centre to fixation).

Procedure

The experimental procedure was the same as for previous experiments in this chapter.

Presentation conditions were as follows:

(1) Face, left visual field (LVF)
(2) Face, right visual field (RVF)
(3) Face, both visual fields (BVF_face)
(4) Face left visual field & corresponding name, right visual field (BVF_face/name)
(5) Face right visual field & corresponding name, left visual field (BVF_name/face)

An example of the bilateral presentation condition in which a face was shown to the LVF and a name to the RVF can be seen in Figure 15.

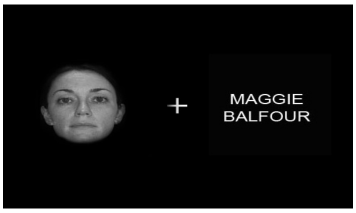

Figure 15. Example of stimuli used in the BVF_face/name trials.

Each identity was shown once in each of the five presentation conditions, giving 16 pictures per category and 160 trials in total. Breaks were allowed every 40 trials. Prior to beginning the experiment participants were shown list of the names of the identities they would be presented with during the trials. As before, a short practice session preceded the experiment proper, but practice faces and names were not shown subsequently.

Results and Discussion

Accuracy

Mean correct response rates for familiar and unfamiliar faces in the 5 presentation conditions are shown in Figure 16.

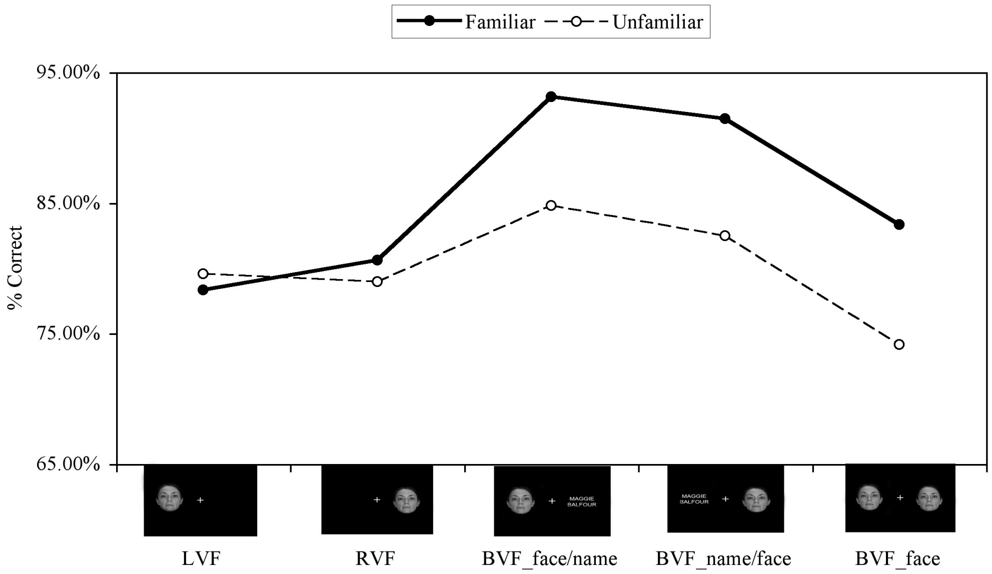

Figure 16. Percentage of correct responses across each of the 5 presentation conditions for familiar and unfamiliar faces.

A two-way within subjects Analysis of Variance was carried out with factors familiarity (familiar / unfamiliar) and presentation condition (LVF / RVF / BVF_name/face / BVF_face/name / BVF_face). Results revealed no main effect of familiarity, $F(1, 29) = 3.48$, $MSE = 0.062$. There was however a significant main effect of presentation condition, $F(4, 116) = 15.983$, $MSE = 0.009$, $p < 0.01$. In addition the presentation condition x familiarity interaction also proved to be significant, $F(4, 116) = 3.364$, $MSE = 0.01$, $p < 0.05$.

Analysis of the simple main effects revealed a significant effect of presentation condition for both familiar, $F(4, 116) = 14.504$, $MSE = 0.009$, $p < 0.01$ and unfamiliar stimuli $F(4, 116) = 5.395$, $MSE = 0.009$, $p < 0.01$. Comparison of means using the Bonferroni adjustment revealed that for familiar stimuli, there was a bilateral advantage for both of the presentation conditions containing a name and complimentary face (BVF_face/name vs LVF, BVF_face/name vs RVF, BVF_name/face vs LVF, BVF_name/face vs RVF, p <0.01). This finding suggests that the hemispheres can collaborate to combine face and name information. There was no significant difference between the BVF_face/name and BVF_name/face conditions, p>0.05. This indicates that there was no bias evident for each hemisphere receiving its favoured mode of stimuli as predicted may be the case. In addition, both conditions containing names and faces (BVF_face/name & BVF_name/face) were significantly more accurate than the bilateral condition containing just faces (BVF_face/name vs BVF_face; BVF_name/face v BVF_face, p < 0.01). Such a result suggests that there is an additional advantage for seeing names combined with faces over faces alone. Whilst the BVF_face condition was significantly more accurate than the LVF, p < 0.01, it failed to reach significance when compared to the RVF, p > 0.01. Consequently, there was no observed bilateral advantage for faces as has been shown previously.

For unfamiliar stimuli, comparison of means using the Bonferroni correction revealed that BVF_face/name and BVF_name/face conditions were significantly more accurate than BVF_face, p < 0.01. There was also a significant bilateral advantage for the BVF_face/name condition (BVF_face/name v LVF, BVF_face/name RVF p<0.01. As with the familiar stimuli, these results seem to demonstrate a performance advantage for receiving names over faces.

Additional name information does then appear to result in interhemispheric collaboration. However, accuracy scores for conditions containing names are nearing 100% and so it seems possible that as with previous experiments, ceiling effects may have been approached and thus obscured the true nature of the findings.

Reaction Times

Median reaction times for familiar and unfamiliar faces across the 4 presentation conditions are shown below in Figure 17.

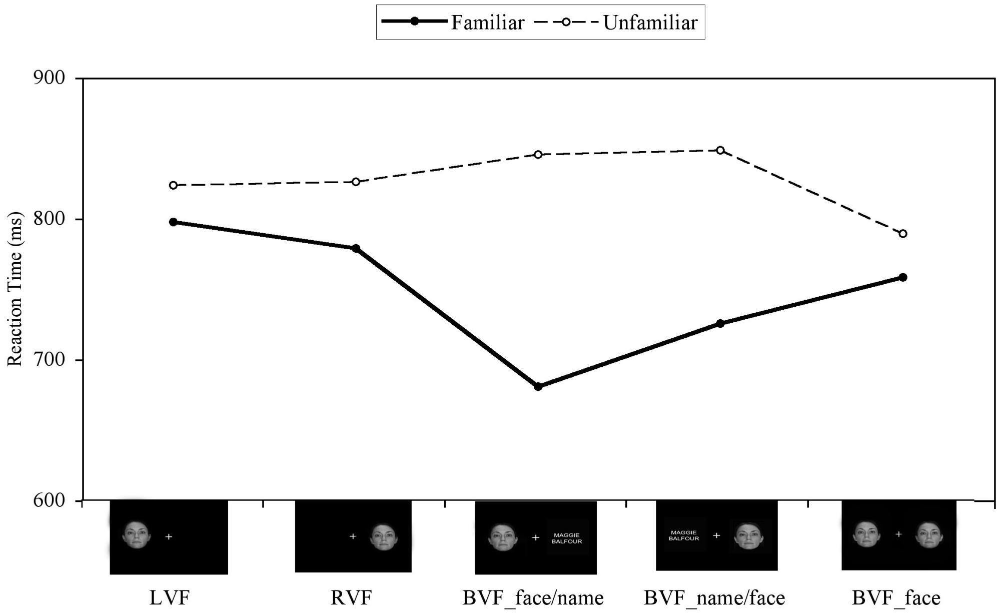

Figure 17. Means of median reaction times across each of the 5 presentation conditions for familiar and unfamiliar faces.

A two-way within subjects Analysis of Variance was carried out with factors as for the accuracy analysis. Results revealed a significant main effect of familiarity *F*(1, 29) = 19.486, *MSE* = 23596.9, *p* < 0. 01 and of presentation condition, *F*(4, 116) = 4.698, *MSE* = 4297.3, *p* < 0.01. In addition there was a significant familiarity x presentation condition interaction, *F*(4, 116) = 13.816, *MSE* = 4181.0, *p* < 0.01.

Analysis of the simple main effects revealed a significant effect of familiarity at the BVF_face/name and BVF_name/face conditions with familiar stimuli being responded to faster than unfamiliar, (BVF_face/name $F(1, 29) = 17.254$, $MSE = 23596.9$, $p < 0.01$, and BVF_name/face, $F(1, 29) = 9.581$, $MSE = 23596.9$, $p < 0.01$). In addition, there was also a significant effect of presentation condition for both familiar, $F(4, 116) = 13.013$, $MSE = 4927.3$, $p < 0.01$, and unfamiliar stimuli, $F(4, 116) = 3.408$, $MSE = 4927.3$, $p < 0.01$. Comparison of means using the Bonferonni adjustment revealed almost an identical pattern of results as for the accuracy analysis. Specifically, there was a bilateral advantage for both of the presentation conditions containing a name and complimentary face (BVF_face/name vs LVF, BVF_face/name v RVF, BVF_name/face v LVF, BVF_name/face v RVF, $p < 0.01$). This finding indicates possible collaboration of name and face information. In addition, there was this time a significant difference between the BVF_face/name and BVF_name/face conditions, $p < 0.01$, suggesting there may indeed be a bias for each hemisphere receiving it's dominant mode of stimuli. Again, BVF_face/name performance was significantly faster than the bilateral condition containing just faces, $p < 0.01$. As with the accuracy data, whilst the BVF_face condition was significantly faster than the LVF, $p < 0.01$, it failed to reach significance when compared to the RVF, $p > 0.01$. Consequently there was again no bilateral advantage for faces as has been shown previously.

Unlike the accuracy results, analysis of the unfamiliar data revealed only an advantage for the bilateral condition containing just faces over both the name and complimentary conditions, BVF_face/name v BVF_face, BVF_name/face vs BVF_face, $p > 0.01$. It would appear therefore that a speed-accuracy trade-off has occurred for the unfamiliar BVF_face condition.

These findings appear to demonstrate that additional name information can be successfully combined with facial identity across the hemispheres as indicated by improved performance on these conditions relative to unilateral presentation conditions and also the bilateral presentation of identical faces. Previous research investigating the classification of face and name identification processes has shown that faces can be categorised based on familiarity faster than written names however the same names can be named faster than faces (Young, McWeeny, Ellis & Hay, 1986). Therefore, the results reported here do not seem to reflect an advantage to one stimulus type but rather the pooling of a shared conceptual activation. In addition, due to the very high accuracy results it seems possible that performance ceiling effects may have been reached and thus may obscure the true magnitude of any effects.

The lack of bilateral advantage for famous faces as previously seen is also an unusual finding and may be an artefact of the aforementioned ceiling effects. It seems possible that showing the names of the identities prior to the experiment may have reduced the difficulty of the experiment. Consequently, it may be of value for further investigations in this area to put in place other measures to increase the difficulty (eg. decrease stimulus size).

Given the findings from Experiment 5 indicating interhemispheric cooperation can occur for cross-domain pairings of face and name information, it is of interest to explore this issue further and establish whether as with words, interhemispheric cooperation can also occur for famous personal names.

Experiment 6: Interhemispheric Communication Investigated With Personal Names

Previous studies demonstrating a bilateral advantage for words but not pseudo-words (Mohr et al, 1994) and also for famous but not unfamiliar faces has been taken as evidence that interhemispheric collaboration occurs only for learned complex information. It therefore seems that interhemispheric collaboration, as indicated by a bilateral advantage, is likely to occur for the presentation of famous names but not unfamiliar names in a manner similar to that with famous faces and words. Experiment 6 will investigate this issue whilst also comparing any advantage to the presentation of two identical faces so as to gain a measure of the magnitude of any effect.

Method

Participants

30 participants (17 females) were paid for their participation in this study. Ages ranged from 18 to 24 years (M = 22.4 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 95.7) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli were comprised of the same 32 face and name images used in Experiment 5.

Procedure

The experimental procedure was the same as for previous experiments in this chapter. Presentation conditions were as follows:

(1) Name, left visual field (LVF)
(2) Name, right visual field (RVF)
(3) Name, both visual fields (BVF_name)
(4) Face, both visual fields (BVF_face)

Each identity was shown once in each of the 4 presentation conditions, giving 16 pictures per category and 128 trials in total. As before, a short practice session preceded the experiment proper, but practice faces and names were not shown subsequently. Prior to starting the experiment subjects were shown a list containing the names of the famous faces that would be seen during the trials.

Results and Discussion

Accuracy

Mean correct response rates for familiar and unfamiliar faces in the 4 presentation conditions are shown in Figure 18.

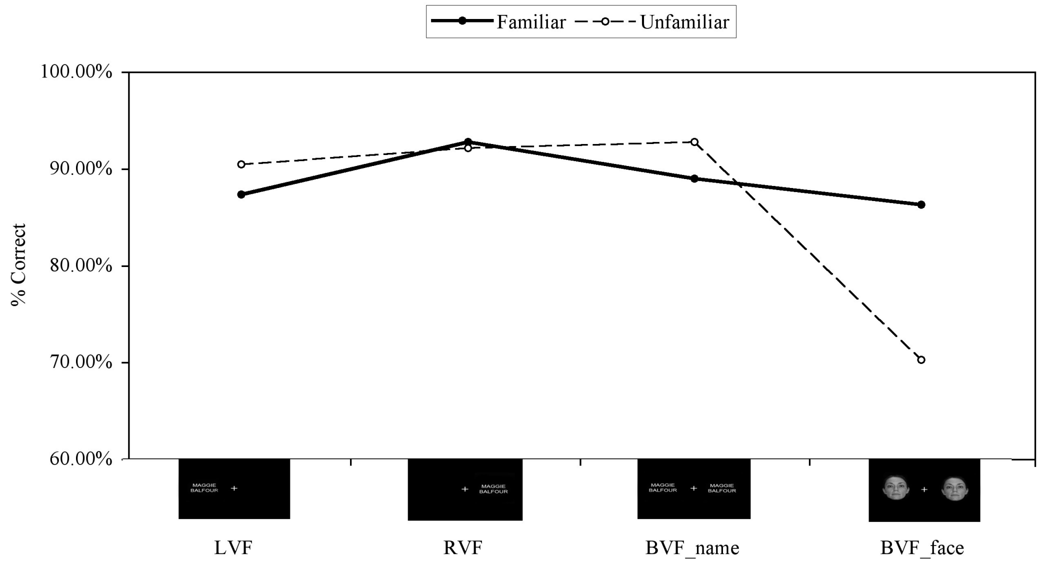

Figure 18. Percentage of correct responses across each of the 4 presentation conditions for familiar and unfamiliar faces.

A two-way within subjects Analysis of Variance was carried out with factors familiarity (familiar / unfamiliar) and presentation condition (LVF / RVF / BVF_names / BVF_faces). There was no main effect of familiarity $F(1, 29) = 1.366$, $MSE = 0.026$, however there was a significant main effect of presentation condition $F(3, 97) = 15.647$, $MSE = 0.016$, $p < 0.01$. In addition, the familiarity x presentation condition interaction was also significant, $F(3, 87) = 13.160$, $MSE = 0.010$, $p < 0.01$.

Analysis of the simple main effects revealed that familiar stimuli were shown to be significantly more accurate than unfamiliar stimuli however only at the BVF_face presentation condition, $F(1,29) = 14.664$, $MSE = 0.026$, $p < 0.01$. Familiar stimuli did not differ significantly across any presentation condition, $F(3, 87) = 1.533$, $MSE = 1.366$, however there was a significant effect of unfamiliar stimuli across presentation conditions, $F(3, 87) = 22.316$, $MSE = 1.366$. Comparison of means using the Bonferroni adjustment revealed that the BVF_face presentation condition was significantly slower than all other conditions, $p > 0.05$.

As with the accuracy results in Experiment 5, it appears that performance may again have reached a ceiling, with scores for conditions reaching close to 100%. Consequently, it is difficult to gain a true measure of any possible collaboration that may be occuring between the hemispheres. There is again an obvious disadvantage for faces compared with names.

Reaction Times

Median reaction times for familiar and unfamiliar faces across the 4 presentation conditions are shown below in Figure 19.

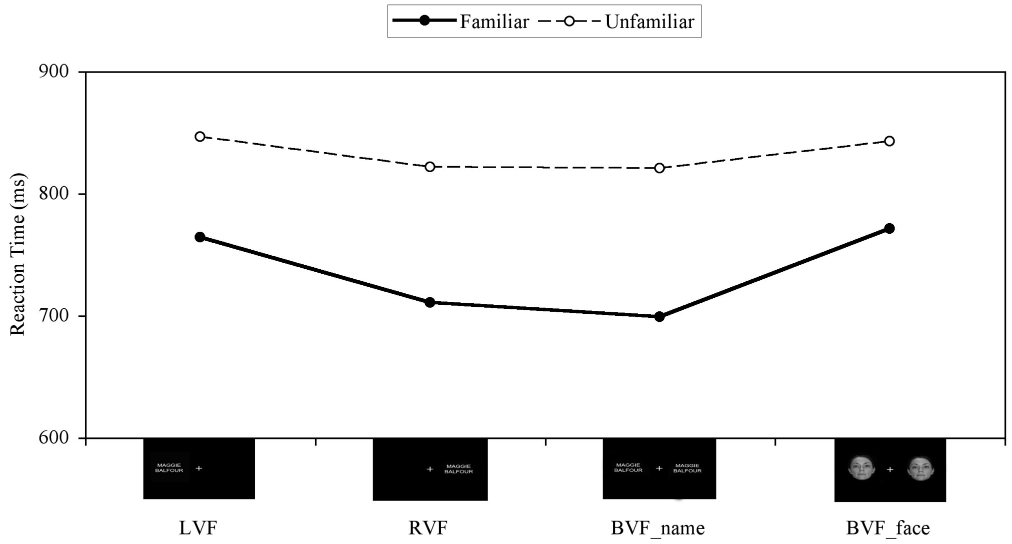

Figure 19. Means of median reaction times across each of the 4 presentation conditions for familiar and unfamiliar faces.

A two-way within subjects Analysis of Variance was carried out with factors as for the accuracy analysis. Results revealed a significant main effect of familiarity, $F(1, 29) = 27.037$, $MSE = 20722.9$, $p < 0.01$, with familiar faces being responded to faster than unfamiliar faces (736ms v 832ms). There was also a significant main effect of presentation condition $F(3, 87) = 5.022$, $MSE = 7493.3$, $p < 0.05$. The familiarity x presentation condition interaction was however not significant, $F(3, 87) = 2.438$, $MSE = 3437.8$.

Contrasts between means for selected factors revealed that the RVF was significantly faster than BVF_face presentation condition, $F(1, 87) = 6.62$, $p < 0.5$. In addition the BVF_name condition was significantly faster than the LVF presentation condition, $F(1, 87) = 8.32$, $p < 0.05$, indicating no real pattern of interest between presentation conditions.

Results for both the accuracy and reaction time performance provide no evidence of any interhemispheric collaboration, possibly as a result of performance ceiling effects. As with Experiment 5, participants were shown the names of the identities they would see during the experiment prior to starting the task and this may have lead to this effect. It would therefore be of interest to repeat this experiment with increased task difficulty, in a manner as described in Experiment 5. It may also be that presenting only single name familiar and unfamiliar stimuli may make them more comparable to the words used in previous experiments that found a bilateral advantage.

Chapter Summary

The aim of the present experiments was firstly to establish whether interhemispheric communication can provide a suitable explanation for the bilateral advantage observed for famous faces (Experiment 3). In addition, the following experiments sought to define the nature of the information communicated during such interaction in an attempt to establish whether this communication occurs at a low sensory or more abstract level of information transfer (Experiments 4, 5 & 6).

Results from Experiment 3 revealed the established bilateral advantage for famous faces (Mohr et al., 2002; Schweinberger et al., 2003). However, no similar performance advantage was observed when both faces were presented centrally. This seems to suggest that the bilateral advantage for famous faces relies on the positioning of faces within the visual system and not merely on the presence of additional stimulus information on bilateral presentations. Whilst such a finding is at odds with Marks and Hellige (1999) who found no advantage for redundant stimuli being presented to both visual fields compared with presentation to the dominant RVF/LH, it may simply be that an advantage for interhemispheric processing is seen only when stimuli are sufficiently complex, such as the use of faces in Experiment 3. Complex stimuli may have more distributed neural networks with links spanning both hemispheres whilst more basic CVC stimuli may only be represented in a single hemisphere. In this way, bilateral presentations may only provide a processing advantage for complex stimuli due to the ignition of wider of neural networks. Consequently, a model of interhemispheric interaction based on Hebbian learning mechanisms seems more useful than a race model in explaining these findings, a claim supported by several neuroimaging and neuropsychological results (Mohr, Endrasss, Hauk, & Pulvermüller, 2007; Pulvermüller, 2005).

However, according to a transcortical cell assembly account of the bilateral advantage, it is also assumed that redundancy gains could be found for meaningful, learned stimuli presented both unilaterally and bilaterally. Mohr et al. (1996) tested this hypothesis using words and pseudowords through comparing unilateral redundant stimulation (two stimuli in either the LVF or RVF) with bilateral redundant stimulation in which one or two stimuli were presented simultaneously in each visual field. Results revealed that when two-word stimuli were presented, no difference was observed between RVF and bilateral conditions. However, when four stimuli were presented (two to each visual field), this produced the optimal performance compared with all other conditions. It was argued that summation in interhemispheric networks might occur within or between hemispheres when several copies of a stimulus are presented at the same time, regardless of stimulus location (Mohr et al. 1996). However, it was not possible to determine the influence of redundancy on unilateral stimulation using this design. The results of Experiment 3 seem to suggest that presenting stimuli to both hemispheres may have an additional effect on the bilateral redundancy gain, perhaps as stated above due to the fact that bilateral stimulation may result in the ignition of more widespread cell assemblies than when only a single hemisphere is stimulated. Further experiments directly comparing redundant unilateral and bilateral stimulation would however be needed to fully establish this.

Given this result, Experiment 4 presented different images of the same identity to each hemisphere to establish if the bilateral advantage is reliant on identical images. Results demonstrated that the bilateral advantage is not an image specific effect, suggesting that hemispheric communication may be occurring at a more abstract level of processing, perhaps related to identity. These findings are consistent with several other studies in the field examining the nature of information combined during the bilateral advantage (e.g. Marks & Hellige, 2003; Patel & Hellige, 2007). Marks and Hellige (2003) presented participants with three-digit numbers as either digit trigrams or as dot-pattern trigrams. These stimulus formats were combined on bilateral redundant trials to produce bilateral consistent and inconsistent conditions in which trigrams would either be in the same format or represent the same numeric quantity in different formats respectively. Consistent with our findings in Experiment 4, results revealed a bilateral gain even when the numeric formats of the stimuli differed. This again indicates that the bilateral advantage is not confined to instances in which physically identical stimuli are used. Of particular interest was the additional finding that the greatest bilateral gain was found when stimuli were presented in the same numeric format. This again mirrors our finding in Experiment 4 in which the greatest bilateral advantage was found when identical famous faces were presented to both hemispheres. In addition, it should be highlighted that the bilateral advantage observed in Experiment 4 only occurred for famous but not unfamiliar faces. This once again lends support to a model of hemispheric communication dependent upon TCAs acquired for learned stimuli only.

Experiments 5 and 6 examined the impact of presenting additional name information (Experiment 5) and also compared how combining familiar names compared to that of familiar faces (Experiment 6). Results revealed that additional name information can be successfully combined with facial identity across hemispheres as indicated by improved performance on these conditions relative to unilateral presentation conditions and the bilateral presentation of identical faces. As with Experiment 2 in Chapter 2, performance was particularly high and consequently ceiling effects may have been reached and obscured the magnitude of any communication. Experiment 6 revealed no real evidence of collaboration occurring for personal names. Such a finding is surprising given previous demonstrations of a bilateral advantage for words. It may be this result has arisen due to an experimental artefact such as the personal names used in Experiment 6 consisted of both a first and last name whilst experiments demonstrating a bilateral advantage with words have used single word items. An issue for future research may therefore be to present famous personal names recognisable from one name only.

The finding in Experiment 5 in which performance was faster when each hemisphere received its preferred stimulus input is particularly interesting. This result suggests that not only can information be communicated cross-hemispherically but the cerebral hemispheres can utilise their differential dominance for name and face processing to optimise the bilateral advantage and this information transfer. Therefore, cross-domain communication can occur with the optimal collaboration occurring when faces are presented to the LVF/RH and corresponding names to the RVF/LH. This finding lends support to the idea that differential hemispheric processing biases arise as a result of cell assemblies that are distributed asymmetrically across both hemispheres with denser connections contained within the specialised hemisphere. Therefore, given that interhemispheric collaboration was greatest when faces were presented to the LVF/RH and corresponding name to the RVF/LH compared to the reverse face/name presentation this may be explained in terms of spreading activation from the dominant to the less dominant hemisphere.

The findings of Experiments 4 to 6 indicate that both superficial and conceptual aspects of the stimulus contribute to the bilateral advantage. Given that most callosal fibers connect homologous regions of the cerebral hemispheres, this finding is perhaps to be expected (e.g. Vercelli & Innocenti, 1993). Therefore, it is possible that different identity formats such as different images of the same identity or personal names may activate areas of the cortex and hence cell assemblies that whilst similar are not completely identical. Consequently, what appears to be important is that each identity format activates sufficiently homologous areas so as to provide adequate activation to produce a bilateral advantage. As observed in Experiment 4, such an advantage may however be less robust than if identical stimuli were presented to both hemispheres. This idea that different stimulus formats access related yet distinct cortical access routes receives support from Patel and Hellige (2007), who demonstrated, in a task difficulty paradigm, that mixing stimulus formats within a hemisphere can increase the processing capacity of that hemisphere, a concept that will be explored further in Chapter 5. It therefore appears that as suggested by Marks

& Hellige (2003), the size of the bilateral advantage may be a product of the extent to which stimuli on bilateral trials activate homologous areas in both hemispheres.

Experiment 5 demonstrated that the bilateral advantage could be enhanced for cross-domain face/name pairings and so an area for further research would be to establish whether this advantage could also be found using semantic information related to a particular identity. It has been proposed that the perceptual and semantic information related to face processing may be differentially lateralised with the right hemisphere specialising in the processing of perceptual information whilst semantic aspects of the face may show either a bilateral or more left hemisphere distribution (Ellis, 1983; Rhodes, 1985; Kampf, Nachson, & Babkoff, 2002). This being the case, not only might evidence of interhemispheric communication be found, adding weight to an account of the information transfer based on FRU-like structures, but it may also provide a means to maximise this collaboration through presenting each hemisphere with its dominant mode of stimuli.

Thus far, it has been demonstrated that information can be communicated cross-hemispherically for a range of face stimuli and formats, with the evidence suggesting that information transfer is reliant on abstract aspects of the stimuli, perhaps related to identity. The next chapter now turns to the issue of priming and whether this effect can be observed both within and cross-hemispheres.

Chapter 4

Within And Across Hemisphere Repetition Priming With Familiar Faces

Introduction

The experiments in Chapter 3 examined the nature and scope of interhemispheric cooperation through the use of a divided visual field paradigm in which various face and name manipulations were made. Results revealed that both abstract identity information and cross-domain face-name pairings could be communicated interhemispherically, with optimal communication occurring when each hemisphere received its dominant mode of stimuli. Many of the qualities of the interhemispheric communication observed appeared to be consistent with the systems governing face processing.

Another means through which interhemispheric cooperation can be examined is through the use of priming paradigms. Priming refers to the phenomenon in which prior exposure to a stimulus facilitates its subsequent processing. Repetition priming in the face domain is well established (e.g. Ellis, Young, Flude & Hay, 1987; Lewis & Ellis, 2000) with robust effects that are long lasting and persistent through changes in image (Bruce & Valentine, 1985; Ellis, Flude, Young & Burton, 1996), and judgement between prime and test (Ellis, Young & Flude, 1990). It has also been demonstrated that repetition priming prevails even with a lack of explicit judgements being made to stimuli (Jenkins, Burton & Ellis, 2002). However, larger priming effects are nonetheless observed when the same item is presented at prime and test (Ellis, et al, 1996). In the case of repetition priming using familiarity decisions, the effect has also been shown to be domain specific (e.g. Bruce & Valentine, 1985) and reliant on the use of familiar faces (Campbell & de Haan, 1998). Perhaps the most widely accepted explanation for such repetition priming effects comes from the IAC model of person recognition (Burton, Bruce & Johnston, 1990), in which presentation of a familiar face is believed to lead to strengthening of the links between the face recognition units (FRUs) and associated person identity nodes (PINS).

One way in which typical priming investigations can be adapted to study interhemispheric communication is through the use of a divided visual field paradigm in which prime and target stimuli are presented to either the same or opposite visual fields. Given the architecture of the visual system, it follows that priming will only occur on across visual field trials if information that is presented to opposite hemispheres is shared. Specifically, interhemispheric communication should allow for primes presented to one hemisphere to impact upon subsequent recognition in the other hemisphere. Not only can this paradigm provide a means for investigating interhemispheric communication through across-field presentations, but intrahemispheric abilities can also be examined in conditions where prime and target are presented to the same hemisphere, requiring no interhemispheric communication.

Several studies have adopted this methodology to explore the lateralisation of language and semantic processing (e.g., Abernethy & Coney, 1996; Collins, 1999; Koivisto & Hämäläinen, 2002). However, to date only two studies have examined lateralised repetition priming in the face domain (Bourne & Hole, 2006; Cooper, et al, 2007). Bourne & Hole (2006, experiment 1) presented participants with lateral prime faces followed by the same image as a central target. Results demonstrated evidence of priming for familiar faces preceded by LVF/RH primes yet no similar effect for RVF/LH primes. This finding was extended by Cooper, et al (2007) through the presentation of lateral primes again followed by centrally presented targets. However, this study differed from Bourne & Hole's, (2006) in that they presented different images of the same identity at prime and test as a means of testing for abstractive priming. Results revealed priming effects for both image–specific and abstractive priming conditions with hemispheric differences in the processing capabilities for these prime and target types also emerging. They concluded that the right hemisphere stores and processes images in an image-dependent manner whilst the left hemisphere operates in a more abstract fashion.

Bourne & Hole (2006, Experiment 2) also explored interhemispheric communication through a repetition priming paradigm in which the same image of familiar and unfamiliar faces were presented at prime and test to either the same or opposite visual fields. Evidence for within LVF/RH priming was found yet no within RVF/LH priming, a surprising result given that both hemispheres are believed to contribute to face processing despite a RH dominance. Importantly, they also found evidence of across-hemisphere priming and consequently interhemispheric cooperation. Whilst this cooperation was observed to occur in both directions (LH to RH and RH to LH), there was evidence of an asymmetry in communication, with greater cooperation occurring from the RH to LH than vice versa. Specifically, transfer of information from the LVF/RH (prime) to RVF/LH (target) facilitated priming in comparison to the within RVF/LH condition, suggesting that interhemispheric cooperation most likely occurred from the RH to the LH to facilitate recognition. In addition, as the reverse effect was not observed when the prime was presented to the RVF/LH and target to LVF/RH, it appears that interhemispheric communication can act to facilitate recognition. The asymmetry of this communication has been explained by way of a RH dominance for face processing (Bourne & Hole, 2006).

However, whilst Bourne & Hole (2006), provide evidence for interhemispheric cooperation for familiar faces using a repetition priming framework, their use of the same image at prime and test leaves open the possibility that the priming effect observed in this study reflects image rather than face-specific identity priming. The present studies therefore aim to extend these findings presented above and to explore whether abstractive identity priming can also occur both within and across the cerebral hemispheres.

Experiment 7: Within And Across Hemisphere Repetition Priming Using Different Images At Prime And Test.

Experiment 7 aims to extend the findings of Bourne & Hole (2006), in which asymmetric repetition priming was observed to occur both within and across hemispheres. Specifically, the presentation of different images of the same identity at prime and test to opposite visual fields should help establish whether cross-hemispheric abstractive priming is possible and consequently provide evidence of interhemispheric cooperation. Given the findings of Cooper, et al. (2007), in which image-specific and abstractive hemispheric priming was observed, combined with the evidence of abstract interhemispheric communication reported in Chapter 3, it would seem that such abstract cross-hemispheric priming is likely. Whilst repetition priming for identities survives a change of image between prime and test, priming is largest when identical images are used (e.g. Ellis, et al, 1996). Therefore, any observed priming effects in this present study may be smaller in magnitude than those reported previously. The presentation of prime and targets within hemisphere will also provide further insight into the operation of each hemisphere in isolation whilst the interhemispheric condition may provide interesting insight into role of interhemispheric communication during face processing.

Method

Participants

32 participants (16 females) were paid for their participation in the study. Ages ranged from 18 to 24 years (*M* = 20.2 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 94.78) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Prime Phase

Stimuli comprised photographs of 32 British and 32 American celebrities. Famous faces consisted of well-known politicians, actors, singers and sports stars and were obtained from the Internet. All were high-resolution photographs, showing full-face views in grey scale. On screen image size was approximately 4.5cm x 6.5cm corresponding to a visual angle of 4.5 x 6.5 degrees shown at distance of 57cm.

Stimuli eccentricity was 3.0cm (centre to innermost edge) corresponding to 3º visual angle.

Target Phase

Different (unseen) images of the same 64 celebrities used in the prime phase were shown as stimuli. These identities were shown either in the same visual field as the prime identity or in the opposite visual field, so that both within and across hemisphere priming could be assessed. An additional 32 famous and 96 unfamiliar faces were also presented as stimuli (half to the left visual field and half to the right visual field). Unfamiliar faces comprised images of anonymous male and female models, which were selected to provide a close match for the famous faces in terms of approximate age, good looks and distinguishing features. During the course of the whole study, the face images were rotated around all experimental conditions so that each face appeared in each condition an equal number of times. Again, as with the prime phase, all images were high-resolution photographs, showing full-face views in grey scale. On screen image size was approximately 4.5cm x 6.5cm corresponding to a visual angle of 4.5 x 6.5 degrees shown at distance of 57cm. Stimuli eccentricity was 3.0cm (centre to innermost edge) corresponding to 3º visual angle.

Procedure

Participants were seated at a fixed distance of 57cm from a 16inch monitor of an Apple Macintosh G5 Workstation and used a chin-rest with a forehead restraint bar centred relative to the viewing screen.

For the Prime Phase, participants were presented with faces for which they were to make a British or American nationality decision. They were instructed not to move their eyes from the fixation cross, and to perform as fast and accurately as possible. Trials began with the presentation of a central fixation cross for 1500ms followed by a face for 150ms in either the LVF/RH or RVF/LH which was immediately followed by a backward mask comprised of a scrambled face shown centrally for 1850ms. The fixation cross remained on screen during stimulus presentation. The inter-trial duration was 500ms in which a blank screen was shown. Responses were recorded for 2000ms after stimulus onset and any response after this period was deemed to be a miss and the next trial was initiated.

Each identity was shown once in either the LVF/RH or RVF/LH comprising 64 trials in total. Order of trials was independently randomised for each participant. A short practice session consisting of all experimental conditions preceded the experimental session. Practice faces were not shown subsequently.

Manual responses were made by computer keyboard. All responses were made bimanually by pressing two “British” keys with the middle fingers of the left and right hands and two “American” keys with the index fingers of both hands. Key assignment was counter-balanced between participants. Although bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used. The experiment was controlled using PsyScope version 10. A trial summary for prime and target conditions can be seen in Figure 20.

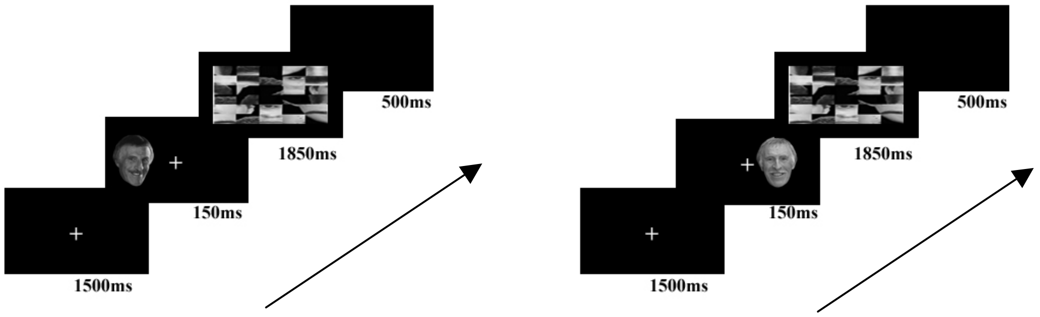

Figure 20: Trial summary for (i) Prime LVF/RH and (ii) Target RVF/LH conditions. This example shows an across LVF/RH to RVF/LH trial**.**

Following completion of the prime phase, subjects were instructed via an onscreen message to contact the experimenter. After this short break, the unexpected test phase was initiated. The experimental procedure for this phase was identical to the prime phase however subjects were this time instructed to make speeded familiarity decisions to the presented faces. Again, responses were made via a bimanual keyboard response with two “familiar” keys with the middle fingers of the left and right hands and two “unfamiliar” keys with the index fingers of both hands. Key assignment was again counter-balanced between participants. Subjects underwent 4 experimental blocks consisting of 64 trials totalling 192 trials. Order of trials was independently randomised for each participant.

Results and Discussion

Prime Phase

The main purpose of the task in the prime phase was to ensure subjects were focusing on the target stimuli. Incorrect responses were discarded and mean RTs and accuracy were calculated for responses to LVF/RH and RVF/LH conditions.

	LVF/RH	RVF/LH
Reaction Time (ms)	990.8	1023.8
Percentage Correct	67.32%	67.06%

Table 3: Mean reaction times and accuracy for Prime Phase stimuli presented to the left and right visual fields.

Prime phase data was not analysed further.

Target Phase

Reaction Times

The data of principal interest were the responses to primed and unprimed famous faces presented during the test phase.

Means of median correct reaction times for the different experimental conditions are shown below in Figure 21

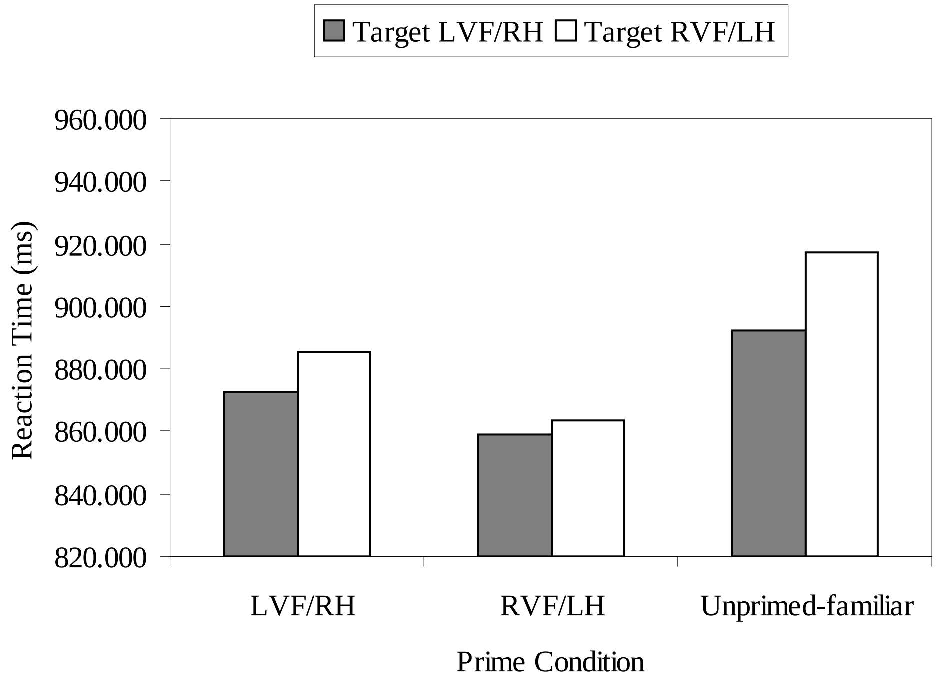

Figure 21. Means of median reaction times to famous faces in the target phase of Experiment 7.

A two-way within subjects ANOVA was carried out with factors Prime Condition (LVF(RH) / RVF(LH) / unprimed) and Target Visual Field (LVF(RH) / RVF(LH)). There was only a significant main effect of prime condition, *F*(2, 62) = 4.151, *MSE* = 7391.4, $p < 0.05$. Neither the main effect of Target Visual Field, *F*(1, 31) = 0.948, *MSE*= 9962.95, or the Prime Condition x Target Visual Field interaction, *F*(2, 62) = 0.180, *MSE* = 9733.82, reached significance.

Comparisons between means for selected factors for the factor Prime Condition revealed only a significant difference between the unprimed and primed RVF/LH conditions, $F(1, 62) = 8.20$, $p < 0.01$.

Accuracy

Percentage of correct responses across experimental conditions is shown below in Figure 22.

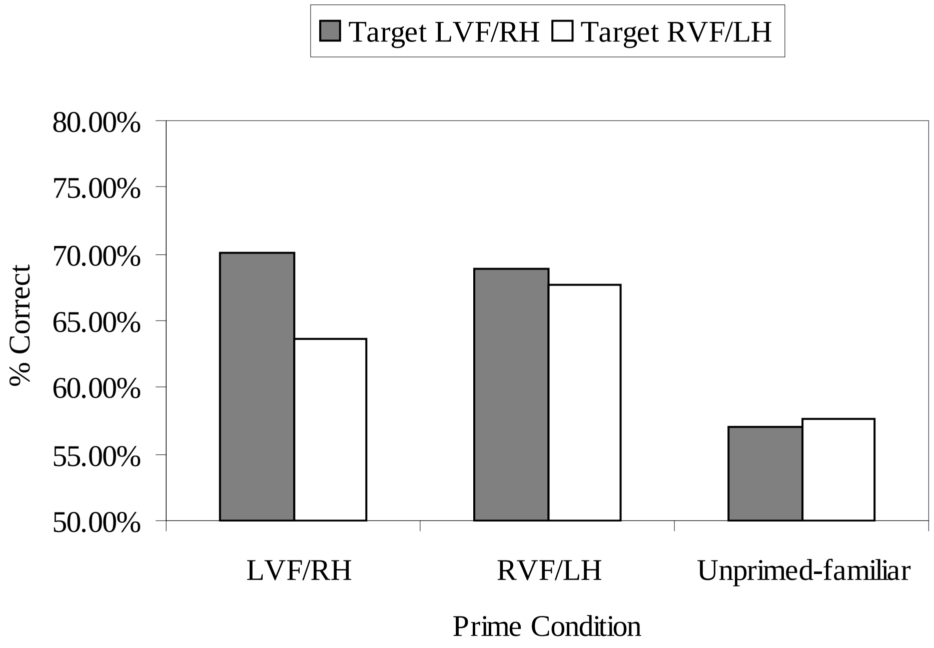

Figure 22. Correct responses across each of the experimental conditions.

A two-way within subjects Analysis of Variance was carried out with factors as for the Reaction Time analysis. Results again revealed only a significant main effect of Prime Condition, $F(2,62) = 16.663$, $MSE = 0.014$, $p < 0.01$. In addition, both the main effects of Target Visual Field, $F(1,31) = 1.933$, $MSE = 0.014$, and the Prime

Condition x Target Visual Field interaction, *F*(2, 62) = 1.965, *MSE* = 0.011, did not prove significant, $p > 0.05$.

Comparison between means for selected factors for the factor Prime Condition revealed that both the LVF/RH and RVF/LH conditions were significantly more accurate than the unprimed condition; LVF/RH v unprimed, *F*(1, 62) = 21.24, $p < 0.01$, RVF/LH vs unprimed, *F*(1, 62) = 28.25, $p < 0.01$. This finding indicates evidence of priming given that both prime conditions were significantly more accurate than the base-line unprimed condition. There was however no difference between the LVF/RH and RVF/LH prime conditions, *F*(1, 62) = 0.50, $p > 0.05$, therefore indicating no asymmetry in recognition facilitation for targets to either visual field.

Results from Experiment 7 therefore indicate that whilst abstractive priming can indeed occur both within and across hemispheres, there is no evidence of any asymmetry between the direction of interhemispheric communication or between any prime conditions. Participants were equally facilitated by primes presented in the same or opposite visual field to target faces with no differentiation in performance between within and across hemisphere conditions. Whilst the finding of interhemispheric identity priming was anticipated, the fact that the asymmetry in interhemispheric communication observed by Bourne & Hole (2006) was not seen, is more surprising. Given that the use of different images at prime and test usually weakens priming effects compared to same image presentations, it might be expected that performance across all conditions might incur greater costs. However, not only did there appear to be any observable costs for interhemispheric communication but priming also occurred when both prime and target were presented to the RVF/LH, again an effect not observed by Bourne & Hole, (2006). The LH is known to have face processing capabilities despite being less dominant than the RH and so priming within this hemisphere is perhaps to be expected. For reasons stated above, it is unclear why these results differed from previous experiments presenting the same image at prime and test. Whether such differences in results observed between those of the current experiment and those of Bourne & Hole (2006) can be explained by differences in processing style or differences between experimental methodologies will be explored in Experiment 8.

Experiment 8: Repetition Priming Using The Same Image At Prime And Test

The aim of Experiment 8 was to re-examine the issue of repetition priming within and across the cerebral hemispheres however through presenting the same face images at prime and test. The purpose of this manipulation is an attempt to determine whether the lack of performance differentiation across prime conditions observed in Experiment 7 can be attributed to differences in processing mechanisms for image-specific and abstractive cross-hemispheric priming. Specifically, if evidence of an asymmetry between interhemispheric communication is observed, then this may imply that the lack of such an effect in Experiment 7 could be attributed to a difference in processing for image specific and abstractive interhemispheric priming. Alternatively, a repeat of an undifferentiated priming effect may simply imply that differences between experimental manipulations and methodology between this experiment and Bourne & Hole’s (2006) study are accountable for the effect.

Method

Participants

24 participants (16 females) were paid for their participation in the study. Ages ranged from 18 to 26 years (M = 21.3 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 95.32) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli comprised the same images used in Experiment 7. However, whilst Experiment 7 presented different images of the same identity at prime and test phases, in Experiment 8 identical images of each identity were presented at these stages. On screen image size was again approximately 4.5cm x 6.5cm corresponding to a visual angle of 4.5 x 6.5 degrees shown at distance of 57cm. Stimuli eccentricity was 3.0cm (centre to innermost edge) corresponding to 3^{o} visual angle.

Procedure

The experimental procedure was the same as for Experiment 7. An example of the prime and target phases can be seen below in Figure 23.

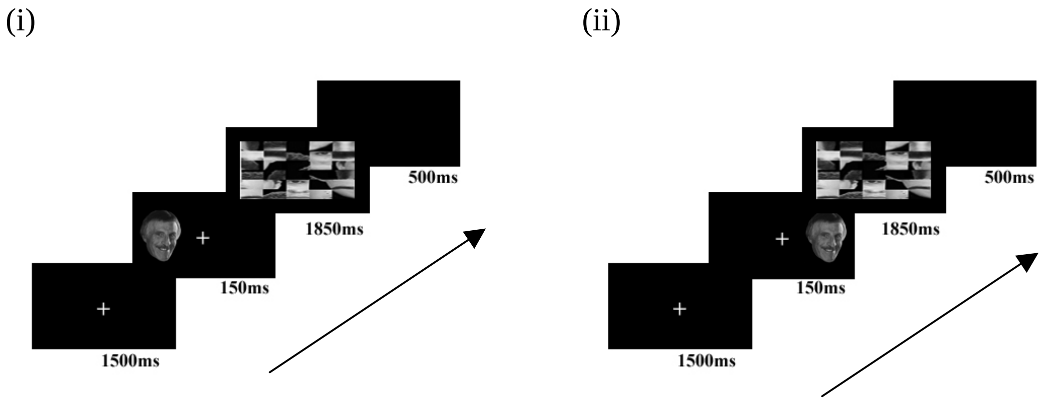

Figure 23**:** Trial summary for (i) Prime LVF/RH and (ii) Target RVF/LH conditions. This example shows an across LVF/RH to RVF/LH trial.

Results and Discussion

Prime Phase

As with Experiment 7, the main purpose of the prime phase was to ensure subjects were focusing on the target stimuli. Incorrect responses were discarded and mean RTs and accuracy were calculated for responses to LVF/RH and RVF/LH conditions.

	LVF/RH	RVF/LH
Reaction Time (ms)	1050.3	1058.5
Percentage Correct	68.27	63.63

Table 4: Mean reaction times and accuracy for Prime Phase stimuli presented to the left and right visual fields.

Prime phase data was not analysed further.

Target Phase

Reaction Times

Again, the data of principal interest were the responses to primed and unprimed famous faces at test phase.

Means of median reaction times for the different experimental conditions are shown below in Figure 24.

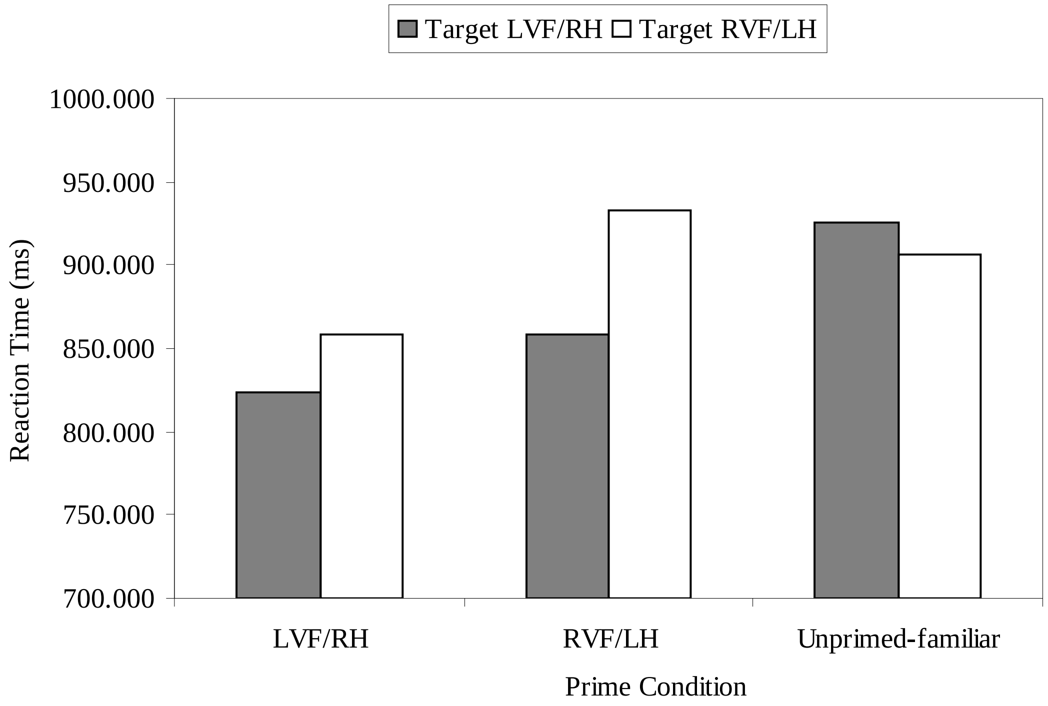

Figure 24. Means of median reaction times to famous faces in the test phase of Experiment 8.

A two-way within subjects Analysis of Variance was carried out with factors Prime Condition (LVF(RH) / RVF(LH) / Unprimed) and Target Visual Field (LVF(RH) / RVF(LH)). Results revealed a main effect of target visual field, $F(1, 23) = 5.968$, $MSE = 5509.7$, $p < 0.05$, and of prime condition, $F(2, 46) = 6.788$, $MSE = 10585.2$, $p < 0.01$. In addition there was a significant prime condition x target visual field interaction, $F(2, 46) = 4.296$, $MSE = 6135.2$, $p < 0.05$.

Analysis of the simple main effects revealed that for the factor Target Visual Field, there was a significant difference between reaction times only at the RVF/LH prime condition, $F(1,23) = 12.00$, $MSE = 5509.7$, $p < 0.001$, with responses being significantly faster when targets were shown to the LVF/RH compared with the RVF/LH. Specifically, the across_RVF/LH to LVF/RH conditions was significantly faster than the within RVF/LH. This finding is in-line with the findings of Bourne & Hole (2006) and presumably reflects processing assistance from the dominant right hemisphere in the across field condition.

There was also shown to be a significant effect of prime condition for both LVF/RH, $F(2, 46) = 6.10$, $MSE = 10585$, $p < 0.001$, and RVF/LH targets, $F(2, 46) = 3.178$, $MSE = 10585$, $p < 0.051$. Looking first at the LVF/RH target conditions, comparing means using the Bonferonni adjustment indicated that when primes were shown to either the LVF/RH or RVF/LH (i.e. prime and target to LVF/RH or prime RVF/LH and target LVF/RH), responses were significantly faster than the unprimed condition ($p < 0.05$). This is an important finding as it indicates that for LVF/RH targets, priming can occur within and across hemispheres. Again this is in-line with the findings of Bourne & Hole (2006). There was no significant difference between reaction times for the LVF/RH and RVF/LH prime conditions suggesting that performance is equally facilitated by RH targets, regardless of whether primes are shown within or across visual fields and with no subsequent cost for interhemispheric communication.

Interestingly, in the case of the RVF/LH targets, there was this time a significant difference between LVF/RH and RVF/LH prime conditions ($p < 0.05$). Specifically, responses when primes were shown to the LVF/RH and targets to the RVF/LH condition were significantly faster than when both prime and target were shown within RVF/LH. This finding again suggesting that RH primes aid subsequent recognition possibly through the transfer of information from the dominant to the less dominant hemisphere. In addition, whilst responses to the LVF/RH prime condition compared to the unprimed condition were not significantly faster, there does appear to be a definite trend in that direction. Interestingly, there was also no significant difference between reaction times to the RVF/LH prime and unprimed conditions, indicating no evidence of priming occurring within the LH. Again this finding differs from results in Experiment 7 in which priming was observed for both prime and targets to the RVF/LH conditions yet it is consistent with the findings of Bourne & Hole (2006).

Accuracy

Percentage of correct responses across experimental conditions is shown below in Figure 25.

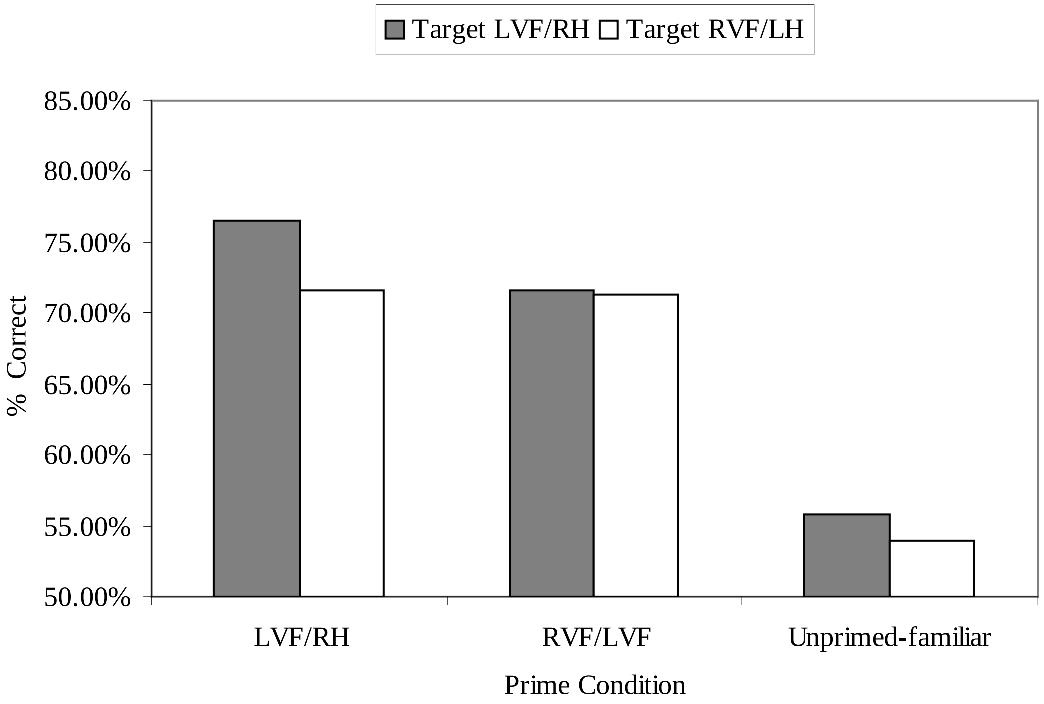

Figure 25. Percentage of correct responses across each of the experimental conditions.

A two-way within subjects Analysis of Variance was carried out with factors as for the Reaction Time analysis. Results revealed a significant main effect of prime condition, $F(2, 46) = 38.381$, $MSE = 0.014$, $p < 0.001$, but no main effect of target visual field $F(1, 23) = 2.113$, $MSE = 0.009$. The target visual field x prime condition interaction also failed to reach significance, $F(2, 46) = 0.389$, $MSE = 0.018$.

Comparisons between means for prime conditions revealed that the LVF/RH and RVF/LH conditions were significantly more accurate than the unprimed condition, $p < 0.01$, reflecting priming for both LVF/RH and RVF/LH prime conditions. There was no significant difference between accuracy for the RVF/LH and LVF/RH prime conditions, $p > 0.05$. The accuracy results therefore reflect a similar pattern of results as those observed in Experiment 7 in which priming occurred for all conditions without differentiation or costs for interhemispheric transfer.

The results of Experiment 8 therefore provide some evidence of an asymmetric repetition priming effect using identical familiar face images at prime and test, similar to that reported by Bourne & Hole (2006). It appears that a face prime in one hemisphere impacts on recognition of a target face in the opposite hemisphere. Such a result is indicative of the process of interhemispheric communication. Moreover, primes to the LVF/RH followed by RVF/LH targets facilitated priming in terms of reaction times compared to conditions in which prime and target were both presented to the RVF/LH. This finding suggests that interhemispheric cooperation occurred from the RH to the LH to aid recognition. However, a similar facilitative effect on processing was not observed when primes were shown to the LH and targets to the RH when compared to within RH prime and targets. This finding suggests that greater cooperation appears to occur from RH to LH than vice versa.

Not only are the results of Experiment 8 in-line with those expected given the relative RH dominance for face processing but they also appear to concur with the asymmetric priming effects observed by Bourne & Hole (2006). This therefore suggests that there may be different processing mechanisms at work for the abstract priming effect observed in Experiment 7 and the image-specific priming observed in Experiment 8 which cannot easily be explained through methodological differences between these and previous experiments.

Chapter Summary

The present experiments were designed to establish whether previously observed asymmetric interhemispheric cooperation achieved through repetition priming (eg. Bourne & Hole, 2006) is reflective of image-specific or more abstract identity priming. This was achieved using a divided visual field priming paradigm in which different images of the same identity were presented at prime and target phases, either within the same visual field or to opposite visual fields (Experiment 7). In addition, it was attempted to determine whether the undifferentiated priming advantage observed during Experiment 7 arose as a result of processing or methodological differences between studies (Experiment 8).

Results from Experiment 7 revealed evidence of abstractive repetition priming, with performance to target faces showing improved performance relative to unprimed faces both within each hemisphere and when prime and target were presented to different visual fields. This finding therefore provides evidence of interhemispheric cooperation with performance in one hemisphere being directly influenced by the presentation of a stimulus to the opposite hemisphere. This finding of interhemispheric identity priming is inline with previous studies in the field that have shown evidence of lateralised abstractive hemispheric priming with unilateral primes followed by central targets (e.g. Cooper, et al, 2007). The results of Experiment 7 are however the first to display that this abstractive priming effect can also occur cross-hemispherically.

However, whilst previous displays of interhemispheric cooperation using repetition priming with faces have shown communication to occur asymmetrically between the hemispheres (Bourne & Hole, 2006), no such similar pattern of results was displayed here in Experiment 7. Specifically, whilst Bourne & Hole (2006) showed a facilitative priming effect occurring in the direction of RH to LH, the results of Experiment 7 indicate that target faces are equally facilitated by primes presented to both the LVF/RH and RVF/LH. This lack of communication asymmetry appears to be driven by the occurrence of priming within the RVF/LH condition, an effect which was not reported in Bourne & Hole's (2006) study. Whilst the occurrence of priming within the LH itself is not surprising given the existence of LH face processing capabilities, priming effects are normally diluted when different images are presented at prime and test compared to instances in which the same images are used (e.g., Bruce & Valentine, 1985; Ellis, et al, 1987). It would therefore be expected that such within LH priming should also have been observed when identical images were presented as prime and target, as in the study carried out by Bourne & Hole, (2006). The question therefore arises as to why this difference exists between performance patterns for image-specific and abstractive priming. One simple explanation could be that methodological differences between the two experiments are responsible for creating this disparity in results. For example, different task demands and procedures were employed by each experiment along with different methods of analyses. Alternatively, such differences could instead reflect a difference in processing strategy between these two interhemispheric priming studies. Whilst some evidence does exist to suggest the underlying processes for same and different image priming is not qualitatively different (e.g. Schweinberger, Pickering, Burton & Kaufmann, 2002) there are instances in which effects that are robust behaviourally can be difficult to locate using imaging techniques. Therefore, this possibility is worth consideration.

Experiment 8 therefore re-examined the priming paradigm initially reported by Bourne & Hole (2006) in which identical images were presented at prime and test however using the same methodology as set out in Experiment 7. It was hypothesised that if a lack of asymmetry was also observed in Experiment 8 then methodological reasons, rather than processing differences, may be causing the disparity in results between those observed in Experiment 7 and Bourne & Hole (2006). As with Experiment 7, results of Experiment 8 again revealed evidence of cross-hemispheric repetition priming when the same image was presented at prime and test. In addition, this facilitation was also observed to be asymmetrical. Specifically, primes to the LVF/RH followed by RVF/LH targets facilitated priming in terms of reaction times compared to conditions in which prime and target were both presented to the RVF/LH. Interhemispheric cooperation therefore appeared to occur from the dominant RH to the less dominant LH. When performance for prime and targets presented to the LVF/RH was compared to the cross–hemispheric RVF/LH prime and LVF/RH target condition, a similar facilitation in processing was not observed. It therefore appears that cooperation occurring from the RH to LH is greater than the communication occurring between the hemispheres in the reverse direction. The direction of this cooperation implies that, as with previous studies, the processing superiority of the RH for faces is acting to facilitate the less able LH (Bourne & Hole, 2006).

Given that this asymmetry in interhemispheric cooperation only appears to be observed during image-specific priming paradigms, it remains to be established why such a difference between these two priming paradigms exists. It seems likely that the lack of evidence of any priming within the LH in Experiment 8 is of primary importance. Various studies have demonstrated a LH involvement in face processing however it is believed to differ qualitatively from the more dominant processing abilities of the RH (Schweinberger et al, 2002). For example, Cooper et al, (2007) showed that the LH stores complex visual information in a more abstract, image independent manner compared with a more image-specific processing style of the RH. Bourne & Hole (2006) suggested that timing differences between levels of FRU activation in the LH and RH might underlie the lack of observed within LH priming in their study. In particular, they hypothesised that face recognition may have a longer lasting effect on the RH which in turn could allow for the within hemisphere priming effects observed. LH activation however may be shorter-lived so that activation within this hemisphere following a prime face could diminish quicker and hence the subsequent presentation of a target face will fail to have the same impact upon recognition. One speculative explanation as to the source of the observed differences between the asymmetrical priming effects could be that the presentation of different images of the same identity results in activation of more widespread representations that are less lateralised than the representations activated after the presentation of identical images, perhaps in a manner akin to semantic representations. Investigations exploring the interhemispheric semantic priming with faces may help elucidate this matter.

Other experiments examining interhemispheric semantic word priming have also revealed an asymmetry in communication with greater communication occurring from the RH to LH than vice versa (Abernethy & Coney, 1996; Collins 1999; Koivisto & Hämäläinen, 2002) making clear that this asymmetrical priming effect can be generalised to a broader range of stimuli. However, whilst the direction of this communication is the same as for the reported experiments using faces, it does not occur from the dominant to less dominant hemisphere. It has therefore been suggested that the direction of interhemispheric transfer may not necessarily occur to facilitate processing but rather the asymmetry observed in all of these experiments may instead reflect a more generalised RH to LH asymmetry (Bourne & Hole, 2006).

In relation to the model of interhemispheric cooperation based upon transcortical cell assemblies discussed in previous chapters (Pulvermüller & Mohr, 1996), the priming effects observed in Experiments 7 and 8 again seem to be consistent with this idea. According to this model, the RH dominance for face processing (as with other hemispheric dominances) arises as a result of an asymmetric distribution of cross-hemispheric cell assemblies, in which a greater proportion of these lie within the dominant RH. This may therefore explain why priming effects can be observed both within and across each hemisphere yet why RH involvement appears to be most beneficial.

Thus far, the reported experiments have investigated the nature and scope of interhemispheric communication. The final experimental chapter turns to the issue of the role that interhemispheric communication plays during cognitive processing. Several theories propose that interhemispheric communication can serve to increase general processing capacity when task demands become great, a proposition that will be investigated in the next chapter.

Chapter 5

The Impact Of Task Difficulty On Interhemispheric Communication

Introduction

The previous chapters have demonstrated a variety of means through which interhemispheric cooperation can occur. The current chapter now turns to the issue of exploring the role that interhemispheric cooperation plays in meeting the demands of particular tasks. For example, while interhemispheric communication has been shown to be advantageous in numerous instances, there are occasions in which the benefits of dividing processing between the hemispheres are outweighed by the costs of interhemispheric transfer. Ascertaining more clearly the basis for such a shift in processing style should help to provide further insight into the role that interhemispheric communication plays in cognitive processing.

Much of the research investigating task difficulty in relation to interhemispheric communication has adopted the use of a paradigm in which participants view briefly presented visual arrays of stimuli arranged in a triangular formation. Participants' task is to indicate whether the bottom item of each 3-item display matches either of the top two items (Banich & Belger, 1990). On trials where the matching stimuli are presented in the same visual field, within hemisphere processing is assumed and on trials where matching items are presented in opposite visual fields, interhemispheric cooperation is deemed necessary in order to complete the task. Numerous studies involving letters, patterns, numbers, objects and faces (Brown et al 1999; Koivisto, 2000; Liederman et al, 1985; Weissman & Banich, 2000; Compton 2002) have demonstrated that within-hemisphere processing is most advantageous for relatively simple tasks, yet as task difficulty increases, a across-hemisphere advantage emerges. It has been suggested that such an advantage may arise through the recruitment of additional neuronal populations on across-hemisphere trials to compensate for the costs associated with interhemispheric communication. For example, a robust finding using simple letter stimuli is that interhemispheric interaction appears most beneficial when participants are required to match letters by name (e.g. A and a) than by physical identity (e.g. A and A or a and a), (Banich & Belger, 1990). Such a finding presumably reflects differences in the cognitive demands of these two tasks. The former task of matching letters by name requires both perceptual analysis and retrieval of an abstract letter-name code, an operation which appears to benefit from the increased computational power of both hemispheres. In contrast, the latter less cognitively demanding task of matching letters by physical identity requires only perceptual analysis, and as such can be sufficiently processed by a single hemisphere.

In an adaptation of this matching design, Weissman and Banich (2000) included a condition whereby target stimuli were presented on the visual midline in addition to either the lower LVF and RVF. Midline presentation was considered to allow for either within or across hemisphere processing. Results revealed that during tasks of low complexity, midline performance resembled that of within hemisphere performance whilst high complexity tasks caused a shift to an approximation of across hemisphere trials. This result was taken as further evidence of the dynamic nature of hemispheric cooperation in relation to task difficulty.

Studies manipulating the degree of practice participants have on a given task also suggest that the benefits of interhemispheric communication may arise as a result of the sharing of cognitive resources (Liederman, Merola, & Martinez, 1985; Weissman & Compton, 2003; Maertens, & Pollmann, 2005). Specifically, it can be assumed that following practice, the processing resources required to carryout a task should decrease in line with a similar increase in processing efficiency. Such a shift in ability is believed to reflect a transition from an algorithmic to a more memory-based processing strategy (Logan, 1988). Given that much of the research investigating interhemispheric communication has focused largely on relatively simple tasks involving letters or numbers, the possibility remains that any advantages incurred by interhemispheric cooperation may well be underestimated with even larger gains to be found under circumstances using more complex tasks and stimuli.

Compton (2002), explored this possibility through the implementation of an unfamiliar face-matching paradigm in which participants were required to match faces for either emotional expression (experiment 1) or character identity (experiment 2). Results revealed that for both match-types, performance was superior for across-field matches compared to within. Moreover, this advantage was shown to be greater for the more difficult character identity task. Further support is therefore offered to the theory that interhemispheric cooperation is most beneficial for complex tasks. An asymmetry in this cooperation was also observed, corroborating the findings of Experiment 7 in which the processing efficiency of each hemisphere appeared to determine the impact that interhemispheric cooperation would have.

This extension of the relationship between task difficulty and interhemispheric communication to an unfamiliar face-matching paradigm provides an interesting addition to the existing body of evidence in this field. However, as mentioned previously, significant differences are believed to exist between the processing of familiar and unfamiliar faces (Hancock, Bruce, & Burton, 2000; Clutterbuck & Johnston, 2002). Specifically, individuals have been shown to more readily match familiar compared with unfamiliar faces, with different processing mechanisms believed to be responsible for this effect (Burton, et al, 2005). It is therefore of interest to explore further the role that interhemispheric communication plays during familiar face perception. Given the automatic processing ability uniquely associated with familiar face matching, it might be expected that the benefits of dividing information across the hemispheres will follow different patterns for familiar and unfamiliar faces.

Experiment 9: The Impact Of Interhemispheric Division Of Labour On Face Recognition.

The aim of Experiment 9 was to examine the impact of manipulations of task difficulty on interhemispheric communication during face perception. More specifically, it sought to establish the effect caused by controlling the cognitive demands of a task through dividing task relevant and task irrelevant stimuli within or across the hemispheres. The experimental design of Experiment 9 was adapted from a study investigating the long-term effects of covert face recognition in which measures of overt and covert face recognition were taken after tasks involving low and high cognitive load (Jenkins, Burton, & Ellis, 2002). It has been suggested that for a given task, task-irrelevant processing of stimuli only occurs under conditions of low perceptual load (Lavie, 1995, 2000). As such, it was hypothesised that repetition priming could provide a means for revealing evidence of covert recognition for task-irrelevant faces presented under high-load conditions, even if overt memory for such faces was lacking.

Jenkins et al (2002), presented participants with low and high-load perceptual tasks involving letter-string identification along with task-irrelevant famous faces. Subsequent memory for these faces was then tested through a surprise recognition test for the celebrities' names and also a face familiarity task. Results demonstrated that manipulating attentional load did indeed impact upon explicit recognition memory as tested via a name recognition test, yet no effect on repetition priming from the same items was observed. In addition, faces from the high-load condition produced the same amount of priming whether explicitly remembered or not.

Experiment 9 therefore examined the possibility that load manipulations may also impact upon the degree to which dividing task related information between the hemispheres affects performance. The hypothesis was tested that under conditions of high cognitive load, dividing information between the hemispheres would be more advantageous than restricting processing to a single hemisphere. It was anticipated that this benefit to processing would be reflected in later tests of memory for the task irrelevant faces. As with Jenkins et al, (2002), participants undertook low and high-load tasks involving letter-string identification in conjunction with the presentation of famous faces. These stimuli were presented to either a single hemisphere simultaneously or divided across both hemispheres. In each instance, the task relevant information was contained within the letter strings rather than the faces. Memory for these famous faces was assessed firstly through an overt recognition memory test of the celebrities' names followed by a speeded familiarity test of the famous faces. This second test of memory was used as a means of testing covertly for any repetition priming effects.

It was predicted that task-irrelevant faces should be processed to a greater degree during the low-load condition compared to those presented under the high-load condition. Even if these faces are not overtly recognised, repetition priming for these faces should still be observed. In addition, a further advantage for face memory would also be predicted when processing is restricted to a single hemisphere during low load tasks, given that the benefits of interhemispheric cooperation are believed to increase with task demands. In contrast, performance for faces presented during the high load task would be expected to improve when information is divided across both hemispheres rather than being contained within one. Due to the inherent perceptual complexity of faces however, an across-field advantage may be observed for both the low and high-load tasks, yet this advantage would still be expected to be greatest for faces presented in the high-load condition.

Method

Participants

24 participants (15 females) were paid for their participation in the study. Ages ranged from 17 to 23 years (M= 19.2 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 94.5) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli consisted of 144 famous faces presented to either the LVF or RVF. For half of these faces a central letter-string was superimposed onto the face, whilst for the other half of faces, a letter-string was presented in the opposite visual field to the face. Letter-strings were either red or green, and contained a target letter (X or N) amongst 3 other letter Ts, randomly organised. Faces were all grayscale photographs. Of the total number of famous faces, 48 were presented in a low-load condition, 48 were presented in a high-load condition and the remaining 48 were presented as new items at test. In addition, for each low and high-load condition, 24 faces were presented to the LVF and 24 to the RVF. Half of these faces (12) were presented in a within-hemisphere condition in which a face with superimposed letter string was presented to a given visual field and half of the faces were presented in an across-hemisphere condition, in which a face was presented to one visual field and letter string to the opposite visual field. Between subjects, the face sets were rotated around experimental conditions so that over the course of the experiment, each face appeared in each condition an equal number of times. The experimental conditions are displayed below in Table 5:

	Within		*Across*	
Low-load	LVF	RVF	Face (LVF) - name (RVF)	Name (LVF) - face (RVF)
High-load	LVF	RVF	Face (LVF) - name (RVF)	Name (LVF) - face (RVF)

Table 5: Experimental conditions for High and Low Load Tasks.

The printed names of the famous faces used as stimuli were also presented during an old/new name recognition task at Stage 2. Finally, different images of the famous identities presented in Stage 1 along with an equal number of matched unfamiliar faces were used as stimuli in a face familiarity task at Stage 3. Examples of experimental conditions can be seen below in Figure 26.

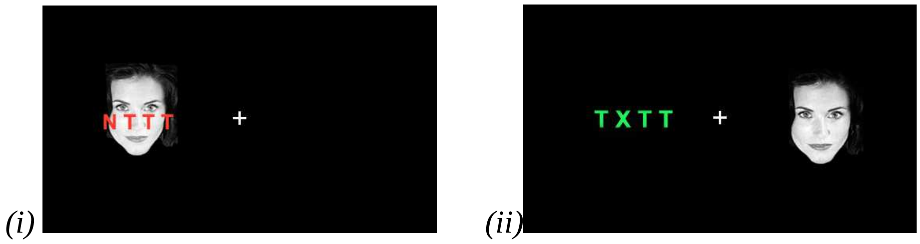

Figure 26: Examples of stimuli displayed in experimental conditions (i) Within LVF (low/high-load) and (ii) Across letters-face (low/high-load).

On screen image size was approximately 4cm high × 3cm wide, corresponding to a visual angle of 4° × 3° shown at distance of 57 cm. Stimuli eccentricity was 3.0cm (center to innermost edge) corresponding to 3° visual angle.

Procedure

Participants were seated at a fixed distance of 57 cm from the 16 in. monitor of an Apple Macintosh G5 Workstation, using a chin-rest with forehead restraint bar.

The experiment consisted of three separate stages, separated by short intervals.

<u>Stage 1</u> consisted of a selective attention stage in which participants made speeded key press responses to either the colour of the letter-string (red or green) in the low-load condition, or to the identity of the target letter (X or N) in the high-load

condition. It was emphasised to participants to focus on the letter-strings throughout the experiment in addition to maintaining their gaze on the central fixation cross. Participants completed two randomised bocks (low-high or high-low), each consisting of 48 trials. Each prime face was encountered only once.

Trials began with the presentation of a central fixation cross for 1500 ms followed by the presentation of a stimulus array for 200ms. The fixation cross remained on screen during stimulus presentation. The inter-trial duration was 500 ms in which a blank screen was shown. Responses were made via bimanual keyboard responses with two “X” or “red” keys with the middle fingers of the left and right hands and two “N” or “green” keys with the index fingers of both hands depending on whether the low or high-load task was being completed. Key assignment was counter-balanced between participants. Although bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used.

<u>Stage 2:</u> Following the selective attention task completed in Stage 1, participants performed a surprise name recognition test on all 144 celebrities’ names. They were required to respond “yes” to celebrities who had been presented in Stage 1 and “no” to celebrities who had not. Responses were again made via bimanual keyboard responses with two “yes” keys with the middle fingers of the left and right hands and two “no” keys with the index fingers of both hands. Key assignment was counter-balanced between participants. As before, although bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used.

Stage 3: Participants were required to make speeded familiarity decisions to different images of the famous faces presented in Stage 1 along with images of the "new" names from Stage 2, resulting in a total of 144 famous faces. An additional 144 matched unfamiliar faces were also presented. Images were presented centrally and participants were required to respond using bimanual key responses.

The experiment was controlled using Psyscope version 10.

Results and Discussion

Stage 1

Accuracy

Mean correct response rates across Low and High-load conditions can be seen below in Figure 27.

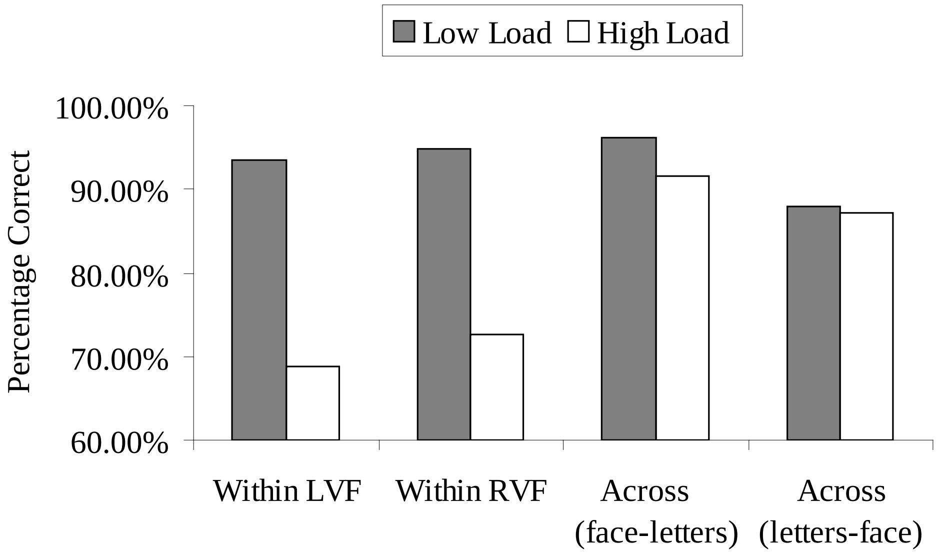

Figure 27: Mean correct response rate across Low and High-load conditions.

A two-way within subjects ANOVA was carried with factors task-load (low / high) and hemispheric condition (within LVF / within RVF / Across face-letters / Across letters-face). Results revealed main effects of task-load, $F(1, 23) = 25.9$, $MSE = 0.03$, $p < 0.01$, and of hemispheric condition, $F(3, 69) = 15.78$, $MSE = 0.009$, $p < 0.01$. In addition there was a significant task-load x hemispheric condition interaction, $F(3, 69) = 17.49$, $MSE = 0.01$, $p < 0.01$.

Analysis of the simple main effects revealed an effect of task-load at both of the within hemisphere conditions (within LVF: $F(1, 23) = 23.2$, $MSE = 0.03$, $p < 0.01$; within RVF: $F(1, 23) = 18.86$, $MSE = 0.03$, $p < 0.01$), with low-load performance being more accurate than high-load. This finding is important as it suggests that the basic experimental load manipulation has been successful. There was no significant difference between task-load for the across field conditions, $p > 0.05$. In addition, for the factor hemispheric condition, there were significant differences in accuracy between both low and high-load conditions (low-load, $F(3, 69) = 3.38$, $MSE = 0.009$, $p < 0.01$; high-load : $F(3, 69) = 31.16$, $MSE = 0.009$, $p < 0.01$). Specifically, for the low-load task, the within RVF condition was significantly more accurate than the across letter-face condition. In addition, there was a significant difference in accuracy between the Across face-letters and Across letters-face conditions, perhaps reflecting a RH dominance for face processing and subsequent asymmetry in communication as suggested in Chapter 4. For the High-load condition, both of the within field conditions were less accurate than both of the across field conditions, $p < 0.05$. Again, this is an important finding, as it appears to demonstrate a shift towards improved performance for Across-field presentations as task difficulty increases. However, performance on Across-field trials was not shown to be superior to the across field performance observed for the low-load task. Therefore, this does not reflect a true across-field superiority for high load tasks. It may be that as performance is close to 100%, ceiling effects were reached thus obscuring any possible further performance advantages that could have been achieved.

Reaction Times

Means of median response time for correct responses across high and low-load conditions are displayed below in Figure 28.

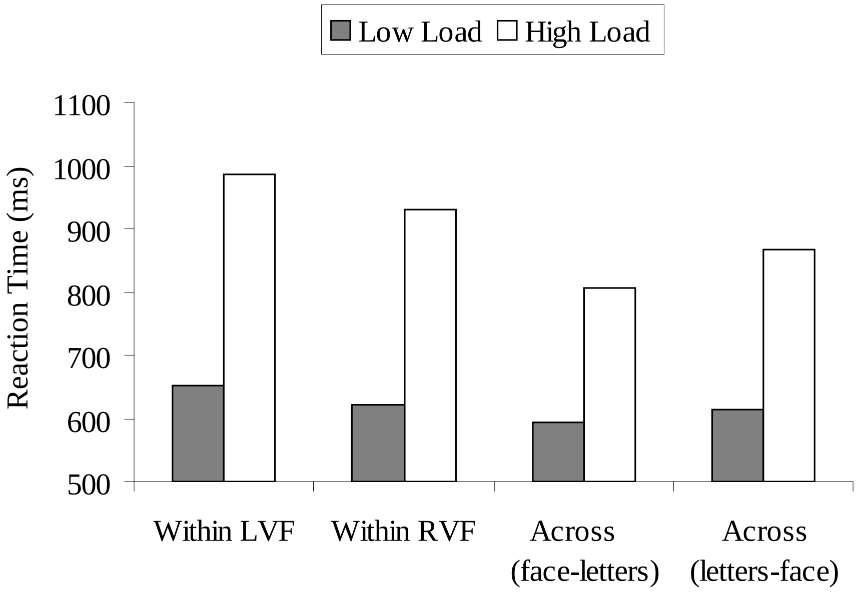

Figure 28: Means of median reaction times across Low and High-load conditions.

A 2-way within subjects Analysis of Variance was carried out with factors as for the Accuracy Analysis. Results revealed main effects of task-load, $F(1, 23) = 108.9$, $MSE = 33932$, $p < 0.01$ and hemispheric condition, $F(3, 69) = 16.44$, $MSE = 7550$, $p < 0.01$. In addition, there was a significant task-load x hemispheric condition interaction, $F(3, 69) = 4.68$, $MSE = 7922$, $p < 0.01$.

Analysis of the simple main effects revealed that low-load performance was significantly faster than high-load performance at all levels of hemispheric condition, $p < 0.05$. This finding again indicates that the experimental manipulation of task-load appears to have been successful. In addition, there were no differences between reaction time performance for the low-load conditions, $F(3, 69)= 1.83$, $MSE = 13789$. There were however significant differences in hemispheric condition performance for high-load conditions, $F(3, 69) = 19.53$, $MSE = 147443$, $p < 0.05$. Specifically, a similar pattern of results observed during the accuracy analysis was seen, with performance being significantly faster for Across-field conditions compared to Within-field conditions, $p < 0.05$. Once again, this would appear to suggest that as task difficulty increases, this is coupled with a benefit for spreading task-load across the hemispheres. Such a result supports findings from previous studies demonstrating an increasing benefit for interhemispheric communication in conjunction with a similar rise in task difficulty (Banich & Belger, 1990; Compton, 2002). Performance for the face-letter condition was again superior compared with the letter-face condition, a finding which possibly reflects the respective hemispheric dominances for faces and words as discussed previously.

Stage 2

Accuracy

Mean correct response rates for Within, Across and New items are displayed below in Figure 29.

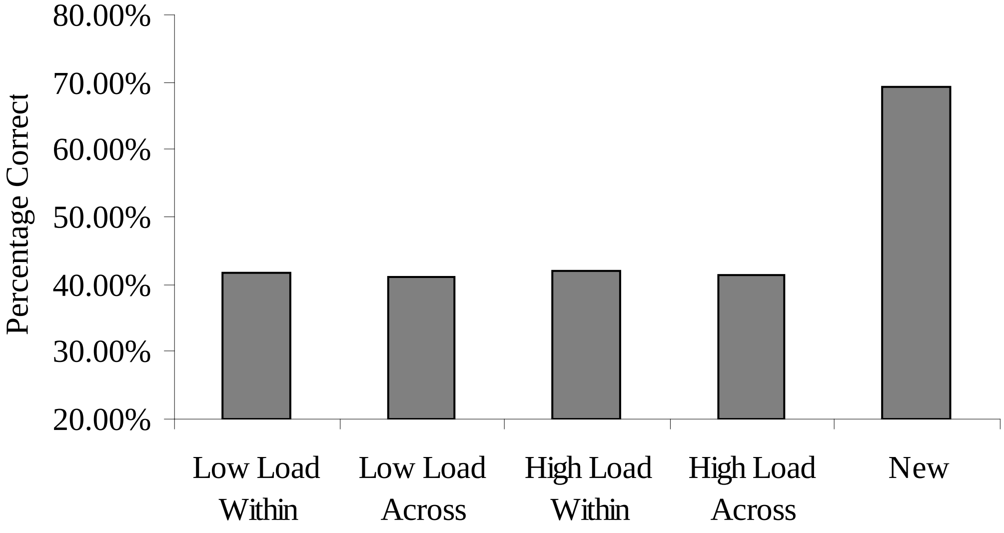

Figure 29: Mean correct response rates for low and high-load within and across items along with mean correct response rates for new items.

A one-way within subjects Analysis of Variance was carried out with levels Low-load Within, Low-load Across, High-load Within, High-load Across and New. Significant differences were shown to exist between means, *F*(4, 23) = 8.357, *MSE* = 0.026, $p < 0.01$. Comparisons between means revealed that all conditions were significantly less accurate than performance to new, unseen names, $p < 0.05$. Performance for this task was however extremely poor, with participants responding below chance for all of the previously observed items from Stage 1. This indicates that a possible response bias to respond “new” has been formed. As has been speculated in previous chapters in which a response bias has been suspected, this may have arisen as a result of the fast exposure time of faces in the periphery of vision during Stage 1. Consequently, a conservative approach to subsequent decisions may have emerged to compensate for a lack of certainty in previous viewings. These results are therefore difficult to interpret and must be viewed with a high degree of caution. A final possibility could be that both the low and high-load tasks in Stage 1 absorbed too great a degree of participants' attention resulting in very little resources remaining to process the task-irrelevant faces.

Reaction Times

A one-way within subjects Analysis of Variance was carried out on means of median correct response times with levels as for the accuracy analysis. Analysis revealed no significant differences between means, *F*(4, 23) = 1.27, *MSE* = 92929. However, there was again a strong trend for responses to new items to be faster than all other conditions. This finding is in-line with the suspected response bias discussed in the accuracy analysis, perhaps arising as a result of over conservative performance by participants or as a consequence of the attentional demands during Stage 1 being too great to allow for any face processing to occur.

Therefore, the results of Stage 2 provide no clear evidence of an explicit improvement in performance for previously observed faces for any conditions. Yet, as stated above, the very low accuracy makes these findings difficult to interpret.

Stage 3

Accuracy Analysis

Mean correct response rates for conditions can be seen below in Figure 30.

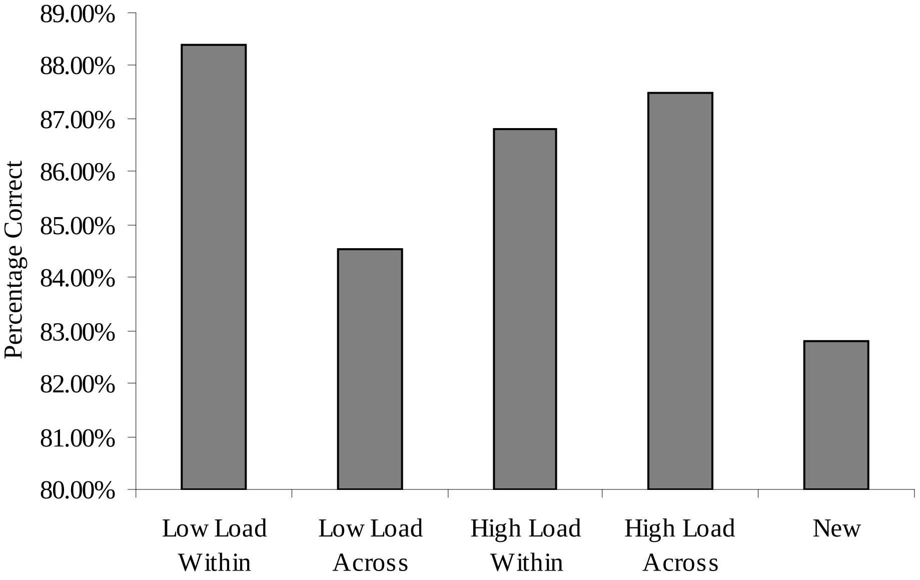

Figure 30: Means of median correct response rates for conditions.

A one-way within subjects Analysis of Variance was carried out between Low-load Within, Low-load Across, High-load Within, High-load Across and New items. Analysis revealed a significant difference between means, *F*(4, 23) = 3.635, *MSE* = 0.004, $p < 0.01$. Comparisons between these means revealed that all conditions except the Low-load Across condition were significantly more accurate than performance for the "New" condition, $p < 0.05$. This finding therefore suggests that despite poor performance during the overt test of memory, participants did nonetheless benefit from prior exposure to faces presented during Stage 1. It therefore appears that the attentional demands during this stage were not too great to allow for this processing of task irrelevant faces to occur. There were however no differences between the within and across-field conditions. As with Jenkins et al (2002), evidence of a covert memory for faces has been displayed, yet this does not appear to be affected by the task load or hemispheric condition under which the faces were initially presented. Finally, the Low-load Across condition was significantly less accurate than the Low-load Within condition, a finding that may have been anticipated if the costs of interhemispheric transfer are greater than the ability for a single hemisphere to carry out the processing alone.

Reaction Times

Means of median reaction times for correct responses across conditions can be seen below in Figure 31.

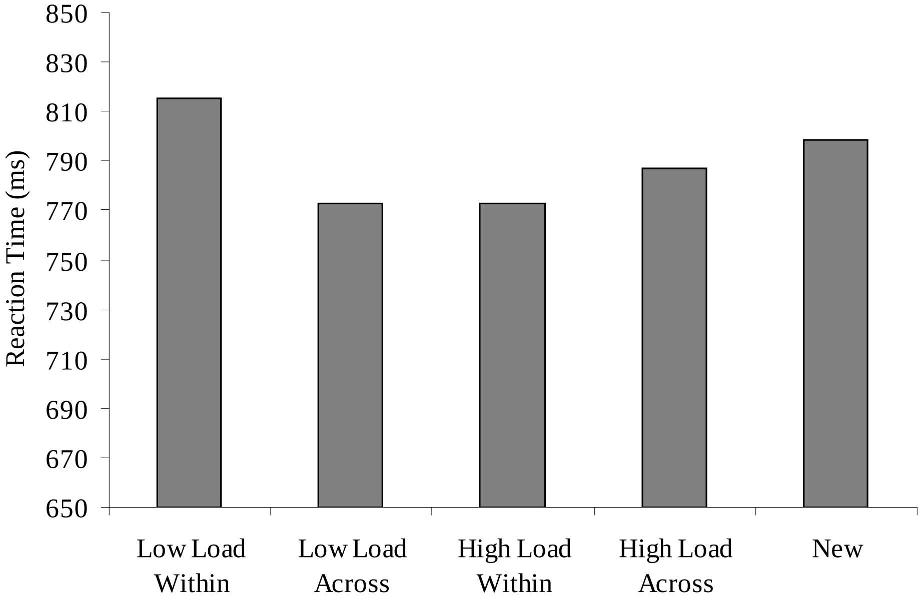

Figure 31: Means of median reaction times for correct responses across conditions.

A one-way within subjects Analysis of Variance was carried out between Low-load Within, Low-load Across, High-load Within, High-load Across and New items. Analysis revealed a significant difference between means, $F(4, 23) = 2.61$, $MSE = 2996$, $p < 0.05$. Comparisons between these means revealed differences only between the Low-load Within and Low-load Across conditions and Low-load Within and High-load Within conditions, $p < 0.01$. Given the accuracy results, it would appear that there is a speed-accuracy trade-off in operation for the Low-load across condition with performance here being faster and less accurate than other conditions. Therefore, unlike the accuracy results, there is no clear evidence of any priming occurring from the reaction times analysis.

It would appear then that there is some limited evidence to suggest that despite any overt memory for the faces presented during Stage 1, a covert memory for these faces does exist, as indicated by improved accuracy during the face familiarity test in Stage 3. This finding offers support to Jenkins et al (2002) who also demonstrated evidence of covert memory for faces which did not appear to be affected by the task load under which faces were initially presented. However, the hypotheses that load manipulations made during the initial presentation of faces would reflect different patterns of subsequent recognition, as a function of whether task information was presented within or across hemispheres was not supported.

It may be that that the load conditions did not function as they had been intended, with the across condition perhaps being inherently easier than the within. Specifically, as the task relevant letter strings were not embedded in the faces on across trials, they may have been clearer to read. As a result, this may inadvertently have led to a blurring of the experimental conditions. Whilst this does not necessarily appear to be the case from the results of Stage 1, the fact that accuracy improves on across-hemisphere trials may not reflect a benefit of increased computational power but rather an advantage caused by the perceptual simplification of the task.

Evidence also exists to suggest that interhemispheric communication can be less efficient when both hemispheres perform on separate tasks (Berger, Windmann, & Güntürkün, 2005). It may therefore be that the division of stimuli in the across-field trials of Stage 1 resulted in each hemisphere performing on separate tasks. Consequently, any intended benefits of the division of perceptual information may have been eliminated.

It appears then that despite an attempt to demonstrate an advantage of interhemispheric communication using a load-manipulation paradigm, this was not successfully achieved. Whether this was a result of task or methodological factors remains unclear from the present analysis. Further means to address the impact of task difficulty on interhemispheric communication related to face processing therefore appear necessary. Therefore the following experiments will continue to explore this issue through the adoption of an alternate methodology previously shown to be sensitive to the manipulations of task difficulty for a range of stimuli.

Experiment 10: The Impact Of Task Difficulty On Interhemispheric Communication During A Face-Matching Task.

The aim of Experiment 10 was to examine whether an advantage for interhemispheric cooperation observed during an unfamiliar face-matching task could be extended to encompass famous faces. Compton (2002) previously demonstrated an across-field superiority when participants were required to match unfamiliar faces for emotional expression or character identity. Moreover, this advantage was shown to be greatest for the more difficult character identity task. Given the established differences between familiar and unfamiliar face processing (Hancock, Bruce, & Burton, 2000; Burton, Jenkins, Hancock & White, 2005), the aim of Experiment 10 was to explore whether a similar pattern of results would be obtained when familiar faces were used as stimuli. As with Comtpon (2002), two different match-types were required which included a physical match between identical images and a more complex identity match between different images of the same identity. It was hypothesised that physical matches would be easier to perform than identity matches due to the assumption that identity matches would be reliant on an additional stage of processing related to perceptual abstraction. Furthermore, it was anticipated that a greater across-field advantage would be observed for identity matches given that interhemispheric communication is presumed to be of particular benefit for complex tasks.

Of further interest to this current experiment was observing how performance for familiar and unfamiliar face matches would compare. It was expected that unfamiliar faces would be more difficult to match, with this being conveyed through a greater across-hemisphere advantage.

Method

Participants

20 participants (14 females) were paid for their participation in the study. Ages ranged from 18 to 26 years (*M*= 19.8 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 93.9) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli comprised two different images of 28 familiar and 28 unfamiliar identities (14 men and 14 women per category) in grayscale. Familiar stimuli were well-known politicians, actors, singers and sports stars. Face images were obtained from the Internet. As with previous experiments, unknown faces were matched to famous faces with respect to gender and any distinguishing features. Differences between pictures of each identity were obtained by selecting images that had been taken using different cameras or at different time periods.

The stimulus arrays for each trial consisted of three faces arranged in a triangular formation. Two faces were presented above a central fixation point and one face below. On screen image size of each face was approximately 3.5 cm high × 2.5 cm wide, corresponding to a visual angle of 3.5◦ × 2.5◦ shown at distance of 57 cm. The top two faces were centered at 2.5◦ above fixation and 5 ◦ to the left and right of the fixation point whilst the bottom face was centered at 2.5◦ below fixation and 2.5◦ to the left or right of this point.

Procedure

Participants were seated at a fixed distance of 57 cm from the 16 in. monitor of an Apple Macintosh G5 Workstation, using a chin-rest with forehead restraint bar. Participants were instructed that they would be presented with arrays of faces for which they were required to indicate whether the bottom face of each array matched either of the top two faces for identity. It was made clear to participants that matching pairs of faces could either be displayed by the same images or by different images of the same identity. In addition, they were instructed not to move their eyes from the fixation cross, and to perform as fast and accurately as possible.

Trials began with the presentation of a central fixation cross for 1500 ms followed by the presentation of a stimulus array for 200ms. The fixation cross remained on screen during stimulus presentation. The inter-trial duration was 500 ms in which a blank screen was shown. Examples of experimental stimulus arrays are shown below in Figure 32.

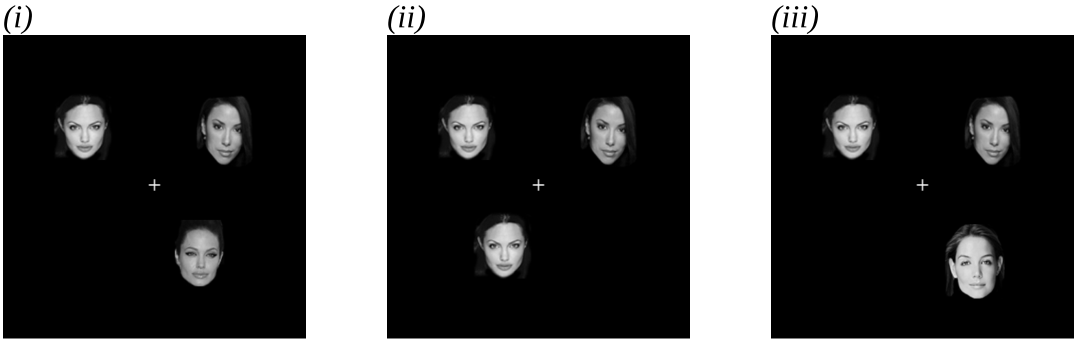

Figure 32: Examples of matching trigrams depicting (i) Across visual field identity match, (ii) Within visual field physical match and (iii) mismatch trials.

Subjects underwent 10 experimental blocks consisting of around 90 trials, creating 896 trials in total. Half of the trials were match trials in which the bottom face matched the identity of one of the top two faces, and half of the trials were mismatch trials in which the bottom face did not match either of the top two faces. Mismatching stimuli were always from the same familiarity category as matching faces. In addition, of the match trials, half the matches were physical matches whereby the matching faces depicted identical images of the same identity and half were identity matches, in which the matching faces were different images of the same identity. The target face (bottom) appeared equally in the LVF and RVF and matches between bottom and top faces could occur either within the same visual field or across visual fields. Order of trials was independently randomised for each participant. A short practice session consisting of all experimental conditions preceded the experimental session. Practice faces were not shown subsequently.

Responses were made via bimanual keyboard response with two “match” keys with the middle fingers of the left and right hands and two “no match” keys with the index fingers of both hands. Key assignment was counter-balanced between participants.

Although bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used. The experiment was controlled using Psyscope version 10.

Results and Discussion

Accuracy

The focus of the reported results is on match trials. Mean correct response rates for familiar and unfamiliar face matches across experimental conditions are shown in Figure 33.

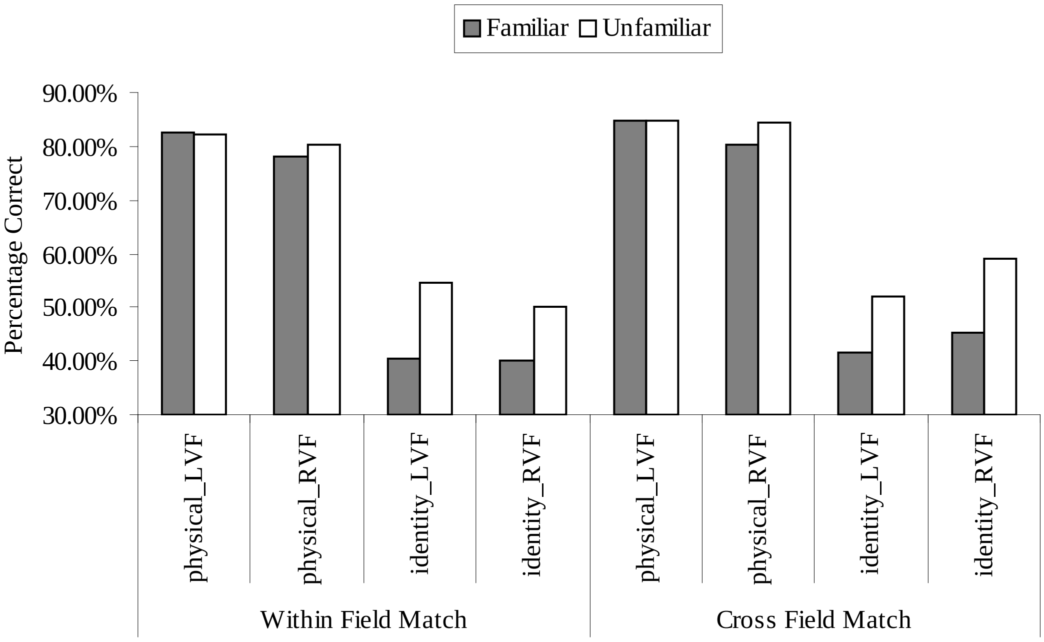

Figure 33: Percentage of correct responses for match trials across all experimental conditions

A four-way within subjects Analysis of Variance was carried out with factors familiarity (familiar / unfamiliar), hemispheric match condition (Within field / Across field), match-type (physical / identity) and visual field of top matching item (LVF / RVF). Results revealed a significant main effect of familiarity, $F(1, 19) = 11.94$, $MSE = 314.74$, $p < 0.0.5$, reflecting more accurate performance for matching unfamiliar faces compared with familiar. The main effect of hemispheric match condition was also significant, $F(1, 19) =5.45$, $MSE=121.73$, $p < 0.05$, with accuracy for within hemisphere matches being greater than that for across. Finally, the main effect of match-type was also significant, $F(1, 19) = 341.86$, $MSE = 272.58$, $p < 0.05$, reflecting more accurate performance for physical matches compared with identity matches.

The three-way interaction comparing hemispheric match condition x match-type x visual field of top matching item, was also significant, $F(1, 19) = 5.26$, $MSE = 40.39$, $p < 0.05$. To analyse this interaction further, the data was split and two 2-factor ANOVAs were conducted, one for the within hemisphere matches and one for the Across-hemisphere matches.

Analyses of the Within-field matches revealed only a main effect of match-type, $F(1, 19) = 294.46$, $MSE = 0.008$, $p < 0.01$, with physical matches being more accurate than identity matches. This finding was expected given that physical matches were assumed to be easier than identity matches. As such a benefit of recruiting additional processing resources may not have been necessary.

Analyses of the across-field matches again revealed a main effect of match-type, $F(1, 19) = 272.64$, MSE 0.009, $p < 0.01$, however no significant main effect of Visual field of top matching item, $F(1, 19) = 1.28$, $MSE = 0.004$. The match-type x Visual field of top matching item interaction also proved to be significant $F(1, 19) = 17.38$, $MSE = 0.002$, $p < 0.01$.

Analyses of the simple main effects for this interaction revealed that physical matches were more accurate than identity matches for both LVF ($F(1, 19) = 169.98$, $MSE = 0.009$, $p < 0.01$) and RVF matches ($F(1, 19) = 106.37$, $MSE = 0.009$, $p < 0.01$). In addition, for physical matches, there was no difference in accuracy if the top matching item was presented to the LVF or RVF ($F(1, 19) = 1.52$, $MSE = 0.004$). However, for identity matches, performance was more accurate when the top matching item was presented to the RVF compared to the LVF ($F(1, 19) = 8.01$, $MSE = 0.004$, $p < 0.01$). This finding suggests that accuracy is greatest for Across-field matches in which the target item is shown to the LVF (RH). Given the established hemispheric dominance of the RH for face processing, it may be that this superior processing ability was in evidence here. Indeed, the results of Chapter 3 have also demonstrated that information transfer between the hemispheres can be asymmetric and greatest in the direction of RH to LH.

The expected across-hemisphere advantage for any form of face-match was not observed, with within hemisphere processing being more accurate than across. Whilst physical matches were shown to be consistently more accurate than identity matches, there was no differentiation between these match-types either within or across hemispheres. This finding was particularly unexpected given that previous studies involving unfamiliar face matching have demonstrated an across-hemisphere advantage for all match-types.

Of particular concern in relation to these results is the fact that performance for identity matches was extremely poor, at a level below chance for familiar faces. Given the robust finding that familiar faces are easier to match than unfamiliar, it would be expected that this performance difference would also be evident here. Why an inversion of this effect can be seen for identity matches is then particularly puzzling. One simple explanation for this anomaly in the data could relate to the degree of difference between images in pairs of matching faces. Specifically, it may be that there was greater variation between pairs of images for familiar faces than unfamiliar in the identity match condition. Such a possibility could easily be tested through presenting these pairs of faces to participants in a speeded same/different identity decision task and comparing response times for familiar and unfamiliar face pairs.

A further speculative possibility could relate to attention capture for meaningful stimuli. Specifically, whilst faces have been shown to capture attention, (Bindemann, Burton, Hooge, Jenkings & De Haan, 2005) some faces have also been shown to be more powerful distracters than others (Stone & Valentine, 2005; Brédart, Delchambre & Laureys, 2006). It may therefore be that different images of familiar faces capture participants' attention more than unfamiliar faces. As a consequence, this may impact upon the ability to disengage processing resources from particular faces and perform the task proficiently within the time constraints of the task. Some evidence in support of this idea can be found from studies demonstrating attention capture for meaningful stimuli (Mack, Pappas, Silverman, & Gay, 2002). In addition, stimuli containing an extra layer of meaning, such as one's own face, have also been shown to be capable of generating additional attentional capture (Brédart, et al, 2006). Therefore, different images of familiar faces may produce greater interference between stimuli than unfamiliar faces and result in a tendency to respond "no-match" in such conditions. Whilst an attentional bias to familiar faces may in some instances facilitate task performance, given the brief exposure and time constraints imposed by this experimental design, such a propensity could also be detrimental. Further investigation to establish if there is any empirical grounding to this suggestion would of course be necessary.

Reaction Times

Again only match trial data is reported. Means of median reaction times for correct responses can be seen below in Figure 34 for familiar and unfamiliar face matches across experimental conditions.

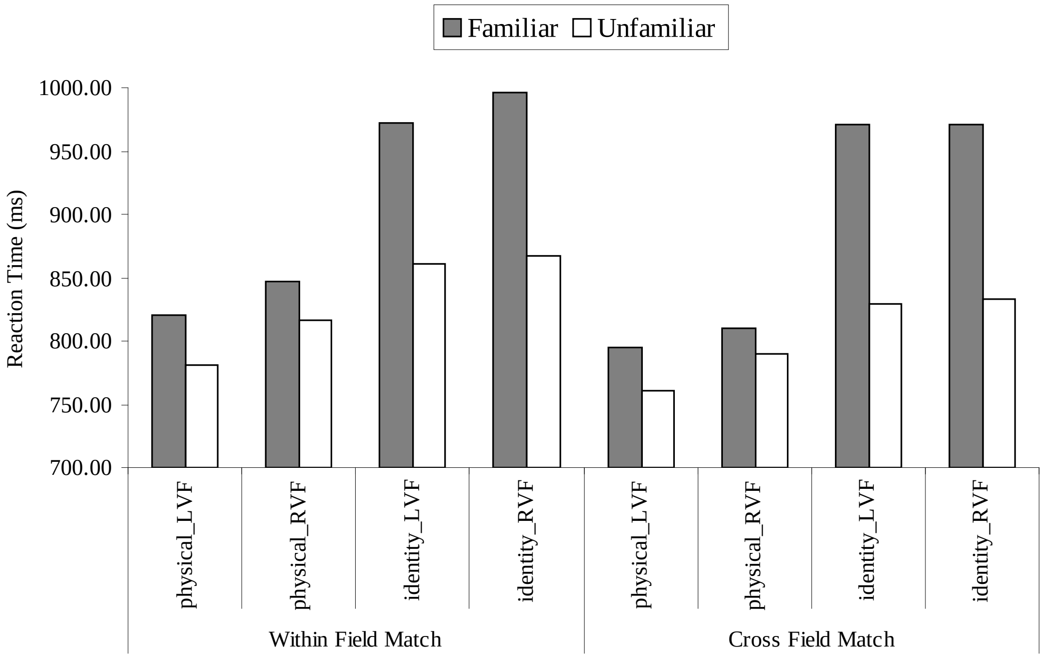

Figure 34: Means of median reaction times for match trials across all experimental conditions.

Due to the very low accuracy performance for the identity match conditions reported above, the reaction time data is difficult to interpret accurately.

A four-way within subjects Analysis of Variance was carried out with factors as for the accuracy analysis. Analysis revealed a main effect of familiarity $F(1,19) = 50.959$, $MSE = 10193.0$, $p < 0.001$, with unfamiliar faces being responded to faster than familiar. There were also significant main effects of hemispheric match condition, $F(1,19) = 8.041$, $MSE = 6288.2$, $p < 0.05$, and match-type, $F(1,19) = 27.681$, $MSE = 35206.6$, $p < 0.001$, in which across-field matches were made faster than within-field matches and physical matches were made faster than identity. This finding that across-field matches were made faster than within-field matches is in-line with Compton (2002), who also demonstrated an across-field advantage when matching unfamiliar faces. The main effect of visual field of top matching item did not reach significance, $F(1, 19) = 2.107$, $MSE = 11616.6$. Finally, the familiarity x match type interaction also proved to be significant, $F(1, 19) = 13.349$, $MSE = 14876.1$, $p < 0.01$.

Analysis of the simple main effects for the familiarity x match-type interaction revealed that for identity matches, performance was significantly faster for unfamiliar faces compared with familiar faces, ($F\ (1, 19) = 66.73$, $MSE = 10193$, $p < 0.01$), with a strong trend in the same direction for physical matches also evident. Again, this finding mirrors that observed in the accuracy data and is particularly surprising given the evidence indicating a superiority for familiar face matching. As suggested above, it may be that differences in the size of image variation between familiar and unfamiliar face pairs is responsible for this anomaly in the data or indeed, a more complex explanation may be required, perhaps relating to differences in attention capture to faces. There was also shown to be a significant effect of match-type for both familiar, $F(1, 19) = 29.16$, $MSE = 35206$, $p < 0.01$, and unfamiliar faces, $F(1, 19) = 4.17$, $MSE = 35206$, $p < 0.01$, with physical matches being responded to faster in both instances. Again, such a result is in-line with the accuracy results, which also showed improved performance for the less complex physical matches.

The finding that across-field matches are faster overall compared to within-field matches is an important finding, suggesting that as with previous studies in this field (e.g. Compton, 2002), utilising the processing abilities of both hemispheres is most effective for complex face stimuli. As expected, physical matches were shown to be faster and more accurate than the more perceptually complex identity matches. However, it was also anticipated that identity matches would show a greater across-field advantage, than physical matches, a finding that was not evident from the present analyses. Compton (2002) also failed to reveal any differentiation between physical and category match-types in her unfamiliar face matching task, despite evidence of a general across-field advantage. It may therefore be that this lack of differentiation between match-types reflects the existence of a ceiling for the advantages that can be incurred from interhemispheric communication.

Therefore, despite evidence of a general across-field advantage in terms of response times, it appears there is no further evidence to suggest an additional benefit of interhemispheric communication for the processing of more complex identity matches. Furthermore, no observed differentiation between hemispheric performance for familiar and unfamiliar matches could be seen, except during identity matches. It may therefore be that patterns of interhemispheric communication do not differ in relation to the complexity of familiar face-matching tasks. Alternatively, the poor accuracy and possible response bias reported above could have acted to obscure any underlying effects. Achieving a means through which performance can be improved does then appear necessary in order to obtain a true interpretation of the impact of task difficulty on familiar face matching.

Experiment 11: A Reinvestigating Of The Impact Of Task Difficulty On Interhemispheric Communication During A Face-Matching Task.

Given the poor accuracy reported in Experiment 10, the aim of Experiment 11 was to attempt to improve general performance so as to gain a clearer impression of the impact task difficulty has on interhemispheric communication during face processing. The design of Experiment 10 was therefore modified to include only the match trials. Participants were required to indicate whether the top left or right face matched the bottom face in each stimulus array. All other aspects of the Experiment 11 were the same as for Experiment 10.

Method

Participants

22 participants (15 females) were paid for their participation in the study. Ages ranged from 18 to 22 years (*M*= 20.6 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient =

91.2) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

Stimuli comprised the same images used in Experiment 10, however, due to the change in experimental procedure, all trials were match trials and consequently no miss-match arrays were used.

Procedure

Participants were seated at a fixed distance of 57 cm from the16 inch monitor of an Apple Macintosh G5 Workstation, using a chin-rest with forehead restraint bar. Participants were instructed that they would be presented with arrays of faces for which they were required to indicate whether the top left or top right face matched the identity of the bottom target face. It was made clear to participants that a match would always be present and that matches between pairs of faces could either be displayed by the same images or different images of the same identity. In addition, participants were instructed not to move their eyes from the fixation cross, and to perform as fast and accurately as possible.

Trials began with the presentation of a central fixation cross for 1500 ms followed by the presentation of a stimulus array for 200ms. The fixation cross remained on screen during stimulus presentation. The inter-trial duration was 500 ms in which a blank screen was shown. Examples of stimulus arrays can be seen in Figure 35.

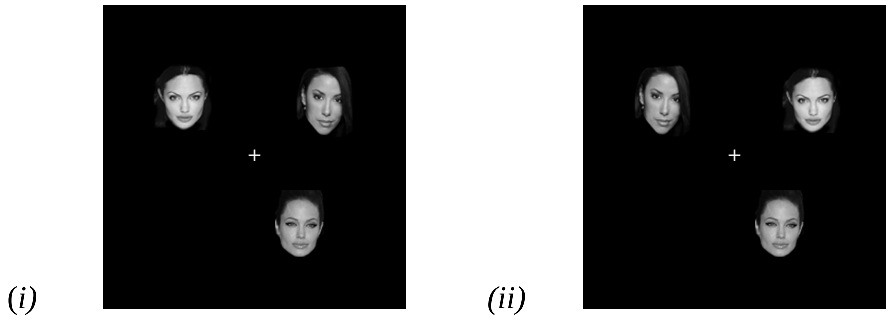

Figure 35: Examples of (i) identity match (LVF), Across-hemisphere array and (ii) physical match (RVF), Within-hemisphere array

Participants underwent 10 experimental blocks consisting of around 45 trials each and creating 448 trials in total. All of the trials were match trials in which the bottom face matched the identity of one of the top two faces. In addition, as with Experiment 9, half the matches were physical matches whereby the matching faces depicted identical images of the same identity and half were identity matches, in which the faces were matched using different images of the same identity. The target face (bottom) appeared equally in the LVF and RVF and matches between bottom and top faces could occur either within the same visual field or across visual fields. A short practice session consisting of all experimental conditions preceded the experimental session. Practice faces were not shown subsequently.

Responses were made via bimanual keyboard response with two “left match” keys with the middle fingers of the left and right hands and two “right match” keys with the index fingers of both hands. Key assignment was counter-balanced between participants. Although bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used. The experiment was controlled using Psyscope version 10.

Results and Discussion

Accuracy

Mean correct response rates for familiar and unfamiliar face matches across experimental conditions are shown in Figure 36.

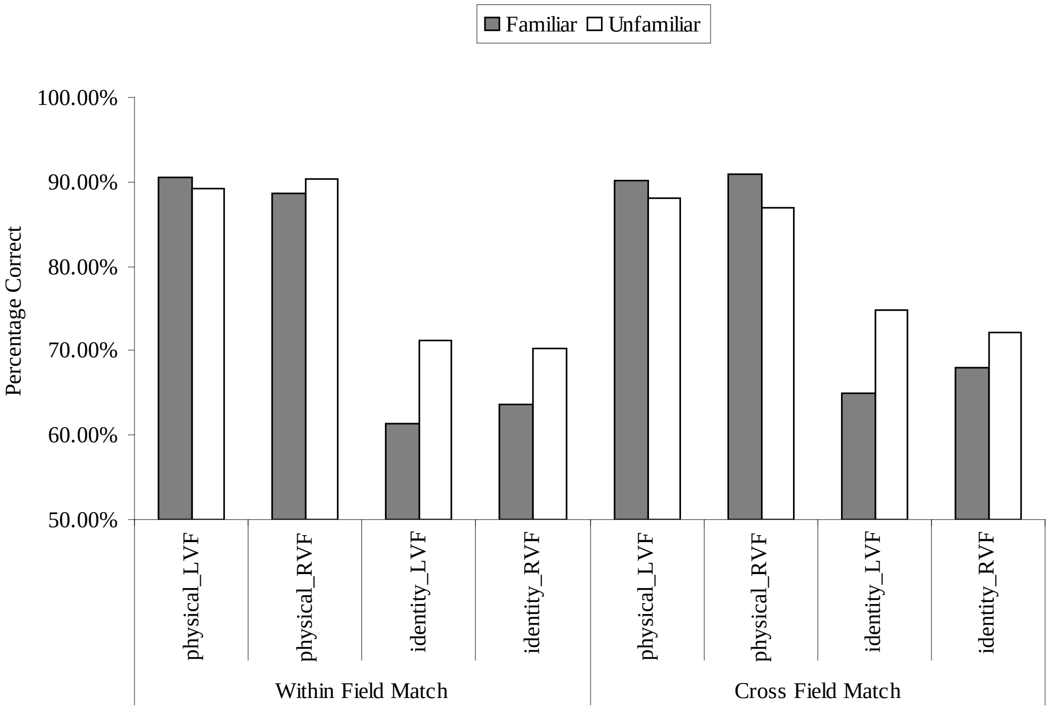

Figure 36: Percentage of correct responses for match trials across all experimental conditions

A four-way within subjects Analysis of Variance was carried out with factors familiarity (familiar / unfamiliar), hemispheric match condition (Within field / Across field), match-type (physical / identity) and visual field of top matching item (LVF / RVF). Results revealed a main effect of familiarity, *F*(1, 21) = 12.46, *MSE* = 68.08, $p < 0.01$, with unfamiliar faces being matched more accurately than familiar. There was also a significant main effect of match-type, *F*(1, 21) = 575.27, *MSE* = 67.74, *p* < 0.01, with physical matches being more accurate than identity matches. Neither of the main effects of hemispheric match condition, *F*(1, 21) = 0.98, *MSE* = 165.42, or visual field of top matching item, *F*(1, 21) = 0.001, *MSE* = 417.16, proved significant. There was however a significant 3-way interaction between familiarity, match-type and visual field of top matching item, *F*(1, 21) = 4.38, *MSE* = 32.83, *p* < 0.05.

Analyses of the simple main effects revealed that for the factor familiarity, there was a significant difference between accuracy for identity matches for which the top matching items were presented in the LVF, *F*(1, 21) = 31.69, *MSE* = 68.07, *p* < 0.01, and the RVF, *F*(1, 21) = 9.28, *MSE* = 68.07, *p* < 0.01. In each of these cases, unfamiliar faces were matched more accurately than familiar. No such performance difference was in evidence between familiar and unfamiliar faces for physical matches to either the LVF or RVF, *p* > 0.05. As discussed in Experiment 10, it may be that this unexpected shift for unfamiliar faces to be matched more accurately than familiar could be an artifact of the stimuli used for identity matches. Alternatively, a more complex explanation involving greater attention capture by familiar faces has also been proposed. Regardless of the cause of this result, it appears that even with the change in methodology intended to boost accuracy, participants still found familiar identity matches too complex to be able to perform accurately within the constraints of the experimental design. There was also shown to be a significant effect of match-type for familiar and unfamiliar faces when top matching items were presented to both the LVF and RVF. Specifically, physical matches were shown to be more accurate than identity matches across all conditions, *p* < 0.05.

It therefore appears that regardless of whether to-be-matched stimuli are presented within a single visual field or divided across both visual fields, accuracy performance is unaffected. This finding is true regardless of whether matches are between identical images or different images of the same identity.

Reaction Times

Means of median reaction times for correct responses can be seen below in Figure 37 for familiar and unfamiliar face matches across experimental conditions.

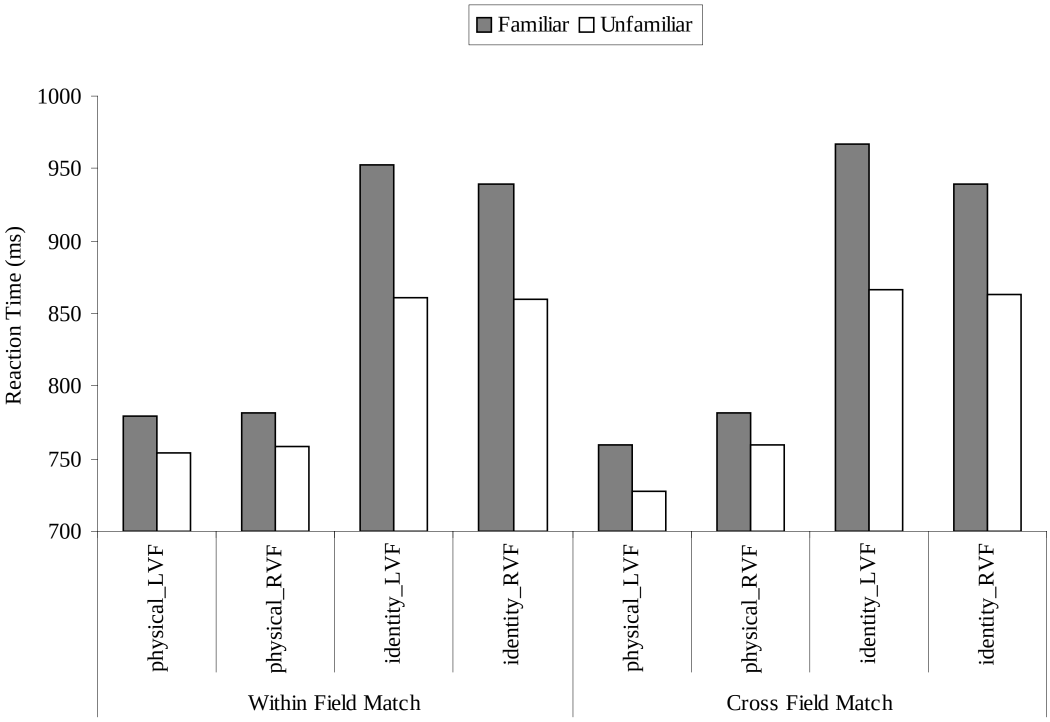

Figure 37: Means of median reaction times for match trials across all experimental conditions.

A four-way within subjects Analysis of Variance was carried out with factors as for the accuracy analyses. Results revealed significant main effects of familiarity, $F(1, 21) = 75.16$, $MSE = 3679$, $p < 0.01$, with unfamiliar faces being responded to faster than familiar, and of match-type, $F(1, 21) = 79.68$, $MSE = 22602$, $p < 0.01$, with physical matches being made quicker than identity matches. The main effects of hemispheric match condition, $F(1, 21) = 0.0349$, $MSE = 18689$, and visual field of top matching item, $F(1, 21) = 0.043$, $MSE = 8486$, however, both failed to reach significance. Finally, there was also a significant interaction between familiarity and match-type, $F(1, 21) = 10.45$, $MSE = 8053$, $p < 0.01$

Analysis of the simple main effects revealed that for the factor familiarity, there was a significant difference between response times for both physical, $F(1, 21) = 7.55$, $MSE = 36797$, $p < 0.01$ and identity matches, $F(1, 21) = 90.5$, $MSE = 3679$, $p < 0.01$, with unfamiliar faces being responded to more quickly in each instance. In addition, for the factor match-type, it was shown that physical matches were faster than identity matches for familiar, $F(1, 21) = 58.93$, $MSE = 22602$, $p < 0.01$, and unfamiliar face matches, $F(1, 21) = 24.48$, $MSE = 22602$, $p < 0.01$.

These results therefore depict a similar pattern of results as for the accuracy analysis. No observable advantage for dividing processing between the hemispheres for either the physical or more complex identity matches can be seen. This pattern of results therefore fails to support the hypothesis that a greater across-field advantage would be observed for the more perceptually complex identity matches. Moreover, whilst unfamiliar matches were faster overall, the same pattern of results was observed for both familiar and unfamiliar face matches. Compton, (2002), suggested that the intermixing of physical and identity matches within the same experimental blocks may play some role in the lack of performance distinction between these match types. Specifically, physical and category match manipulations required the same decision type and consequently what was varied between match-types was the perceptual demands. Previous studies demonstrating an across-field advantage for identity matches using letters as stimuli have presented physical and identity match-type trials in separate blocks. As a result, participants received different task instructions for each match-type and therefore carried out different decision processes for physical and identity matches. Such studies have assumed this across-hemisphere advantage for identity matches arose as a result of differences between the difficulty of decision type between physical and identity matches. Yet, if interhemispheric interaction is not as effective in facilitating perceptual processes, this could account for why the physical versus category manipulation in the present study had little influence on the inter-hemispheric advantage.

It has been suggested that the general pattern of results in which unfamiliar faces were matched more accurately and faster than familiar may possibly represent inconsistencies in the properties of familiar and unfamiliar stimuli pairs or an indication that attention capture caused by familiar faces rendered the task too difficult for participants. Despite changes in methodology intended to boost performance in the identity match condition, it may be that this match-type remains too complex under these experimental conditions.

One further factor that may have impacted on the current results relates to the possibility that the visual system has a limited capacity for processing faces (Bindemann, Burton & Jenkins, 2005). The existence of such a bottleneck may therefore act in obscuring any advantages that could be achieved through dividing processing between the hemispheres. This possibility will be explored in the final experiments of this chapter.

Experiment 12: Interhemispheric Communication Investigated During A Semantic Decision Task.

Several studies have suggested that face processing may be subject to capacity limits whereby only a single face is capable of being processed at any one time (Boutet & Chaudhuri, 2001; Bindeman, Burton & Jenkins, 2005). This being the case then one reason for the poor performance reported in Experiments 10 & 11 could relate to the issue of multiple faces competing for limited face processing resources. The aim of Experiment 12 was therefore to explore this possibility through presenting participants with a semantic matching task comprised of a combination of face and non-face items. Through manipulating the number of faces presented in each visual array, it was hoped that a comparison of results between different stimulus combinations would be able to provide further insights into the impact of task difficulty on interhemispheric communication.

The same methodological paradigm as set out in Experiment 11 was used as the basis for Experiment 12, however participants were required to match pairs of stimuli for nationality. Matches could occur between pairs of faces, flags or a combination of both faces and flags. It was hypothesised that matches between pairs of faces would prove most challenging for participants and as such this match-type may benefit most from across-hemisphere processing. In contrast, matches between pairs of flags were expected to be more straightforward, with any across-hemisphere advantage anticipated to be less than that for pairs of faces. Indeed, in a task involving the semantic categorisation of pictures, Koivisto (2000), demonstrated that dividing processing across the hemispheres improved performance for relatively complex tasks involving the categorisation of pictures from the same category. However, no similar advantage was observed for the less complex task of categorising visually identical stimuli.

For cross-domain matches between faces and flags, several different patterns of results are possible. One outcome could be that, as with Koivisto (2000), an across-hemisphere advantage will be observed for semantic matches between items of the same category. This being the case then the magnitude of this effect would be expected to lie somewhere between that of the face-face and flag-flag matches. The results of a further classification task using pictures and words have also shown an advantage for dividing processing across the hemispheres for within domain matches (Koivisto & Revonsuo, 2003). However, the same study also showed that cross-domain matches (between words and pictures) produced no difference between performance for stimuli presented unilaterally or to both hemispheres. The authors speculated that a lack of cross-hemisphere advantage was observed in this instance due to different cortical access routes being required for the processing of different stimulus modalities. As a result of these different access routes, simultaneous processing could occur within a single hemisphere, without overloading the processing capacity. Consequently, in relation to the present experiment, it may be that cross-domain matches between faces and flags will exhibit a similar lack of dissociation between within and across hemisphere matches.

Method

Participants

18 participants (10 females) were paid for their participation in the study. Ages ranged from 18 to 23 years (*M*= 19.8 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient = 93.5) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

12 different images each of Tony Bair (British Prime Minister at time of testing), George Bush (American President at time of testing), the Union Jack (British flag) and the Stars and Stripes (American flag) served as stimuli. Flags were cropped to elliptical shapes so as to produce a close resemblance to the face outlines. All images were converted to grayscale.

Similar to previous experiments in this chapter, stimulus arrays were created for each trial consisting of three stimuli arranged in a triangular formation. Two stimuli were presented above a central fixation point and one below. On screen image size of each face and flag was approximately 3.5 cm high×2.5 cm wide, corresponding to a visual angle of 3.5◦ ×2.5◦ shown at distance of 57 cm. The top two stimuli were centered at 2.5◦ above fixation and 5 ◦ to the left and right of the fixation point whilst the bottom stimulus was centered at 2.5◦ below fixation and 2.5◦ to the left or right of this point.

Procedure

Participants were seated at a fixed distance of 57 cm from the 16 inch monitor of an Apple Macintosh G5 Workstation, using a chin-rest with forehead restraint bar. Participants were instructed that they would be presented with arrays of faces and flags for which they were required to indicate whether the bottom item of each array (target) matched either the left or right of the top two items for nationality. It was made clear to participants that a match would always be present and that matches could occur between pairs of items that were flags, faces or a combination of both flags and faces. In addition, they were instructed not to move their eyes from the fixation cross, and to perform as fast and accurately as possible.

Trials began with the presentation of a central fixation cross for 1500 ms followed by the presentation of a stimulus array for 200ms. The fixation cross remained on screen during stimulus presentation. The inter-trial duration was 500 ms in which a blank screen was shown. Examples are given below in Figure 38.

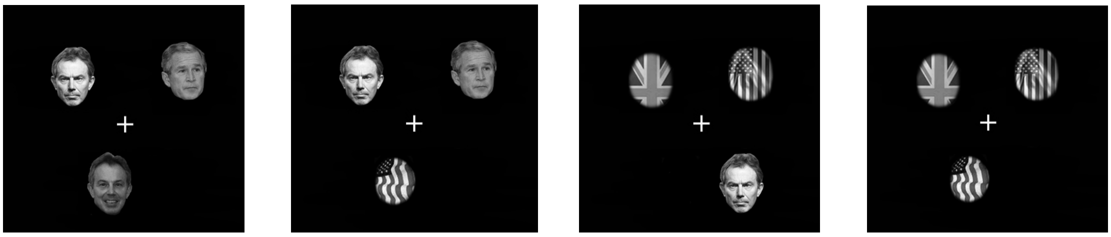
(i) *(ii)* *(iii)* *(iv)*

***Figure 38**:* Examples of (i) Within LVF, face-face match, (ii) Across RVF, face-flag match, (iii) Across LVF, flag-face match and (iv) Across RVF, flag-flag match.

Subjects underwent 4 experimental blocks consisting of around 96 trials, and creating 384 trials in total. All of the trials were match trials in which the bottom item matched the nationality of one of the top items. In addition, half the matches were British and half were American. The target item (bottom) appeared equally in the LVF and RVF and matches between bottom and top items could occur either within the same visual field or across visual fields. A short practice session consisting of all experimental conditions preceded the experimental session.

Responses were made via bimanual keyboard response with two “left match” keys with the middle fingers of the left and right hands and two “right match” keys with the index fingers of both hands. Key assignment was counter-balanced between participants. Although bimanual responses were required, only the fastest response on each trial was analysed, regardless of the hand used. The experiment was controlled using Psyscope version 10.

Results and Discussion

Accuracy

Mean correct response rates are shown below in Figure 39.

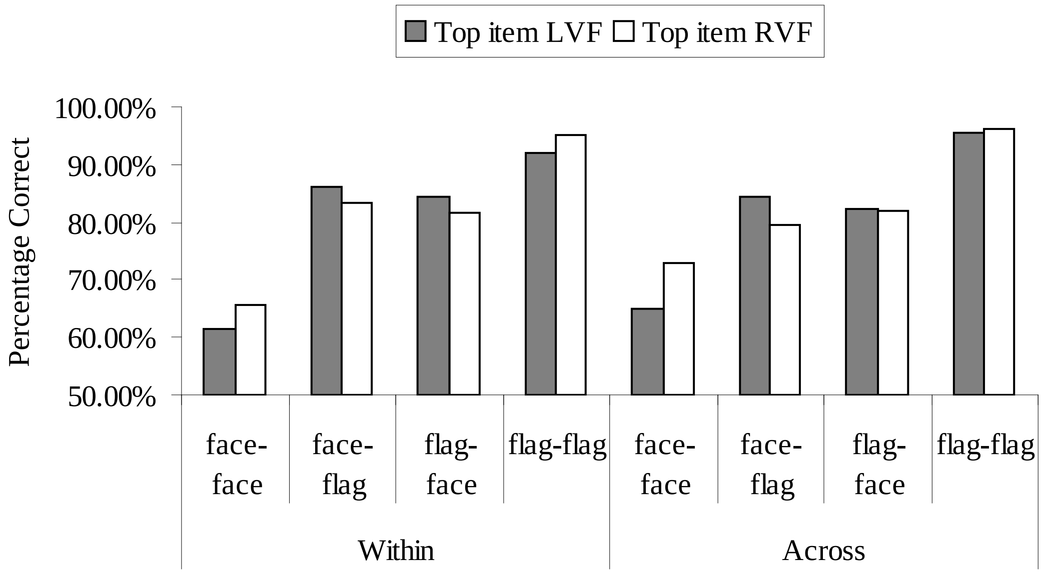

Figure 39: Percentage of Correct Responses across conditions

A 3-way within subjects ANOVA was carried out with factors hemispheric condition (Within / Across), match-type (face-face / face-flag / flag-face / flag-flag) and visual field of top matching item (LVF / RVF). Results revealed only a main effect of match-type, $F(1, 17) = 106.2$, $MSE = 93.38$, $p < 0.01$, with face-face matches being least accurate and flag-flag matches most accurate. Both the main effects of hemispheric condition, $F(1, 17) = 2.38$, $MSE = 46.85$, and visual field of top matching item, $F(1, 17) = 0.89$, $MSE = 103.44$, did not prove significant. There were also two significant interactions. One between hemispheric condition and match-type, *F*(3, 51) = 4.95, *MSE* = 38.60, $p < 0.01$, and the other between match-type and visual field of top matching item, *F* (3, 51) = 3.369, *MSE* = 78.18, $p < 0.01$.

Analysis of the simple main effects for the interaction between hemispheric condition and match-type revealed that for the factor hemispheric condition, there was a significant difference between performance only at the face-face condition, *F*(1, 17) = 10.89, *MSE* = 46.85, $p < 0.01$. Performance on the across condition was shown to be more accurate than that for the within. This is an important finding as it demonstrates that dividing processing between both hemispheres is of benefit in matching familiar faces. It is also indicative of the fact that face-face matches are more complex than the other match-types, possibly as a result of multiple faces leading to an over taxation of attentional resources. Some support is therefore offered to the idea that participant's ability to process and match faces in Experiment 11 may have been affected by a capacity limit. As with Experiment 11, participants were again presented with 3 faces in this match-condition and therefore it would appear that the decision type involved in the match-decision is also of importance (identity vs. semantic).

A significant difference between match-type for both the Within, *F* (3, 51) = 61.13, *MSE* = 93.38, $p < 0.01$ and Across-field conditions, *F* (3, 51) = 47.16, *MSE* = 93.38, $p < 0.01$ was also found. Specifically, for both Within and Across-field match conditions, comparing means using the Bonferonni adjustment indicated that face-face matches were significantly less accurate than all other match-types, $p < 0.05$, whilst flag-flag matches were significantly more accurate than all match-types, $p < 0.05$. Again, this finding suggests that face-face matches proved most complex for participants and as such the benefits of across hemisphere processing were most evident. There was no significant difference between the face-flag and flag-face conditions.

The lack of observable across-hemisphere advantage for cross-domain matches would seem to support the results of Koivisto & Revonsuo, (2003). Specifically, it may be that the processing of these different stimulus modalities requires different access routes to the relevant semantic information. As such, the processing resources of any single hemisphere may not be overloaded in the manner possibly caused by within domain face-faces matches.

Analysis of the simple main effects for the interaction between match-type and visual field of top matching item revealed that for the factor match-type, significant differences in accuracy existed for both the LVF, $F\ (3, 51) = 64.247$, $MSE = 93.38$, $p < 0.01$, and RVF, $F\ (3, 51) = 44.815$, $MSE = 93.38$, $p < 0.01$, top matching item conditions. For both the LVF and RVF top matching item conditions, comparing means using the Bonferonni adjustment indicated that the face-face condition was again significantly less accurate than all other match conditions whilst the flag-flag condition was more accurate than all other match conditions.

Reaction Times

Means of median reaction times for correct responses can be seen below in Figure 40.

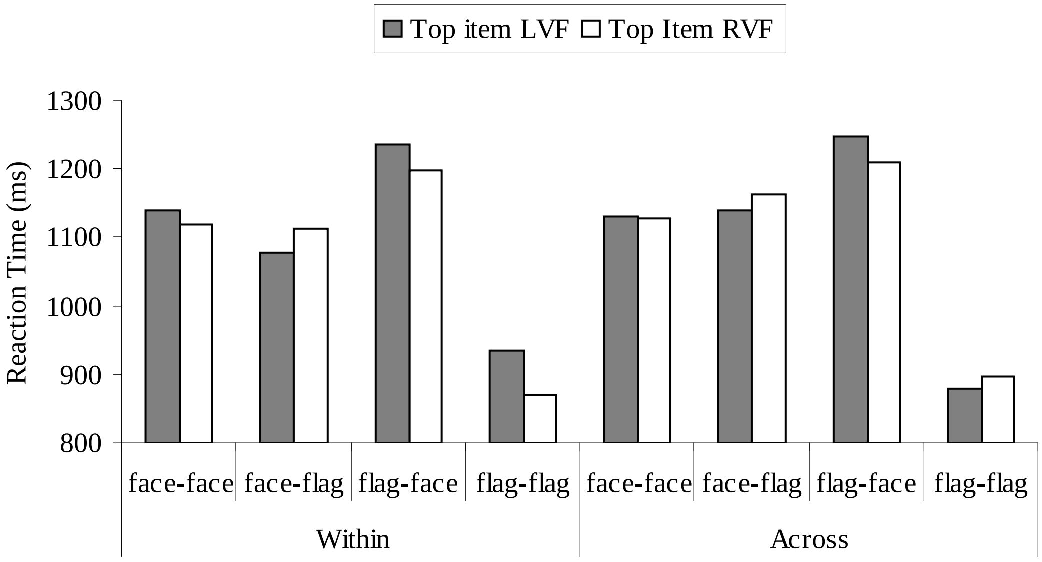

Figure 40: Means of median reaction times across conditions

A 3-way within subjects ANOVA was carried out with factors as for the accuracy analysis. Results revealed significant main effects of hemispheric condition, *F*(1, 17) = 22.81, *MSE* = 4656, *p* < 0.01, and match-type, *F*(3, 51) = 42.82, *MSE* = 22741, *p* < 0.01. Of these, within field matches were shown to be faster than across, whilst flag-flag matches were shown to be quickest and flag-face slowest. There was however no significant main effect of visual field of top matching item, *F*(1, 17) = 0.63, *MSE* = 11370, *p* < 0.01. Finally, a significant interaction between hemispheric condition x match-type x visual field of top matching item was also found, *F*(3, 51) = 11.30, *MSE* = 5959, *p* < 0.01. To analyse this interaction further, the data was split and two 2-factor ANOVAs were conducted, one for the within hemisphere matches and one for the across-hemisphere matches.

Analyses of both the within and across-hemisphere matches revealed only a significant main effect of match-type (within: $F(3, 51) = 43.51$, $MSE = 17988$, $p < 0.01$; across: $F(3, 51) = 43.51$, $MSE = 17988$, $p < 0.01$). Contrasts between means in both cases revealed that flag-flag matches were significantly faster than all other match-types, $p < 0.05$. Flag-face matches were also shown to be significantly slower than both face-face and face-flag matches, whilst there was no observable difference between face-face and face-flag matches, $p < 0.05$.

Therefore, unlike the accuracy results, no advantage was observed for across hemisphere face-face matches. Indeed, it would appear that no advantage for any condition was evident when matches occurred across both hemispheres. Performance for flag-face matches was slowest overall, a finding that is surprising given that this condition contains fewer faces than both the face-face and face-flag matches. Such a finding would therefore appear to be at odds with theories of capacity limits for faces. It may be that the stimulus characteristics of the flag stimuli are harder to distinguish between than those of faces however, evidence to this effect cannot be seen in the flag-flag condition. It would therefore be useful to explore how the present results compare to match conditions in which the non-matching item in each case is of a different stimulus modality to the matching items. Such a comparison should be able to provide a clearer impression of the underlying processes involved in this current experiment.

In summary, whilst there is some evidence that dividing task information between the hemispheres is of benefit for the more perceptually complex face-face matches in terms of accuracy, this advantage was not mirrored in the reaction time results.

Overall, it appears that performance both within and across hemispheres is fairly comparable. Support is therefore offered to Koivisto & Revonsuo (2003) who also demonstrated an advantage for dividing processing across the hemispheres for within domain matches yet observed no distinction between unilateral and bilateral performance for cross-domain matches (between words and pictures).

Following on from these findings, the final experiment in this chapter looks again at the issue of whether a capacity limit for face processing may have impacted upon participant's ability to carry out face matching tasks involving multiple faces such as those in Experiments 10 and 11. Through the presentation of different non-face items, it is hoped that further insights relating to the impact of task difficulty on interhemispheric communication might be gained.

Experiment 13: Interhemispheric Communication Investigated During A Semantic Decision Task With Faces And Names.

The aim of Experiment 13 was again to address the issue of whether manipulating the number of face and non-face items presented during a semantic matching task might influence patterns of interhemispheric communication as a factor of task difficulty. The results of Experiment 12 demonstrated an across-field advantage for accuracy in face-face matches only. No further evidence of an across-field advantage for any of the other match-types was found. Experiment 13 therefore substituted the British and American president's names at time of testing (BUSH and BLAIR) for the American and British flags used in Experiment 12 in order to establish the impact that interhemispheric communication would have on these different match-types. An additional focus of this experiment was to ascertain how patterns of results would compare to those achieved in Experiment 12 in which a combination of flags and faces were presented as stimuli.

Previous research involving the naming and classification of famous faces and names has shown that faces are generally categorised based on semantic information faster than written names (Young, et al, 1986). These results were however obtained after the presentation of a single stimulus item. It would therefore be expected that if a capacity limit for face processing does have the ability to impact on performance during these current face-matching paradigms, then face-face matches would still remain more difficult than name-name matches. Consequently, face-face matches may benefit more from across-hemisphere processing than names, given these are not believed to be subject to such similar processing constraints, (Bindemann et al, 2005).

As a result of the across-hemisphere advantage observed for face-face matches in Experiment 12, it was expected that a similar advantage would also be obtained for face-face matches in Experiment 13. Finally, establishing the outcome of cross-domain face and name matches was also of interest so as to determine whether a lack of observable difference between within and across hemisphere processing would again be displayed.

Method

Participants

18 participants (14 females) were paid for their participation in the study. Ages ranged from 18 to 25 years (*M*= 20.3 years). Each participant had normal or corrected-to normal vision. All participants were strongly right-handed (mean laterality quotient =

94.1) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971) and had no left-handed first-degree relatives. Participants were recruited on the basis that they could recognise British and American celebrities.

Stimuli

12 different images each of Tony Blair (British Prime Minister at time of testing), and George Bush (American President at time of testing), along with 12 versions of the name BLAIR and BUSH in different typefaces served as stimuli. All face images were converted to grayscale whilst names appeared in white font on a black background.

Similar to previous experiments in this chapter, stimulus arrays were created for each trial consisting of three stimuli arranged in a triangular formation. Two stimuli were presented above a central fixation point and one below. On screen image size of each face was approximately 3.5 cm high×2.5 cm wide, corresponding to a visual angle of 3.5◦ ×2.5◦ shown at distance of 57 cm. The top two stimuli were centered at
2.5◦ above fixation and 5 ◦ to the left and right of the fixation point whilst the bottom stimulus was centered at 2.5◦ below fixation and 2.5◦ to the left or right of this point. Examples of stimulus arrays can be seen below in Figure 41

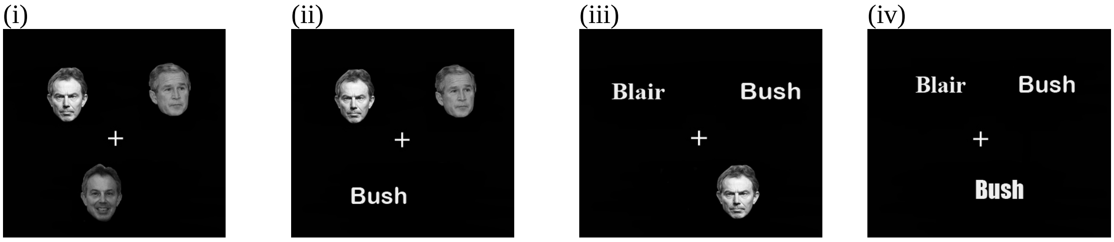

Figure 41: Examples of (i) Within LVF, face-face match, (ii) Across RVF, face-name match, (iii) Across LVF, name-face match and (iv) Across RVF, name-name match.

Procedure

The experimental procedure was the same as for Experiment 12 with the exception that the presentation of the names BUSH and BLAIR substituted the presentation of the American and British flags.

Results and Discussion

Accuracy

Mean correct response rates are shown below in Figure 42.

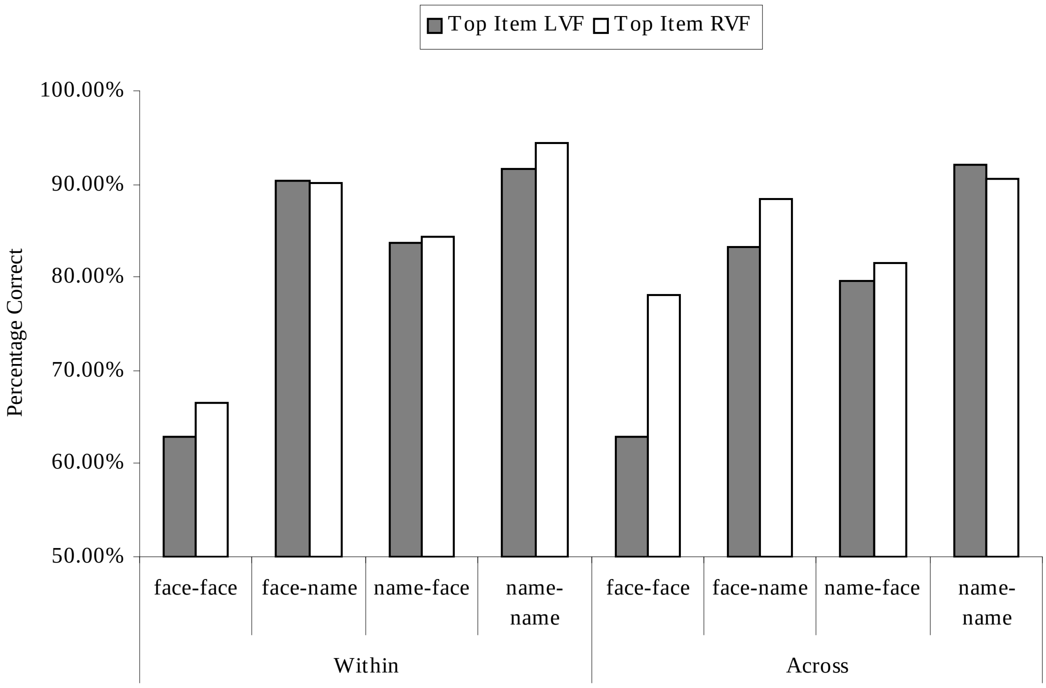

Figure 42: Percentage of correct responses across experimental conditions

A 3-way within subjects ANOVA was carried out with factors hemispheric condition (Within / Across), match-type (face-face / face-name/ name-face / name-name) and visual field of top matching item (LVF / RVF). Results revealed significant main effects of match-type, $F(3, 51) = 76.01$, $MSE = 109.44$, $p < 0.01$, and of visual field of top matching item, $F(1, 17) = 5.97$, $MSE = 135.97$, $p < 0.05$. No significant main effect of hemispheric condition was observed, $F(1, 17) = 0.757$, $MSE = 81.52$. There was also a significant interaction between hemispheric condition, match-type and visual field of top matching item, $F(3, 51) = 3.791$, $MSE = 53.54$, $p < 0.05$.

Analyses of the simple main effects revealed that face-face matches were more accurate when matches were across-hemisphere and the top-matching item was in the RVF as opposed to the same match-type within hemisphere, $F(1, 17) = 14.79$, $MSE = 81.52$, $p < 0.01$. This is an important finding as it replicates the across-field advantage obtained in Experiment 12 for face-face matches. Face-face matches were again the only to show an across-field advantage implying that such matches are most cognitively demanding for participants to process. Performance was also shown to be more accurate for across hemisphere face-face matches in which the top matching item was presented to the RVF compared with the LVF, $F(1, 17) = 14.99$, $MSE = 135.97$, $p < 0.01$. It may be that as reported previously in this thesis, an additional advantage can be obtained for cross-hemispheric matches in which the top-matching item is displayed to the less dominant RVF/LH. Whilst this seems plausible, it has also been reported that differences in laterality are not believed to impact upon the benefits of interhemispheric communication relating to task difficulty (Banich, 1995). Moreover, it would be expected that performance for across-hemisphere face-face matches in which the top-matching item was presented to the LVF/RH would in turn be more accurate than those presented the RVF/LH. This was not shown to be the case and therefore why such a difference between these two match conditions exists remains unclear.

Performance for face-name matches on the other hand was shown to be more accurate for within hemisphere matches compared to across, $F(1, 17) = 5.32$, $MSE = 81.52$, $p < 0.01$. This reverse pattern of results for cross-domain matches implies that perhaps this match-type is less demanding and the resources of a single hemisphere are alone capable of carrying out the processing.

Differences existed between match-type performance at all experimental conditions (within LVF: $F(3, 51) = 28.91$, $MSE = 109.4$, $p < 0.01$; within RVF: $F(3,51) = 24.895$, $MSE = 109.4$, $p < 0.01$; across LVF: $F(3,51) = 24.543$, $MSE = 109.4$, $p < 0.01$; across RVF: $F(3,51) = 5.63$, $MSE = 109.4$, $p < 0.01$). Comparisons between means using the Bonferroni adjustment revealed that for within-field matches in which the top matching item was presented to the LVF or RVF, and across-field matches in which the top matching item was presented to the LVF, face-face matches were least accurate. This is a similar finding to the face-face match performance revealed in Experiment 12, and indicates that perhaps due a capacity limit for face processing, this match-type is most demanding for participants. For both within and across-field matches, no difference was shown to exist between face-name and name-face matches when the top matching item was presented to the LVF or RVF, $p < 0.05$. For within-hemisphere matches, name-name matches were shown to be more accurate than all match types except face-name, $p < 0.05$. However, for across-field matches, name-name matches were significantly more accurate than all other match-types when the top matching item was presented to the LVF, $p < 0.05$.

Reaction Times

Means of median reaction times for correct responses can be seen below in Figure 43 for all experimental conditions.

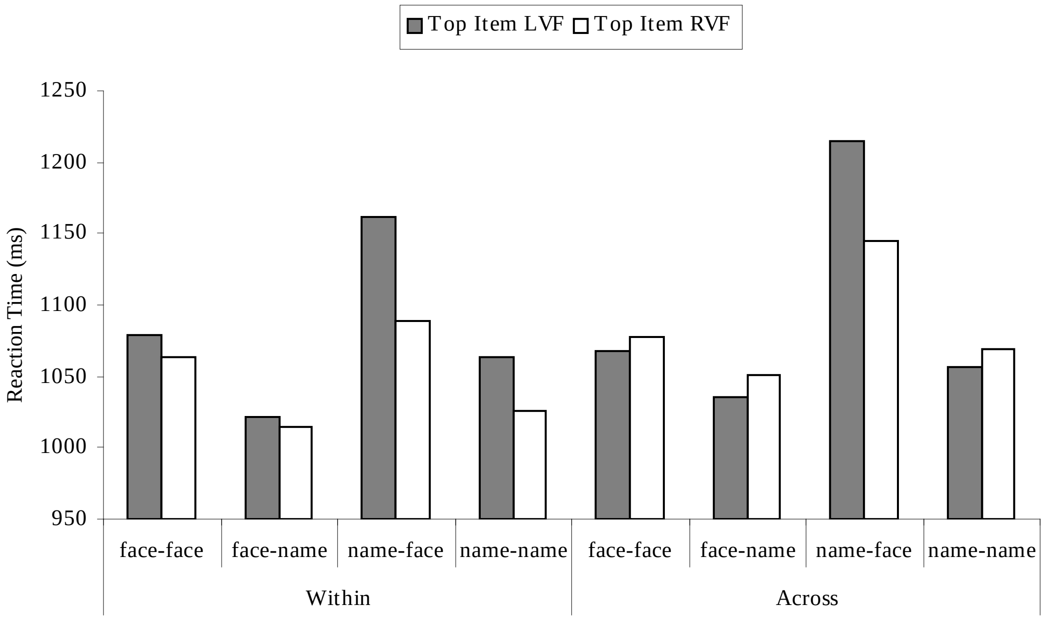

Figure 43: Means of median responses across experimental conditions

A 3-way within subjects Analysis of Variance was carried out with factors as for the accuracy analysis. Results revealed significant main effects of hemispheric condition, $F(1, 17) = 7.31$, $MSE = 6212$, $p < 0.05$, and of match-type, $F(3, 51) = 8.10$, $MSE = 24918$, $p < 0.01$, with within-visual field matches being faster than across. The main effect of visual field of top matching item was not significant, $F(1, 17) = 2.05$, $MSE = 15517$. Finally, there was a significant match-type x visual field of top matching item interaction, $F(3, 51) = 3.95$, $MSE = 5383$, $p < 0.05$.

Analysis of the simple main effects revealed that for the factor visual field of top matching item, there were significant differences in reaction times for name-face matches, with LVF matches being slower than RVF, $F(1, 17) = 6.04$, $MSE = 15117$, $p < 0.01$. Such a difference may reflect the respective left and right hemisphere dominances for name and face processing. Significant differences were also shown to exist between reaction times for match-types when the top-matching item was presented to the LVF, $F(3, 51) = 6.99$, $MSE = 24918$, $p < 0.01$. No similar differences in match-type performance was found when the top-matching item was presented to the RVF, $F(3, 51) = 1.96$, $MSE = 24918$.

For matches in which the top-matching item was presented to the LVF, comparing means using the Bonferonni adjustment indicated that name-face matches were significantly slower than all other match-types, $p < 0.05$. This finding differs from the accuracy pattern in which face-face matches were shown to be least accurate. There is however a similarity between this result and the reaction time findings in Experiment 12 whereby flag-face matches were shown to be slowest. Given that name-face matches contain fewer faces that face-name matches, this finding is surprising and appears to be at odds with theories relating to capacity limits for face processing. As suggested in Experiment 12, it would be useful to explore how these results compare to match conditions in which the non-matching item in each case was of a different stimulus modality to the matching item. Such a manipulation should be able to provide a clearer impression of the processes involved in this current experiment. Again, similar to Experiment 12, face-face matches were significantly slower than face-name matches, $p < 0.05$. No difference however was observed between face-face and name-name matches. This finding also differs from the accuracy performance in which face-face matches were shown to be less accurate than all other match-types.

The pattern of results observed in the reaction time analyses is therefore less clear than that obtained from the accuracy data. Evidence of an across-field advantage for any match type is not observable. Not only does this imply that task-difficulty has not impacted upon patterns of interhemispheric communication, but consequently, it also appears that face-face matches are not subject to any greater capacity limitations than other match-types. As discussed in the accuracy analysis, this may be due to the potentially different cortical access routes required for the processing of different stimulus modalities.

In summary, the results of Experiment 13 show a very similar pattern to those results observed in Experiment 12. Specifically, whilst there is some evidence that dividing task information between the hemispheres is of benefit for the more perceptually complex face-face matches in terms of accuracy, this advantage was not mirrored in the reaction time results. Again, performance for within and across-hemisphere matches did not appear to differ systematically. It may be that as suggested by Koivsto & Revonsuo (2003), no advantage for dividing processing occurred due to the processing of different stimulus modalities requiring different cortical access routes. Consequently, simultaneous processing may have been able to progress within a single hemisphere without overloading the processing resources.

There is some evidence to suggest that capacity limits for face processing impacted upon the observed results. Specifically, face-face matches were shown to be least accurate and the only match-type to benefit from across-hemisphere processing. This finding implies that processing resources were particularly taxed for such matches. Moreover, within-domain name-name matches did not show a similar across-hemisphere advantage, perhaps due to the fact that names are not believed to be subject to the same processing limitations as faces. Consequently, these match-types were less cognitively demanding to carry out.

Chapter Summary

The aim of this final experimental chapter was to explore the impact of task difficulty on interhemispheric communication during tasks involving face processing. Previous studies have demonstrated that task difficulty increases the benefits of interhemispheric communication. It was therefore hypothesised that manipulating the difficulty of decisions associated with faces could also provide a means through which to study this effect. Whilst the effect of task difficulty on face processing has previously been studied using unfamiliar faces, this has yet to be extended to familiar faces. The superior ease with which familiar faces can be matched makes clear the distinct differences that exist between the processing of these face types (Hancock, Bruce, & Burton, 2000; Burton, Jenkins, Hancock & White, 2005). As such, it was believed that any advantage obtained for dividing information processing between the hemispheres would be greater for unfamiliar compared with familiar faces.

Experiment 9 sought to establish whether controlling the cognitive demands of a task through the division of task relevant and task irrelevant stimuli within or across the hemispheres would impact upon performance. Participants undertook low and high-perceptual load tasks involving letter-string identification presented along with task-irrelevant famous faces. This information was presented to either a single hemisphere or divided across both hemispheres. The hypothesis was tested that under conditions of high cognitive load, dividing information between the hemispheres would be more advantageous than restricting processing to a single hemisphere. This benefit to processing was expected to be reflected in later tests of memory for the task irrelevant faces. Results revealed that performance for the initial test of cognitive load was faster for across-field conditions compared to within-field. Such a finding suggests a shift towards a performance benefit for spreading task-load across the hemispheres as task difficulty increases. Support is therefore offered here to previous studies demonstrating a benefit for interhemispheric communication with increasing task difficulty (e.g. Banich & Belger, 1990; Compton, 2002). In the subsequent overt test of memory for the faces presented during the load manipulation task, there was no clear evidence of any explicit improvement in performance for any conditions. However, accuracy for this test was below chance thus making these findings difficult to interpret. Results for the final test of memory for the faces presented during Stage 1 suggested that despite a lack of overt memory, a covert memory for these faces did exist. This finding is inline with Jenkins et al (2002) who also demonstrated evidence of covert memory for faces that was not affected by the task load under which faces were initially presented.

Despite this result, load manipulations during the initial presentation of faces did not result in different patterns of subsequent recognition, regardless of whether task information had been presented within or across hemispheres. Such a finding therefore appears to conflict with theories proposing that task difficulty increases the benefits of interhemispheric communication. It is however worth considering that possible methodological factors may also have led to this finding. Specifically, the load conditions during the Stage 1 selective attention task may not have functioned in the manner they were intended. Because the task relevant letter strings were not embedded in the faces on across-field trials, they may subsequently have been clearer to read and inadvertently led to clarity between the experimental conditions being lost. This explanation would perhaps reveal why a priming effect was observed which did not differ significantly across experimental conditions. Indeed, the results from Stage 1 show an increase in accuracy for across-hemisphere trials. This was interpreted as a sign of a benefit of sharing cognitive load between the hemispheres, however, it may instead reflect an advantage caused by the perceptual simplification of the task. It would therefore be of interest to repeat the experiment presenting the task-relevant letter-strings beneath the faces in both conditions so as to more evenly balance the perceptual difficulty of the task. A final consideration in relation to the current results is that there is some evidence to suggest that interhemispheric communication can be less efficient when both hemispheres perform on separate tasks (Berger, Windmann, & Güntürkün, 2006). Therefore, it may be that the across-field trials in Stage 1 of the current experiment created a situation in which each hemisphere was carrying out a separate process. This being the case then any intended benefits of dividing cognitive load between the hemispheres may have been eliminated.

Experiments 10 and 11 therefore adopted a different methodology to address the issue of the impact of task difficulty on interhemispheric communication during face processing. Stimuli were presented in visual trigrams and participants were required to match pairs of faces either within a single visual field or across both visual fields.

Both physical and identity matches for famous and unfamiliar faces were examined, a manipulation intended to alter the degree of difficulty for which matches could be made. It was hypothesised that any across-field advantage would be greatest for the more complex identity matches involving matches between different images of the same identity. In addition, unfamiliar face matches were also expected to show a greater across-field advantage compared to familiar faces. Results revealed that accuracy performance for Experiment 10 was extremely poor. Of particular note was the finding that unfamiliar faces were matched more quickly and accurately than familiar faces, particularly during identity matches. Such a departure in performance from previous studies comparing familiar and unfamiliar face matching abilities led to the assumption that some additional factor was responsible for these results. The most straightforward of these explanations is the possibility that greater differences between pairs of faces existed for familiar identity matches than unfamiliar. As such, familiar identity matches would have been more challenging for participants to complete accurately. An alternative explanation in which attention capture for different images of familiar faces may be greater than that for unfamiliar faces was also proposed. It was hypothesised that the inability to disengage attention from familiar faces may be greater than for unfamiliar faces. Therefore, different images of familiar faces may produce greater interference between stimuli than unfamiliar faces and result in a tendency to respond “no-match” in such conditions. Such a possibility remains an issue for future research.

Experiment 11 therefore re-examined these same issue altering the methodology in an attempt to boost accuracy and gain a clearer picture of any underlying effects. Results again revealed no observable advantage for dividing processing between the hemispheres for physical or more complex identity matches. Not only does this finding fail to support the experimental hypotheses, but it is also inconsistent with previous experiments in the field. For example, Compton (2002) demonstrated superior performance for across-field matches compared to within-field when participants were required to match unfamiliar faces for emotional expression or character identity. This advantage was also shown to be greatest for the more difficult character identity task. However, Compton (2002) also found little evidence to differentiate hemispheric performance for category and physical matches. It was suggested that this finding could possibly be accounted for by floor effects whereby if participants perform near chance due to the category decision being too difficult at both within and across-field conditions then any overall advantage might be obscured. Given the relatively poor accuracy reported in Experiments 10 & 11, it would seem that such an interpretation might also warrant some consideration here. Alternatively, the intermixing of physical and identity matches within the same experimental blocks may also have impacted upon the present lack of differentiation between physical and identity matches. Welcome & Chiarello (2008) have however suggested that the flexibility of the mechanism controlling interhemispheric communication is such that the degree to which interhemispheric communication benefits performance arises from the processing demands of a single trial rather than from experience gained on past trials.

One final factor that may have impacted upon the results of Experiments 10 and 11 could relate to a suggested capacity limit for processing faces. Indeed, it has been proposed that the visual system is only capable of processing one face at a time (Bindeman, Burton & Jenkins, 2005). Experiments 12 & 13 therefore sought to establish how varying the number of faces in a semantic matching task would impact upon patterns of interhemispheric communication. The hypothesis was tested that the greater the number of faces in a match array, the more cognitively demanding the task would be. This increase in task difficulty was anticipated to increase the benefits of interhemispheric communication.

The results of both experiments revealed evidence that dividing task information between the hemispheres is of benefit for the more perceptually complex face-face matches in terms of accuracy. Performance for cross-domain and within-domain flag or name matches did not however appear to differ systematically within or across hemispheres. Such a lack of benefit from interhemispheric communication may be explained by the suggestion that different cortical access routes are required for accessing the stimulus properties of these different stimulus modalities (Koivsto & Revonsuo, 2003). This would result in the ability for simultaneous processing to occur within a single hemisphere without overloading the processing capabilities. Further support for this idea that different stimulus formats access related, yet distinct, cortical access routes can also be found from Patel and Hellige (2007), who demonstrated in a task difficulty paradigm, that mixing stimulus formats within a hemisphere can increase the processing capacity of that hemisphere.

Results from Experiments 12 and 13 also provided some evidence in support of the theory that capacity limits for face processing may have impacted upon the patterns of results observed for this chapter. In particular, face-face matches involving a match between stimulus arrays containing 3 faces were shown to be least accurate and the only match-type to benefit from across-hemisphere processing. This finding therefore implies that hemispheric processing resources were particularly taxed for such matches. Within-domain name-name matches did not show a similar across-hemisphere advantage, a finding which appears to confirm that names are not subject to the same capacity limits as faces. More surprising however is the result that flag-face matches in Experiment 12 and name-face matches in Experiment 13 were significantly slower than all other match-types. Given that both of these match-types contain fewer faces than the respective face-flag or face-name matches, this appears to conflict with theories relating to face capacity limits. Exploring the outcome of additional conditions in which the non-matching item is of a different stimulus modality would be of use to gain a clearer understanding of this unexpected pattern of results in both experiments. It may be the case that flag-face and name-face conditions are reliably slower than other conditions due to interference effects between the matching and non-matching items. Studies comparing unilateral processing with bilateral processing of different stimuli have shown that a distracter stimulus in the unattended visual field can influence performance (Boles, 1983, 1994). For example, greater interference effects have been shown to exist between nonface target and distracter items than between two faces (Bindemann et al, 2005). It could therefore be that such effects are of importance here in explaining the pattern of results between cross-domain matches.

The lack of any clear and consistent support in favour of an advantage for dividing processing between the hemispheres appears to contradict previous theories relating to task difficulty and interhemispheric communication. Whilst it may be that methodological factors relating to the current experiments are responsible for such a finding, it could also be the case that the benefits of distributing processing load across both hemispheres are not outweighed by the costs of transferring information across the corpus callosum. Whilst the degree of cerebral lateralisation for a task is not believed to influence patterns of interhemispheric communication (Belger & Banich 1998), it remains possible that differences in the ability for each hemisphere to contribute to processing are nonetheless important. Clear differences for within left and right hemisphere performance were not however evident suggesting that both hemispheres could indeed carry out the match decisions to a similar extent. Despite this, an asymmetry in across-field communication was evident at various points throughout this chapter, indicating that influence of hemispheric capabilities may still be significant.

All of these points will be considered further in the final, concluding chapter.

Chapter 6

Summary and Conclusions

Determining the instances and means through which communication between the cerebral hemispheres occurs has provided the main focus for this thesis. It is widely acknowledged that the hemispheres do not operate in isolation during the processing of complex visual stimuli, with a large body of evidence in support of such a claim emerging from both divided visual field and neuroimaging studies (e.g. Banich & Belger, 1995; Mohr, et al, 2002; Schweinberger, et al, 2003; Pulvermüller, 2005; Mohr, Endrasss, Hauk, & Pulvermüller, 2007). Despite the integral nature of interhemispheric communication to cognitive processing, both the circumstances under which this takes place and the nature of the information that can be communicated are still relatively poorly understood. Moreover, various approaches to studying interhemispheric communication have emerged, and it appears that the particular paradigm used for investigation as well as the question being addressed can be instrumental in the pattern of results produced. Through exploring the impact of a range of such approaches, this thesis aims to gain insight into how such information transfer operates during the processing of identity information.

Studies investigating the bilateral advantage provide a means for exploring the depth of identity information that can be communicated cross hemispherically. Such studies have demonstrated that the simultaneous presentation of identical stimuli to both visual fields can lead to superior performance relative to a single stimulus presented unilaterally. In the face domain, these performance advantages have been shown to occur only for familiar but not unfamiliar faces (Mohr, et al, 2002; Schweinberger, et al, 2003), a finding which has been interpreted by some as evidence that interhemispheric communication in such circumstances is reliant on the activation of learned cell assemblies spanning both hemispheres. Through extending this paradigm to incorporate the presentation of distinct but complimentary identity information to each visual field it was hoped that insights relating to the nature of possible hemispheric interactions could be gained (Chapters 2 & 3). Specifically, it was aimed to establish whether it was possible to achieve abstract identity driven collaboration with stimuli denoting the same concept or whether cross-hemispheric communication is restricted to more high-level stimulus driven interactions.

An emerging pattern of results from several studies in this thesis point towards the conclusion that the information being combined during interhemispheric communication contains information specific not just to the high level image characteristics of a face, but also to more abstract, identity associated elements. The bilateral advantage obtained in Experiment 1 after the presentation of complimentary left and right face halves provided the first indication that interhemispheric communication in such circumstances is not reliant on identical information being presented to each visual field. Performance restrictions in relation to ceiling and floor effects in Experiment 2 with upper and lower face halves, restricted further evidence of such visual identity collaboration. However, this finding was extended in Experiments 4 and 5 to reveal that both cross image and cross-domain face and name pairings could also result in a bilateral advantage. Both of these experiments served as important indicators of the type of information transfer that is capable of being achieved using such a divided visual field paradigm. Specifically, it appears that abstract identity information obtained from faces or names can be combined to improve performance relative to single hemisphere performance. While there has been an indication of this finding in other domains using less visually complex stimuli such as numbers (e.g. Marks & Hellige, 2003), these studies provide the first evidence to extend this finding to the face domain. No evidence of collaboration between the hemispheres was however achieved after the presentation of personal names, a surprising effect given the previously-observed bilateral advantage for words (Mohr, et al, 1994). The fact that performance appeared to be occurring near ceiling may provide an explanation as to why the expected pattern of results was not achieved.

The evidence of abstractive priming obtained in Experiments 7 and 9 made clear that this depth of communication is not restricted to methods of investigation such as those based on the bilateral redundant paradigm. Unlike the divided visual field paradigm utilised in Chapters 2 and 3 which does not necessarily require interhemispheric communication in order to perform the task, divided visual field repetition priming studies are reliant on performance in one hemisphere being directly influenced by the presentation of a stimulus in the opposite visual field. Cross-hemisphere image-specific priming and abstractive priming with lateralised primes and central targets have both been demonstrated previously with faces (Bourne & Hole, 2006; Cooper, et al, 2007). However, Experiment 7 is the first study to demonstrate cross-hemispheric abstractive identity priming using different images of the same identity at prime and target. This finding adds further strength to the claim that it is not just low-level visual characteristics of a stimulus that can be communicated cross-hemispherically but rather deeper levels of information transfer can also occur at a non-image specific level, perhaps akin to identity. One suggestion has been that the cortical representations that may be responsible for the bilateral advantage and interhemispheric priming effects may be neurobiological equivalents of face recognition units (FRUs) (Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999; Burton, Jenkins, Hancock, & White, 2005). Such FRUs are said to allow for the identification of faces independently of variations in image and would therefore be plausible structures to be involved in this form of communication.

The above findings are consistent with several other studies in the field which point towards the likelihood that both superficial and conceptual aspects of a stimulus contribute to interhemispheric collaboration effects (e.g. Marks & Hellige, 2003; Patel & Hellige, 2007). Indeed, as has been suggested by Marks & Hellige, the size of the bilateral advantage obtained may be determined by the extent to which stimuli on bilateral trials activate homologous areas in both hemispheres. For example, Marks & Hellige (2003), revealed evidence of a bilateral advantage when numeric quantities were presented to each visual field in different visual formats. While this finding and several others in this thesis do indeed suggest that abstract identity information can be combined across hemispheres, the results of Experiment 4 revealed that the greatest bilateral gain was found after the presentation of identical faces rather than different images of the same identity. Therefore, as with many other explorations into face recognition, there appears to be an extra advantage for co-operation at the image level. This finding mirrors the results of Marks & Hellige (2003) and may well be related to the fact that most callosal fibres connect homologous regions of the two hemispheres (e.g. Vercelli & Innocenti, 1993). In relation to the neurocognitive explanation of the bilateral advantage discussed previously, it could be that different identity formats activate areas of the cortex and hence cell assemblies that are similar yet not completely identical. As a result, provided that both formats activate sufficiently homologous areas then activation will be enough to produce a bilateral advantage, although perhaps one that is smaller than would be produced for identical stimuli. Although different identities sharing a common concept may not activate completely homologous cortical areas, it is possible that some shared representations of a given CA will be activated. Further insights into the precise nature of such communication might be explored further by examining the effect of semantic judgments of personal identity on the bilateral advantage or through cross-hemispheric semantic priming studies. The latter has successfully been achieved in the language domain (e.g., Abernethy & Coney, 1996; Collins, 1999; Koivisto & Hämäläinen, 2002) and it would therefore be interesting to establish whether this transfers to the domain of faces.

There are however some inconsistencies with the above results and those of the cross-domain face-name pairings achieved in Experiment 5. Performance here was shown to be most advantageous when visual field inputs were of a different stimulus modality (face-name) rather than identical (face-face). These results therefore do not seem to reflect an advantage to one stimulus type but rather the pooling of a shared conceptual activation. As with other results in this thesis, such contrasting results may be explained by the notion that the simultaneous activation of different cortical access routes allows for each hemisphere to operate more effectively. In addition, the optimal bilateral performance was achieved when each hemisphere received its dominant mode of stimulus. Such a finding opens the door to exploring the impact of different processing biases on optimising hemispheric communication.

Support for the proposition that different stimulus formats access related yet distinct cortical access routes can be found from Patel and Hellige (2007), who demonstrated, in a task difficulty paradigm, that mixing stimulus formats within a hemisphere can increase its processing capacity. Indeed, the results from the task difficulty paradigms in Experiments 12 and 13 would also seem to confirm this suggestion. Specifically, as will be discussed in greater detail later, matches between cross-domain pairings did not appear to benefit from dividing processing load between the hemispheres. It may be that this was due to the different stimulus modalities being processed through different cortical routes without overloading the capacity of any one hemisphere.

The above studies appear to reflect evidence that interhemispheric communication can occur at non-image specific levels. Evidence that such communication may also occur asymmetrically in the direction of RH to LH was also obtained from further studies in this thesis (Experiments 8, 9 and 10). Given that the RH is known to be dominant in the processing of faces, the direction of the cooperation implies that the processing superiority of the RH may be acting to facilitate the less specialised LH. As mentioned previously, asymmetric interhemispheric communication has been observed in repetition priming studies cross-hemispherically with identical faces (Bourne & Hole, 2006) and also with different images of the same identity presented laterally at prime and centrally at target (Cooper, et al, 2007). However, of interest in this thesis was the finding that a similar asymmetry in processing did not extend to the presentation of different images of the same identity at prime and test (Experiment 7) and was restricted to the presentation of identical images at both experimental phases (Experiment 8). This finding is particularly intriguing given that image-specific priming effects are usually smaller in magnitude than abstractive (Bruce & Valentine, 1985; Ellis, Young, Flude, & Hay, 1987). The results of Experiment 8 suggest that the contrast between previous studies demonstrating asymmetric priming effects (e.g. Bourne & Hole, 2006) and the lack of any such directional bias in Experiment 7 are not brought about by differences in methodology. Consequently, it would appear that the variation in observed communication asymmetry between Experiments 7 and 8 may be driven by different processing mechanisms employed during the image specific and abstractive priming tasks. Although the underlying processes for these priming types is not assumed to be qualitatively different (e.g. Schweinberger, Pickering, Burton & Kaufmann, 2002) the fact that instances exist in which robust behavioural effects are difficult to locate using imaging techniques makes this possibility worthy of consideration.

The restriction of priming occurring within the left hemisphere to Experiment 7 would seem to form the basis of the observed inconsistency in asymmetric communication. Given that both hemispheres are known to posses face processing capabilities a lack of priming with the LH is perhaps surprising. Possible explanations for this were explored in Chapter 4, including the possibility that differences in timing of FRU activation between the left and right hemispheres may be responsible. It was further speculatively suggested that the abstractive priming process during Experiment 7 may have allowed for the activation of wider and less lateralised cognitive representation than did the image-specific priming process so as to have a facilitative effect on priming. However, the bilateral advantage observed in Experiment 4, involving different images of the same identity was not shown to be as great as that achieved with identical face images. It was suggested here that different identity formats may activate areas of the cortex and hence cell assemblies that are similar yet not completely identical. In turn this may result in hemispheric interaction that is less robust than after the activation of identical images. While these two findings appear difficult to reconcile, it may be that the differences in methodological paradigms may play some role here. Specifically, the bilateral redundant paradigm requires for the immediate activation of shared stimulus concepts, whereas repetition priming studies are reliant on more sustained levels of activation. Therefore, if abstractive priming leads to longer lasting and more widespread activation than image specific priming, this could offer an account for the differences in asymmetrical communication. Finally, as discussed in Chapter 4, there remains the possibility that this asymmetry in communication may be a more general RH to LH processing bias rather than a mechanism to enhance processing. For example, semantic priming studies have shown interhemispheric cooperation appears to occur in the reverse direction of less dominant to more dominant hemisphere (RH to LH) (Abernethy & Coney, 1996; Collins 1999; Koivisto & Hämäläinen, 2002).

The focus of the final experimental chapter was to investigate further the purpose of interhemispheric communication and more specifically to ascertain whether dividing cognitive processing between both hemispheres is more beneficial to performance than constraining to one. A methodological paradigm adopted from Banich & Belger (1990) was employed in which participants were required to match faces presented either within a single hemisphere or across both hemispheres. Results from previous studies have suggested that as task difficulty increases, a general shift towards performance benefiting from dividing processing between the hemispheres typically emerges (Brown et al 1999; Koivisto, 2000; Liederman et al, 1985; Weissman & Banich, 2000; Compton 2002). As such, it was expected that a similar pattern of results would be observed for tasks involving variations in complexity decisions related to faces. An advantage for dividing task relevant information between the hemispheres has previously been observed during an unfamiliar face matching task (Compton, 2002) for which cross-hemispheric processing was shown to be most beneficial for identity matches compared with less complex expression matches. Results from experiments in Chapter 5 were however somewhat inconclusive with neither Experiments 9, 10 or 11 demonstrating any advantage for dividing processing load between the hemispheres, regardless of the complexity of the matching task. Simplifying the experimental design to eliminate possible floor effects also failed to impact on patterns of results in any significant manner (Experiment 10). Therefore, establishing whether methodological factors were responsible for the lack of differentiation between within and across hemisphere trials or whether theoretical limitations had not been considered therefore appeared to be of importance. Unexpected findings such as that of unfamiliar faces being matched more accurately than familiar (Experiment 10) may well have been caused by a failure to balance certain image characteristics between stimuli or as a result of differences in attention capture for familiar and unfamiliar faces. While these factors may have played a role in confounding the observed results, the possibility that a capacity limit to face processing (Bindeman, Burton & Jenkins, 2005) was instrumental was also considered.

To determine the impact of capacity limits on these matching tasks, Experiments 12 and 13 varied the number of faces in a semantic matching task. This allowed the hypotheses to be tested that the greater the number of faces in a match array, the more cognitively demanding the task would be. Such an increase in task difficulty was anticipated to increase the benefits of interhemispheric communication. Performance results revealed that the perceptually more complex semantic matches between pairs of faces were indeed least accurate and the only match-type to benefit from across-hemisphere processing. This finding provides perhaps the most compelling support to the notion that division of labour between the hemispheres can aid complex cognitive tasks. Moreover, support would seem to be offered to the idea that these match types proved most difficult to participants due to restrictions in the processing capacity of faces. This bottleneck in processing capacity may have been in operation throughout all experiments in this thesis involving the simultaneous presentation of multiple faces. Therefore, it is worth considering that limitations to the processing of more than one face may provide an alternative explanation as to why the bilateral advantage obtained for cross-domain face-name stimuli was greater than that for within domain face-faces in Experiment 5.

Performance for cross-domain and within domain flag or name matches did not however appear to differ systematically within or across hemispheres. It was suggested that different cortical access routes may be accessed for these different stimulus modalities and as such the processing resources of a single hemisphere are not over-loaded (Koivsto & Revonsuo, 2003). Patel & Hellige (2007), also found no evidence of an increase in the benefits of interhemispheric communication as task difficulty increased when using numeric quantities with different visual formats (dots and digits). The authors concluded here that identification of these different stimuli could take place in parallel through different cortical access routes without interference between stimuli. While such matching experiments differ from experiments investigating the bilateral advantage in that the former investigate whether the hemispheres can cooperate and the latter seek to determine whether or not cooperation will occur, the finding that matches could occur for non-identical and semantically related stimuli does still lend further support to the existing evidence that abstract qualities of an image, relating to identity can be communicated cross-hemispherically.

Indications of possible interference effects between matching and non-matching items were also evident in the results of Experiments 12 and 13. Specifically, flag-face and name-face matches were shown to be significantly slower than all other match types. While this finding is difficult to reconcile with theories of capacity limits in that these conditions contained fewer faces than both face-face and face-flag/name conditions, there is some evidence to suggest that a distracter stimulus in the unattended visual field can influence performance (Boles, 1983, 1994). Moreover, greater interference effects have been shown to exist between non-face target and distracter items than between two faces (Bindemann et al, 2005). Such interference effects may therefore have been in operation during Experiments 12 & 13. Further investigations whereby the non-matching item in a stimulus array is of a different stimulus modality to the matching item would be of interest to establish more clearly the underlying cause of this unexpected pattern of results.

Methodological factors do appear to account for the lack of any clear and consistent evidence of an advantage for dividing processing as task complexity increases. Despite this, it is worth considering that possible theoretical limitations may also be responsible. For example, it seems plausible that bilateral processing may occur for all stimuli types, regardless of complexity. Increasing task complexity may simply increase the strength of this activation occurring in both hemispheres. Some support for this theory can be seen in an fMRI study focusing on neural recruitment related to linguistic complexity (Just et al, 1996). It was demonstrated that even at the lowest level of sentence complexity, bilateral activation was present. As complexity increased, the strength of these existing signals was also shown to increase accordingly. Therefore, it may simply be that indirect methods of evaluating patterns of hemispheric interaction are not sensitive enough to provide a full picture of the mechanisms occurring in relation to task complexity.

Several of the experiments reported in this thesis appeared to have been affected by the presence of floor effects. As mentioned above, accuracy in Experiment 2 involving complimentary upper and lower face halves was around chance for conditions containing just the lower half of the face. In addition, performance in experiments exploring the impact of task difficulty (Chapter 5) also produced several results for which accuracy was particularly low. Although low accuracy in divided visual field paradigms is not uncommon, (e.g. Mohr, et al, 2002) it appears that factors such as the brief exposure time of numerous complex face stimuli in the periphery of vision resulted in participants frequently failing to cope with the demands of the task. Consequently, the resulting floor effects in such experiments may have acted to obscure the true nature of any underlying effects. Related to this issue concerns the analysis of reaction times for experiments where accuracy was near chance. Specifically, in instances where performance was particularly poor, the number of correct responses on which reaction time analysis could be based was very limited. Moreover, the conclusions that can be drawn from such reaction times associated with near chance accuracy must be limited and tentative. Consequently, it seems prudent that in experiments where floor effects are suspected, greater attention is placed upon the interpretation of accuracy data.

The patterns of interhemispheric communication described throughout the experiments in this thesis may be characterised by various theoretical models. The most predominant of these are a neurocognitive account of interhemispheric communication based on Hebbian learning principles and transcortical cell assemblies and an alternative race model hypothesis. Attempting to reconcile results within such theories is difficult. For many of the reported experiments, the observed behavioural results can be explained by a neurocognitive model yet a race model explanation is also not falsified by the data. As outlined previously, a race model assumes that if both stimuli are processed independently and in parallel, the hemisphere that is most efficient for a particular task normally completes it first and initiates a response. However, if the less specialised hemisphere occasionally completes the task fastest, the overall average processing speed will be faster than unilateral presentation to the specialised hemisphere. According to this model, a bilateral advantage would be seen for any kind of stimuli.

Experiment 3 attempted to bring about some resolution to this conflict and determine whether the bilateral advantage may be attributed to interhemispheric communication or a race between competing stimuli. While the established bilateral advantage for famous faces (Mohr et al., 2002; Schweinberger et al., 2003) was observed, no similar performance advantage was evident when both faces were presented centrally. Positioning of faces within the visual array and not merely the presence of additional stimulus information on bilateral presentations therefore appears critical for the bilateral advantage. Such findings were consequently interpreted as offering support to a neurocognitive model. Although a neurocognitive model of the bilateral advantage does also predict redundancy gains for multiple copies of meaningful stimuli presented anywhere in the visual system (Mohr et al, 1996), the results seem to suggest that presenting stimuli to both hemispheres may have an additional effect on the phenomenon. The effect of redundancy on unilateral stimulation was not tested, however, this may be a result of bilateral stimulation igniting more widespread cell assemblies compared with the stimulation of only a single hemisphere. Further investigations in relation to this would clearly be of benefit.

Another of the major arguments against race models comes from the differentiation in bilateral advantage observed between familiar and unfamiliar faces (Mohr et al, 2002; Schweinberger et al, 2003). Indeed, there was no evidence of a bilateral advantage being elicited by unfamiliar faces in any experiment reported in this thesis. Neurocognitive models suggest that familiar faces may become represented in learned CAs spanning both hemispheres and the dual stimulation of such TCAs underlies the processing advantage observed in the bilateral advantage. It has therefore been argued, and seems plausible, that if a race between the hemispheres is responsible for producing the bilateral advantage then this should not differentiate between familiar and unfamiliar stimuli. As CAs should only exist for concepts that have been learned, bilateral stimulation will produce no facilitation for previously unlearned stimuli such as unfamiliar faces. Many aspects of a model of hemispheric interaction based on TCAs are compelling. However, it is worth considering that the differentiation in performance relating to the familiarity of face stimuli may be grounded at a more basic level. Specifically, an imbalance in the difficulty of familiar and unfamiliar decisions in relation to the task could offer an alternative explanation. Deciding whether or not a face is familiar is a very different process compared with deciding if it is unfamiliar. This may therefore impact on the pattern of results observed for unfamiliar faces. As a result an explanation of the bilateral advantage based on a race between the hemispheres may then be appropriate. In addition, a lack of bilateral advantage for the recognition of emotional expression (Schweinberger et al, 2003) has typically been interpreted as evidence that interhemispheric communication is dependent upon the activation of concepts that have been acquired through learning. However, it may again simply reflect a paradigm that more evenly equates decisions to stimuli.

This thesis applies a range of approaches to establish greater understanding of the nature and limitations of the identity information that can be communicated cross-hemispherically along with providing some insights into the purpose of such communication. Several lines of evidence were obtained to indicate that both physical and abstract aspects of identity can be transferred. It was further suggested that the cortical representations responsible for such collaboration may be neurobiological equivalents of FRUs. Mixing stimulus formats appears to have differential effects on hemispheric collaboration dependent on the particular method of investigation. While different images of the same identity resulted in a weaker display of the bilateral advantage in Experiment 4, further studies involving cross-domain, cross-image and semantic associations did however appear to benefit from these different stimulus modalities. This may be related to such representations activating different cortical access routes (Koivsto & Revonsuo, 2003; Patel & Hellige, 2007). Experiments exploring the effect of task difficulty on interhemispheric communication certainly appeared to provide further evidence that this may be the case. There was little indication that patterns of hemispheric communication differ significantly in relation to the complexity of a task. Finally, further insights into the underlying mechanisms of such results were obtained with support being offered to both a neurocognitive and race-model framework. To help further elucidate the underlying theory to account for these findings it appears that further research is required into the effect of both redundant unilateral and bilateral stimulation and also the decision making criterion. In addition, it may have been beneficial to have limited the number of conditions in several of the experiments in this thesis to only the primary conditions of interest. Specifically, several experiments contained multiple comparisons between experimental conditions of which not all were greatly informative of the process of interhemispheric communication. Limiting the number of comparisons between conditions may have provided a clearer insight into the mechanisms of communication occurring. In addition, a secondary impact of such a manipulation may have been to improve performance accuracy. For example, fewer experimental conditions may have prevented participants from becoming confused by the multiple perceptual changes between conditions as well as reducing the number of trials per experiment to prevent fatigue. As stated above, poor accuracy was an issue for several experiments in this thesis and therefore greater attempts to improve general performance accuracy may have been beneficial to the interpretation of many results. Finally, scope exists for further experimental investigation into the nature of the information that can be communicated cross-hemispherically and whether the cortical representations proposed to be responsible for the benefits of interhemispheric communication can indeed be likened to neurobiological equivalents of FRUs. For example, further utilisation of the divided visual field priming paradigm applied in Chapter 4 to explore within and across hemisphere semantic priming, would provide an interesting opportunity to determine the extent of abstract identity information that can be communicated between the hemispheres.

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APPENDIX A

Experiment 1: Results Table

	Condition	**Accuracy** *(Percentage Correct)*	*(Standard Error)*	**Mean of Median Reaction Time** *(ms)*	*(Standard Error)*
Familiar	Left hemiface to LVF (L_LVF)	67.88%	*2.30*	891.63	*23.10*
	Right hemiface to LVF (R_LVF)	69.10%	*2.28*	878.24	*24.18*
	Left hemiface to RVF (L_RVF)	64.06%	*2.91*	938.33	*28.99*
	Right hemiface to RVF (R_RVF)	67.88%	*2.13*	854.01	*20.23*
	Left hemiface to LVF & RVF (L_BVF)	71.53%	*2.04*	849.26	*23.18*
	Right hemiface to LVF & RVF (R_BVF)	74.48%	*2.44*	849.57	*24.33*
	Left hemiface to LVF & complimentary right hemiface to RVF (LR_BVF)	76.56%	*2.42*	866.51	*24.96*
	Right hemiface to LVF & complimentary left hemiface to RVF (RL_BVF)	68.75%	*1.96*	835.42	*19.44*
Unfamiliar	Left hemiface to LVF (L_LVF)	70.14%	*2.87*	975.61	*26.59*
	Right hemiface to LVF (R_LVF)	69.97%	*2.48*	985.47	*25.66*
	Left hemiface to RVF (L_RVF)	71.88%	*3.12*	966.43	*24.63*
	Right hemiface to RVF (R_RVF)	69.62%	*3.15*	979.60	*27.43*
	Left hemiface to LVF & RVF (L_BVF)	69.79%	*2.82*	927.10	*27.82*
	Right hemiface to LVF & RVF (R_BVF)	68.06%	*2.91*	911.44	*24.54*
	Left hemiface to LVF & complimentary right hemiface to RVF (LR_BVF)	67.71%	*3.28*	968.44	*30.28*
	Right hemiface to LVF & complimentary left hemiface to RVF (RL_BVF)	67.36%	*2.65*	991.65	*32.50*

Experiment 2: Results Table

	Condition	**Accuracy** *(Percentage Correct)*	*(Standard Error)*	**Mean of Median Reaction Time** *(ms)*	*(Standard Error)*
Familiar	Upper half to LVF (upper_LVF)	78.91%	*2.54*	797.88	*28.93*
	Upper half to RVF (upper_RVF)	75.00%	*3.91*	786.41	*28.20*
	Lower half to LVF (lower_LVF)	44.53%	*4.41*	920.72	*38.43*
	Lower half to RVF (lower_RVF)	53.52%	*4.38*	942.78	*40.15*
	Upper half to LVF & RVF (upper_BVF)	78.13%	*2.28*	793.75	*32.50*
	Lower half to LVF & RVF (lower_BVF)	58.98%	*3.70*	853.94	*23.77*
	Upper half to LVF & complimentary lower half to RVF (up/low_BVF)	81.64%	*3.04*	796.50	*25.11*
	Lower half to LVF & complimentary upper half to RVF (low/up_BVF)	82.03%	*2.54*	823.53	*35.00*
Unfamiliar	Upper half to LVF (upper_LVF)	75.00%	*2.61*	897.19	*35.50*
	Upper half to RVF (upper_RVF)	76.95%	*3.26*	925.47	*39.43*
	Lower half to LVF (lower_LVF)	78.52%	*2.79*	893.66	*30.56*
	Lower half to RVF (lower_RVF)	76.17%	*2.92*	868.91	*32.76*
	Upper half to LVF & RVF (upper_BVF)	76.17%	*2.81*	912.25	*34.33*
	Lower half to LVF & RVF (lower_BVF)	75.00%	*3.61*	916.88	*43.61*
	Upper half to LVF & complimentary lower half to RVF (up/low_BVF)	74.22%	*2.48*	929.44	*45.88*
	Lower half to LVF & complimentary upper half to RVF (low/up_BVF)	71.09%	*3.69*	926.63	*42.05*

Experiment 3: Results Table

	Condition	**Accuracy** *(Percentage Correct)*	***(Standard Error)***	**Mean of Median Reaction Time** *(ms)*	***(Standard Error)***
Familiar	LVF (LVF)	67.07%	*1.92*	889.77	*29.02*
	RVF (RVF)	72.84%	*2.25*	868.92	*27.37*
	Both visual fields, horizontal (BVF_H)	75.96%	*2.44*	779.40	*23.94*
	Upper visual field, (Upper_VF)	71.39%	*2.78*	875.15	*30.86*
	Lower visual field, (Lowever_VF)	70.43%	*3.15*	906.75	*31.26*
	Both visual fields, vertical (BVF_V)	68.75%	*3.36*	863.02	*34.23*
Unfamiliar	LVF (LVF)	81.73%	*2.79*	883.75	*30.33*
	RVF (RVF)	80.53%	*3.11*	870.75	*28.49*
	Both visual fields, horizontal (BVF_H)	80.29%	*3.08*	840.87	*21.48*
	Upper visual field, (Upper_VF)	75.96%	*2.77*	844.73	*27.44*
	Lower visual field, (Lowever_VF)	74.04%	*2.77*	844.27	*24.44*
	Both visual fields, vertical (BVF_V)	74.04%	*3.04*	888.63	*27.62*

Experiment 4: Results Table

	Condition	**Accuracy** *(Percentage Correct)*	*(Standard Error)*	**Mean of Median Reaction Time** *(ms)*	*(Standard Error)*
Familiar	Left visual field (LVF).	72.10%	*2.26*	849.80	*30.11*
	Right visual field only (RVF).	72.99%	*2.49*	823.73	*26.82*
	Identical images both visual fields, (BVF_same)	79.02%	*2.64*	767.59	*34.58*
	Different images of the same identity to both visual fields, (BVF_diff)	79.69%	*2.33*	795.73	*32.15*
Unfamiliar	Left visual field (LVF).	73.88%	*3.02*	846.50	*25.90*
	Right visual field only (RVF).	68.53%	*3.14*	820.82	*24.08*
	Identical images both visual fields, (BVF_same)	68.97%	*2.94*	850.43	*28.65*
	Different images of the same identity to both visual fields, (BVF_diff)	70.09%	*2.70*	805.50	*28.11*

Experiment 5: Results Table

	Condition	**Accuracy** *(Percentage Correct)*	***(Standard Error)***	**Mean of Median Reaction Time** *(ms)*	***(Standard Error)***
Familiar	Face, left visual field (LVF)	78.33%	*2.95*	797.65	*30.28*
	Face, right visual field (RVF)	80.63%	*2.46*	778.92	*26.47*
	Face, left visual field & corresponding name, right visual field (BVF_face/name)	93.13%	*1.60*	680.77	*21.34*
	Face, right visual field & corresponding name, left visual field (BVF_name/face)	91.46%	*2.06*	725.60	*25.32*
	Face, both visual fields (BVF_face)	83.33%	*2.70*	758.33	*28.20*
Unfamiliar	Face, left visual field (LVF)	79.58%	*2.92*	823.75	*27.72*
	Face, right visual field (RVF)	78.96%	*3.18*	825.93	*28.58*
	Face, left visual field & corresponding name, right visual field (BVF_face/name)	84.79%	*2.96*	845.52	*33.34*
	Face, right visual field & corresponding name, left visual field (BVF_name/face)	82.50%	*3.37*	848.37	*32.25*
	Face, both visual fields (BVF_face)	74.17%	*2.87*	789.20	*28.12*

Experiment 6: Results Table

	Condition	**Accuracy** *(Percentage Correct)*	*(Standard Error)*	**Mean of Median Reaction Time** *(ms)*	*(Standard Error)*
Familiar	Name, left visual field (LVF)	87.29%	*2.85*	764.32	*25.54*
	Name, right visual field (RVF)	92.71%	*1.50*	710.70	*21.35*
	Name, both visual fields (BVF_name)	88.96%	*2.22*	699.02	*21.85*
	Face, both visual fields (BVF_face)	86.25%	*3.45*	771.20	*31.27*
Unfamiliar	Name, left visual field (LVF)	90.42%	*3.04*	846.52	*32.17*
	Name, right visual field (RVF)	92.08%	*1.58*	821.87	*29.82*
	Name, both visual fields (BVF_name)	92.71%	*1.34*	820.67	*34.84*
	Face, both visual fields (BVF_face)	70.21%	*3.01*	842.72	*34.87*

Experiment 7: Results Table

Condition	**Accuracy** *(Percentage Correct)*	*(Standard Error)*	**Mean of Median Reaction Time** *(ms)*	*(Standard Error)*
Prime LVF, Target LVF	70.12%	*2.87*	872.63	*23.90*
Prime LVF, Target RVF	63.67%	*2.94*	885.16	*30.24*
Prime RVF, Target RVF	67.77%	*2.38*	863.52	*28.66*
Prime RVF, Target LVF	68.95%	*2.67*	859.13	*24.16*
Unrpimed familiar LVF	57.03%	*3.23*	892.27	*30.04*
Unprimed familiar RVF	57.62%	*2.93*	917.42	*31.48*

Experiment 8: Results Table

Condition	**Accuracy** *(Percentage Correct)*	*(Standard Error)*	**Mean of Median Reaction Time** *(ms)*	*(Standard Error)*
Prime LVF, Target LVF	76.56%	*2.07*	823.08	*26.66*
Prime LVF, Target RVF	71.61%	*2.41*	858.54	*29.29*
Prime RVF, Target RVF	71.35%	*2.32*	932.40	*32.12*
Prime RVF, Target LVF	71.61%	*2.49*	858.15	*30.94*
Unrpimed familiar LVF	55.73%	*2.91*	925.17	*42.34*
Unprimed familiar RVF	53.91%	*3.01*	906.13	*32.60*

Experiment 9: Results Tables

Stage 1

		Accuracy ***(Percentage Correct)***	***(Standard Error)***	**Mean of Median Reaction Time** ***(ms)***	***(Standard Error)***
Low Load	Within LVF	93.40%	*1.81*	651.58	*24.82*
	Within RVF	94.79%	*1.72*	620.63	*23.09*
	Across, Face-Letters	96.18%	*1.50*	594.00	*23.05*
	Across, Letters-Face	87.85%	*2.13*	612.94	*19.91*
High Load	Within LVF	68.75%	*3.96*	986.42	*55.35*
	Within RVF	72.57%	*3.74*	930.79	*36.70*
	Across, Face-Letters	91.67%	*2.70*	805.50	*34.93*
	Across, Letters-Face	87.15%	*2.30*	866.65	*40.37*

Stage 2

	Accuracy ***(Percentage Correct)***	***(Standard Error)***	**Mean of Median Reaction Time** ***(ms)***	***(Standard Error)***
Low Load Within	*41.67%*	4.41	*1198.56*	152.79
Low Load Across	*40.97%*	4.10	*1106.92*	95.72
High Load Within	*41.84%*	4.35	*1093.69*	76.66
High Load Across	*41.32%*	4.51	*1129.97*	104.02
New	*69.32%*	3.59	*1004.25*	52.78

Stage 3

	Accuracy ***(Percentage Correct)***	***(Standard Error)***	**Mean of Median Reaction Time** ***(ms)***	***(Standard Error)***
Low Load Within	*88.38%*	2.07	815.43	*37.36*
Low Load Across	*84.55%*	2.58	773.07	*25.49*
High Load Within	*86.81%*	2.50	773.08	*30.17*
High Load Across	*87.50%*	2.38	787.14	*30.71*
New	*82.81%*	2.34	798.75	*24.23*

Experiment 10: Results Table

		Accuracy ***(Percentage Correct)***	***(Standard Error)***	**Mean of Median Reaction Time *(ms)***	***(Standard Error)***
Familiar	Physical match, within LVF	82.68%	*2.32*	820.30	*31.48*
	Identity match, within LVF	40.54%	*2.72*	972.75	*46.98*
	Physical match, within RVF	78.04%	*3.02*	846.50	*28.97*
	Identity match, within RVF	40.18%	*2.94*	995.95	*51.09*
	Physical match, across, LVF/RVF	84.64%	*2.25*	794.48	*28.31*
	Identity match, across, LVF/RVF	41.43%	*2.90*	970.65	*40.37*
	Physical match, across, RVF/LVF	80.18%	*2.01*	810.48	*28.85*
	Identity match, across, RVF/LVF	45.36%	*3.26*	971.45	*43.32*
Unfamiliar	Physical match, within LVF	82.32%	*3.13*	781.38	*25.17*
	Identity match, within LVF	54.64%	*3.28*	860.70	*43.24*
	Physical match, within RVF	80.36%	*3.36*	815.88	*29.13*
	Identity match, within RVF	50.18%	*2.88*	867.43	*30.58*
	Physical match, across, LVF/RVF	84.82%	*2.36*	760.58	*26.04*
	Identity match, across, LVF/RVF	51.96%	*3.30*	829.45	*27.45*
	Physical match, across, RVF/LVF	84.46%	*2.46*	790.08	*26.54*
	Identity match, across, RVF/LVF	59.11%	*3.10*	832.53	*36.67*

Experiment 11: Results Table

		Accuracy ***(Percentage Correct)***	***(Standard Error)***	**Mean of Median Reaction Time** ***(ms)***	***(Standard Error)***
Familiar	Physical match, within LVF	90.58%	*1.97*	779.34	*34.69*
	Identity match, within LVF	61.36%	*2.10*	952.02	*46.01*
	Physical match, within RVF	88.64%	*2.22*	781.43	*28.56*
	Identity match, within RVF	63.64%	*2.99*	939.18	*37.96*
	Physical match, across, LVF/RVF	90.10%	*1.50*	759.09	*36.07*
	Identity match, across, LVF/RVF	64.94%	*2.08*	966.86	*55.86*
	Physical match, across, RVF/LVF	90.91%	*2.42*	781.59	*30.12*
	Identity match, across, RVF/LVF	68.02%	*2.85*	939.36	*46.38*
Unfamiliar	Physical match, within LVF	89.12%	*1.80*	754.27	*28.97*
	Identity match, within LVF	71.27%	*1.77*	860.75	*35.73*
	Physical match, within RVF	90.26%	*1.54*	759.00	*30.55*
	Identity match, within RVF	70.29%	*2.37*	859.39	*36.18*
	Physical match, across, LVF/RVF	88.15%	*1.68*	727.89	*34.38*
	Identity match, across, LVF/RVF	74.84%	*2.00*	866.27	*44.97*
	Physical match, across, RVF/LVF	87.01%	*2.26*	759.80	*32.01*
	Identity match, across, RVF/LVF	72.08%	*2.43*	863.07	*44.89*

Experiment 12: Results Table

		Accuracy ***(Percentage Correct)***	***(Standard Error)***	**Mean of Median Reaction Time** ***(ms)***	***(Standard Error)***
Within	Face-Face, LVF	61.34%	*3.05*	1138.81	*49.35*
	Face-Face, RVF	65.74%	*2.93*	1118.75	*41.29*
	Face-Flag, LVF	86.11%	*2.63*	1078.92	*38.24*
	Face-Flag, RVF	83.33%	*2.21*	1113.58	*41.49*
	Flag-Face, LVF	84.26%	*2.75*	1235.86	*35.95*
	Flag-Face, RVF	81.48%	*2.00*	1198.08	*35.41*
	Flag-Flag, LVF	92.13%	*1.84*	933.17	*39.23*
	Flag-Flag, RVF	95.14%	*1.69*	870.31	*36.14*
Across	Face-Face, LVF/RVF	64.81%	*3.66*	1130.72	*55.11*
	Face-Face, RVF/LVF	72.92%	*2.90*	1128.19	*38.70*
	Face-Flag, LVF/RVF	84.26%	*1.95*	1139.47	*48.40*
	Face-Flag, RVF/LVF	79.40%	*2.39*	1163.31	*41.89*
	Flag-Face, LVF/RVF	82.41%	*2.09*	1248.11	*41.24*
	Flag-Face, RVF/LVF	81.94%	*2.08*	1209.92	*26.75*
	Flag-Flag, LVF/RVF	95.60%	*1.60*	879.28	*50.04*
	Flag-Flag, RVF/LVF	96.30%	*1.42*	896.11	*50.47*

Experiment 13: Results Table

		Accuracy ***(Percentage Correct)***	***(Standard Error)***	**Mean of Median Reaction Time *(ms)***	***(Standard Error)***
Within	Face-Face, LVF	62.96%	*2.75*	1078.78	*35.90*
	Face-Face, RVF	66.44%	*3.22*	1063.44	*38.83*
	Face-Name, LVF	90.28%	*2.31*	1021.61	*39.22*
	Face-Name, RVF	90.05%	*1.39*	1014.78	*39.88*
	Name-Face, LVF	83.80%	*2.47*	1161.00	*46.22*
	Name-Face, RVF	84.26%	*1.98*	1088.42	*27.21*
	Name-Name, LVF	91.67%	*2.43*	1063.53	*37.32*
	Name-Name, RVF	94.44%	*1.17*	1025.31	*41.03*
Across	Face-Face, LVF/RVF	62.96%	*3.35*	1068.06	*38.71*
	Face-Face, RVF/LVF	78.01%	*2.56*	1077.50	*36.70*
	Face-Name, LVF/RVF	83.33%	*2.65*	1035.94	*40.49*
	Face-Name, RVF/LVF	88.43%	*2.47*	1050.92	*38.86*
	Name-Face, LVF/RVF	79.63%	*3.90*	1215.22	*51.17*
	Name-Face, RVF/LVF	81.48%	*2.96*	1145.33	*34.19*
	Name-Name, LVF/RVF	92.13%	*2.38*	1056.25	*38.50*
	Name-Name, RVF/LVF	90.51%	*2.35*	1068.58	*38.08*