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The neural systems sustaining face and proper-name processing

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Summary

This PET study has revealed the neural system involved in implicit face, proper-name and object name processing during an explicit visual 'same' versus 'different' matching task. Within the identified system, some areas were equally active irrespective of modality (faces or names) or type of stimuli (famous and non-famous) while other areas exhibited differential effects. Our findings support the hypothesis that faces and names involve differential pre-semantic processing prior to accessing a common neural system of stored knowledge of personal identity which overlaps with the one associated with object knowledge. The areas specialized for the perceptual analysis of faces (irrespective of whether they are famous or non-famous) are the right lingual and bilateral fusiform gyri, while the areas specialized for famous stimuli (irrespective of whether they are faces or names) spread from the left anterior temporal to the left temporoparietal regions. One specific area, the more lateral portion of the left anterior middle temporal gyrus, showed increased activation for famous faces relative to famous proper names and for famous proper names relative to common names. The differential responsiveness of this region when processing familiar people suggests functional segregation of either personal attributes or, more likely, the demands placed on processes that retrieve stored knowledge when stimuli have highly similar visual features but unique semantic associations.

Keywords: faces; proper names; semantic processing; temporal lobe; PET

Abbreviation: BA = Brodmann area

Introduction

The ability to recognize and distinguish one person from another is a fundamental skill necessary for everyday social interactions. It is usually dependent on the face or the name, but the person's voice, clothing, posture or other contextual clues can help. The amazing efficiency with which the brain meets this need and the observation that patients with brain lesions can show selective impairments of face or proper-name processing have inspired many experiments. Functional models have been developed to account for the multiple cognitive components involved in face processing and the selective patterns of impairment observed after brain damage. The work presented in this paper attempts to delineate the neural system associated with processing faces and proper names. For this purpose, we first review theories of the cognitive components thought to be involved.

The most accepted functional model of face processing was first proposed by Bruce and Young in 1986. Subsequently, it has been refined (Burton *et al.*, 1990; Young and Bruce, 1991) and developed to encompass proper names (Valentine *et al.*, 1991). The model entails a multistage, sequential processing organization (Fig. 1). Perceptual analysis is common to all routes and it results in structural encoding from which different types of information can be extracted in parallel for processing structural features (directed visual processing), expression analysis and lip reading. Recognition, association with knowledge of personal identity and name generation are then required for the complete identification of familiar faces. Recognition is thought to involve face-specific processing, but knowledge of a person's identity (biographical knowledge) and name retrieval are modality independent and common to verbal (written or heard proper names) and non-verbal (voice patterns and gait characteristics) processes. The notion of face specificity is supported by neurophysiological evidence of face-selective cells in

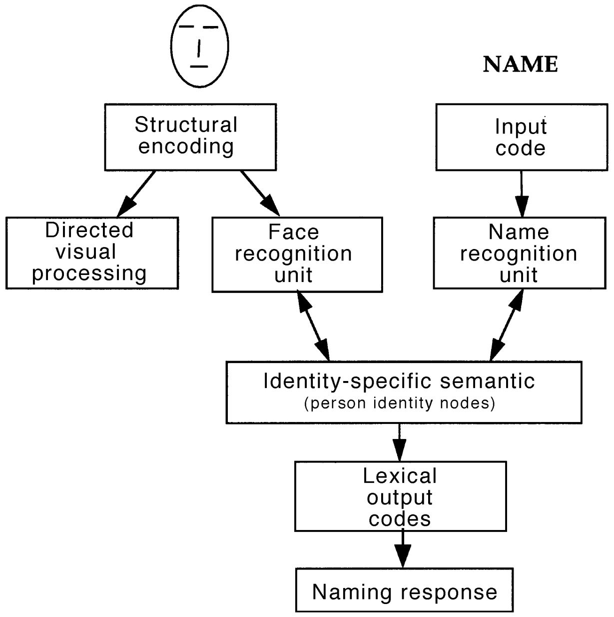


Fig. 1 Functional model of face and proper-name processing, adapted and simplified from Bruce and Young (1986) and Valentine *et al.* (1991).

monkeys (Desimone, 1991; Perrett *et al.*, 1992) and by human evoked potential studies (Nobre *et al.*, 1994).

Evidence for the sequential and distinct nature of the stages involved in face identification comes from behavioural dissociations observed in both normal and patient populations. Studies with normal subjects suggest that the stages involved in face identification are strictly sequential. For instance a face can look familiar without being identified and biographical information can be retrieved without recollection of the name. On the other hand, the opposite dissociation, i.e. remembering a person's name without remembering who he/she is, appears to be extremely rare (Young *et al.*, 1985; Cohen and Faulkner, 1986; Brennen *et al.*, 1990). Patient studies indicate that selective deficits can occur at different stages of the model. Deficits prior to face recognition are probably responsible for the impairment in the identification of familiar faces in prosopagnosia (Bodamer, 1947), when there is also evidence of impaired perceptual processing of unfamiliar faces (Grailet *et al.*, 1990; Shelton *et al.*, 1994). Deficits specific to face recognition and identification are indicated in certain patients with prosopagnosia who appear to have normal perceptual skills, and to be able to access biographical knowledge of people when the input is the person's voice or name (Tranel *et al.*, 1988; case 3 of De Renzi *et al.*, 1991). Selective deficits in biographical knowledge are characterized by defective person identification, irrespective of whether the inputs are faces, voices or proper names (Kapur *et al.*, 1986; Ellis *et al.*, 1989; Hanley *et al.*, 1989; Kartsounis and Shallice, 1996). Finally, patients can be impaired in the generation of names of familiar people (from faces or definitions) with intact biographical knowledge and relatively preserved name production for common objects (McKenna and Warrington, 1980; Semenza and Zettin, 1988; Lucchelli and De Renzi, 1992). Selective sparing of proper-name production has also been reported (Cipolotti *et al.*, 1993; Semenza and Sgaramella, 1993), and proper-name comprehension can be preserved even when common-name comprehension is severely impaired (Warrington and McCarthy, 1983; Van Lancker and Klein, 1990; McNeil *et al.*, 1994). These findings suggest that there are specific connections between the semantic system and proper-name systems which can be selectively disrupted (Burke *et al.*, 1991). Together, patient studies have been taken to support: (i) the notion of a modality-independent semantic system for personal identity, which can be separately accessed by differentiated pre-semantic systems and (ii) differential processing at the lexical level for common and proper names.

However, numerous methodological confounds concerning patient studies have been pointed out (see Farah, 1990; Young *et al.*, 1993), and many issues are still a matter of debate. For instance, there is still no general agreement on the hypothesized dissociation between the processing of unfamiliar and familiar faces (Davidoff and Landis, 1990; Farah, 1990). This issue is directly related to the notion of the specificity of face processing, which has been questioned since the first cases of prosopagnosia were described. Some authors suggest that a specific deficit with face recognition and identification results from the increased demands of such visual discrimination: faces are more difficult to process than other categories of object because they are complex stimuli, which require the discrimination of one specific item within a visually ambiguous category (Lhermitte *et al.*, 1972; Damasio *et al*. 1990). Yet, prosopoagnosic patients have been shown to be able to select specific instances of objects among multiple alternatives (De Renzi, 1986; De Renzi *et al.*, 1991; Sergent and Signoret, 1992; Farah *et al.*, 1995). Another hypothesis, proposed by Farah (Farah, 1990, 1991; Farah *et al.*, 1995), is that face recognition differs from object recognition because the former is mostly based on the global structure of the stimulus, without any need for detailed parsing of internal features.

At the semantic and lexical levels, a similar argument relating to the specificity of faces and proper names applies. Some evidence seems to support the idea that the semantic system is not only categorically organized (i.e. people are separated from other entities) but also modality specific (i.e. visual knowledge is separated from verbal knowledge about people) (De Renzi, 1986; De Renzi *et al.*, 1991). Other findings have suggested that the apparent specialization of the semantic system for people's identity can be explained by the fact that the biographical information associated with an individual is unique. Only a limited number of other object categories have such unique semantic associations (Ellis *et al.*, 1989; Kartsounis and Shallice, 1996). For instance, object names apply more generally to items that share visual and semantic properties (Wittgenstein, 1955; Semenza and Zettin, 1989; Cohen, 1990), whereas proper names have a one-to-one relationship with their referents which could be seen as a facilitating factor in the retrieval of unique semantic information from a specified name, but a confounding factor in the phase of name production (Burke *et al.*, 1991; Lucchelli and De Renzi, 1992). It also explains why patients who fail to retrieve proper names (relative to common names) can also have an impairment with geographical names which, like people's proper names, have a unique relationship between semantics and phonology (Semenza and Zettin, 1988, 1989). Nevertheless, this interpretation in terms of 'difficulty' cannot account for patients with the reverse dissociation, i.e. a selective deficit in naming common objects, with spared proper names (Semenza and Sgaramella, 1993; Cipolotti *et al.*, 1993).

In summary, two main interpretations of face-specific deficits have been made. One is that faces are very unique stimuli and are thus served by specific dedicated systems. The other is that faces and objects are processed by a shared system, but they place different demands on the system. At the perceptual level, identification of faces requires an exceptionally high level of visual discrimination because, as a category, faces have numerous visually similar exemplars. In contrast, at the semantic/naming level, faces have a unique identity, not shared by visually-similar faces.

Two sources of evidence are available regarding the functional anatomy of the different stages of face identification: the association of deficits with lesion sites and functional imaging. Group studies on unselected samples of patients with unilateral brain damage have shown that subjects with right hemisphere lesions are selectively impaired in the processing of unfamilar faces, such as recognizing an unfamiliar face from immediate memory (De Renzi and Spinnler, 1966; Warrington and James, 1967; De Renzi *et al.*, 1968) or matching photographs of unknown faces (Benton and Van Allen, 1968; Carlesimo and Caltagirone, 1995). This suggests an important role for the right hemipshere in the processing of faces, irrespective of their familiarity. The sites specific to face recognition and biographical knowledge are uncertain. There is general agreement that posterior right hemisphere damage is necessary for the occurrence of prosopagnosia, but disagreement over the involvement of the left hemisphere (Meadows, 1974; Damasio *et al.*, 1982, 1990; De Renzi *et al.*, 1994). The crucial site for loss of biographical knowledge across all modalities seems to be the anterior temporal lobe, but the type of pathology available does not indicate clearly which hemisphere is more important. Of the three cases reported, one was a right temporal lobectomy with a long history of epilepsy (Ellis *et al.* 1989); another was a herpes simplex encephalitis (Hanley *et al.*, 1989) which is known to be a multisite pathology, and the third had no apparent lesion on CT (Kapur *et al.*, 1986). More recently, the involvement of the left temporal lobe has been implied from semantic dementia patients who have loss of semantic memory, in particular for familiar people (Hodges and Graham, 1998). In contrast, the laterality of the lesion site in proper-name anomia is more consistent. Most of the reported patients had extensive left hemisphere lesions, involving multiple regions (thalamus and temporal lobe; for a review see Semenza *et al.*, 1995).

Most functional neuroimaging studies have concentrated on the perceptual analysis of unfamiliar faces compared with other categories of objects (Sergent *et al.*, 1992; Haxby *et al.*, 1994; Grady *et al.*, 1996; Puce *et al.*, 1996). While increased fusiform activation for processing faces was found in all studies, either in the right hemisphere or bilaterally, the issue of face specificity is still not definitely established. This is because, using pictorial stimuli of objects and faces, there is an important confounding effect of visual processing demands, with faces being the most demanding on parallel integration of features. In a few neuroimaging studies processing at the semantic level has also been investigated (Sergent *et al.*, 1992; Kapur *et al.*, 1995; Damasio *et al.*, 1996) but the results are not convergent. Sergent *et al.* (1992) compared semantic categorization of familiar faces, with a gender decision on unfamiliar faces, and found activations in bilateral fusiform gyri, the right lingual gyrus, the right parahippocampal region, bilateral temporal poles and the gyrus rectus. With the same contrast, Kapur *et al.* (1995) found increased activation in the left hippocampus only. Damasio *et al.*, (1996) contrasted naming famous faces and objects with a task where subjects had to respond 'up' if unfamiliar faces were presented the correct way up and 'down' if they were upside down; enhanced activity for famous faces was found in the bilateral temporal poles and the left sided activation was attributed to a dedicated lexical retrieval system.

The present study reports two PET experiments which are designed to address three issues. First, what are the neural systems involved in face and proper-name processing? Secondly, is there a shared neural system underlying the semantic storage of biographical information, irrespective of whether it is accessed from faces or proper names, or are there face- and name-specific semantic regions? Finally, are the identified anatomical regions specific to people, or are they shared by other categories of objects? To address the last question, we used names instead of pictorial stimuli to avoid the confound of visual complexity.

Methods

Task

The first study comprised six experimental conditions, two involving faces (famous and non-famous), two involving names (famous and non-famous) and two control conditions (scrambled faces to control for pictorial stimuli and strings of consonants to control for words) (Fig. 2).

The second study also comprised six experimental conditions, two involving proper names (an arbitrary first name, i.e. 'David', or the complete name of a famous person, i.e. 'Marilyn Monroe'), two involving common names (one word, i.e.'table' or double-barrelled words, i.e.'compact disc') and two control conditions (one line or two lines of consonant strings).

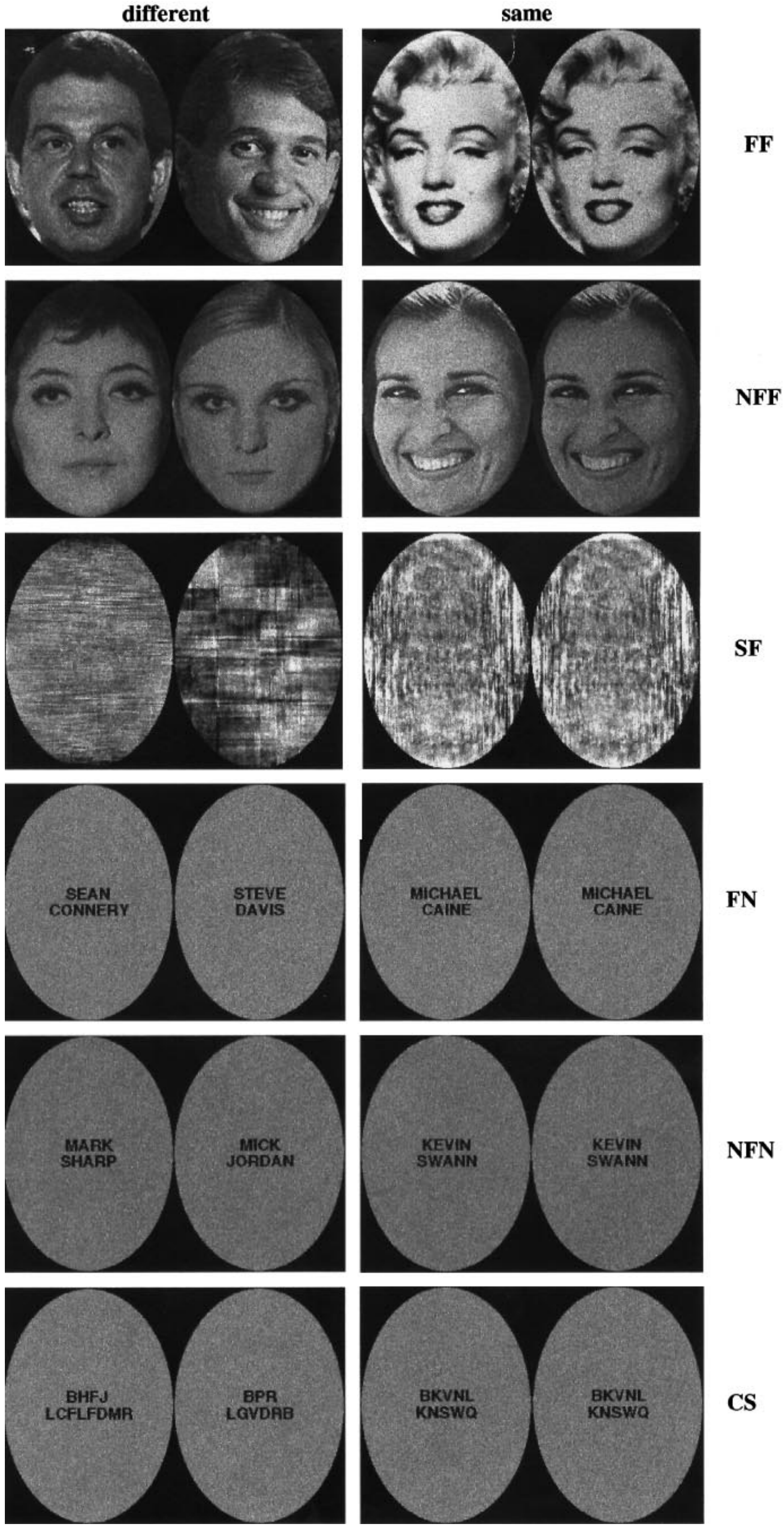


Fig. 2 Examples of the stimuli used in Experiment 1. FF = famous faces; NFF = non-famous faces; SF = scrambled faces; FN = famous names; NFN = non-famous names; CS = consonant strings.

The task was the same in both experiments. Subjects decided whether the two stimuli, displayed simultaneously as pairs, were the same or different. Since this explicit task was common to all conditions (faces, words and controls), it cannot account for the activation differences observed when contrasting different stimulus types. Rather, activation differences reflect implicit face and name processing. Implicit processing studies, of which this is an example, are becoming increasingly used because one can control for attentional set (see Price *et al*., 1996) in a better way than when activation and baseline tasks are different.

Stimuli

Experiment 1

In the first experiment, six types of stimuli were used: famous and non-famous faces, famous and non-famous proper names, scrambled faces and consonant strings.

The 56 famous faces used in Experiment 1 were selected from a pool of 200 black and white photographs of celebrities. The selection was determined by a behavioural study conducted on 20 normal male subjects (age range, 18–33 years). They were shown each face on a computer screen for 5 s, and had to name the person. Only those faces that at least 19 subjects named within the 5 s were included in the pool of stimuli used in the PET study (the names are listed in Appendix 1). All of the famous faces were of celebrities belonging to different categories of professions and currently very well known. Each face was framed with a black oval mask to eliminate differences in the picture background. The framed faces were then paired to obtain a single stimulus made of two faces displayed one next to the other on a black background with a dimension of 9.4×13.6 cm (see Fig. 2). The viewing distance was ~40 cm creating a visual angle of 37.6°. To ensure attention to the stimuli, the two faces in the 'different' pairs were made as similiar as possible by matching for age, sex and general appearance, whilst the two faces in the 'same' pairs differed in contrast and brightness to reduce the immediate similarity (see Fig. 2). The same procedure was followed for non-famous faces. These faces belonged to unknown individuals, and were matched for apparent age and sex with the famous stimuli.

The control stimuli were made by scrambling both type of faces, i.e. famous and non-famous faces. To maintain a constant spatial frequency power density spectrum in these scrambled faces, the manipulation was on the phases of each spatial frequency in the image. The phases of each lower frequency component, starting from the lowest frequency, was swapped with the phase of a corresponding higher frequency component, starting with the highest. A pattern was obtained that was no longer recognizible as a face. The scrambled faces were also framed and paired in the same way as the corresponding face-pairs.

The famous-name stimuli were the complete names corresponding to the famous faces. Subjects did not see the same faces and names during the experiment, but the tests were counterbalanced so that each celebrity was seen, either as a name or as a face, by all subjects.

The non-famous names were obtained by mixing the first names and surnames of celebrities. However, in cases of particularly unique surnames such as 'Schwarzenegger' a more common surname with the same number of syllables as the original name was selected from the Central London telephone directory ($>$50 people listed with that name). This was done to prevent subjects from associating the non-famous name with a celebrity. The names were then paired, with the number of letters matching (i.e. no more than four letters difference between the two names), and with the initial letter of the name matching.

Consonant letter strings were obtained by substituting the vowels in the names with consonants and scrambling all the letters so that the original names were no longer recognizable (10 subjects). The division into two sequences of letters was maintained, and the initial letters in a pair were the same as in the proper names. Names and consonant strings were displayed, as in the face conditions, in the oval frame on a black screen (see Fig. 2). Names and the corresponding consonant strings were written in capital letters with the first name and surname arranged on two lines.

Experiment 2

The second experiment also comprised six types of stimuli: proper names (one-word first names and complete two-word famous proper names), common object names (one-word and double-barrelled common names) and one-line or two-line consonant strings as controls.

The 28 names needed to make 20 pairs for the two scanning sessions of the famous names condition were randomly chosen from the list used in Experiment 1. The single proper names were the first names of the other 28 celebrities. The common single and double-barelled object names were chosen to match the proper names for the number of syllables (see Appendix 2 for a list of these stimuli). Because an index of frequency was not found for double-barelled common names, these stimuli were matched for frequency with single common names using one of the two words used in each double name.

The consonant strings were obtained using the same method as in Experiment 1. The stimuli were framed, paired and displayed as in Experiment 1.

Procedure

Each of the six conditions was repeated twice making a total of 12 scans but no stimulus was repeated twice in the same subject. Each stimulus pair was presented in the centre of a Macintosh computer screen at a distance of 40 cm from the subject. The response was a key-press response: the right button for 'same' pairs and the left button for 'different' pairs. Reaction times and accuracy of performance were recorded. All the stimuli were novel to the subjects. In each of the 12 scans the task lasted 1 min, starting 10 s before data acquisition. Stimuli were presented at a rate of one pair every 5 s, with a 1-s inter-stimulus interval, so that 10 pairs were seen in each scan. Of the 10 pairs, four were different and six were the same. The subjects were instructed to decide whether the two stimuli displayed (faces, names, scrambled faces or consonant strings) were the same or different. Before each scan, subjects were told which kinds of stimuli they were going to see. This was to reduce false recognition in the non-famous conditions. The order of presentation of pairs was randomized and the conditions were counterbalanced within and between subjects. After the scanning session, subjects were questioned about the strategy they had used to perform the task and whether they had recognized, and mentally named, the famous faces. The subjects' responses verified our assumption that recognition, and in most cases naming, is obligatory for very familiar faces, even when not required by the task.

Subjects

Six male subjects (age range 21–38 years) took part in Experiment 1 and six in Experiment 2 (age range 19–28 years). They were all right handed and native English speakers. All subjects were healthy, on no medication and free from any history of neurological or psychiatric illness. All subjects gave informed consent. The study was approved by the local hospital ethics committee and the Administration of Radioactive Substances Advisory Committee (UK) (ARSAC).

PET scanning

Each subject underwent 12 PET relative perfusion scans over a 2-h period. Scans were obtained using a Siemens/CPS ECAT EXACT HR+ (model 962) PET scanner (Siemens/CTI, Knoxville, Tenn., USA) with collimating septa retracted. Participants received a 20-s intravenous bolus of $H_2{}^{15}0$ at a concentration of 55 MBq/ml and at a flow rate of 10 ml/min through a forearm cannula. For each subject, a T_1-weighted structural MRI was obtained with a 2-T Magnetom VISION scanner (Siemens, Erlangen, Germany).

Data analysis

The data were analysed with statistical parametric mapping (SPM96 software from the Wellcome Department of Cognitive Neurology, London, UK; http//www.fil.ion.ucl.ac.uk/spm) implemented in Matlab (Mathworks Inc., Sherborn, Mass., USA) using standardized procedures (Friston *et al.*, 1995*a, b*). The smoothing kernel was a 3D Gaussian filter of 16 mm. Condition and subject effects were estimated according to the general linear model at each voxel. To test hypotheses about regionally specific condition effects, these estimates were compared using linear compounds or contrasts. The resulting set of voxel values for each contrast was a statistical parametric map of the *t*-statistic.

Experiment 1

There were six types of contrast for Experiment 1. For clarity, these are described below with categories abbreviated; categorical contrasts are indicated by minus signs within brackets, interactions are indicated by minus signs between brackets and conjunctions are indicated by plus signs between brackets (plus signs within brackets indicate summation). The conjunction analysis (Price and Friston, 1997) reveals areas where there is a significant main effect of two contrasts with the interactions ($P > 0.05$) excluded. This is equivalent to identifying areas that are equally active in two contrasts. FF refers to famous faces, FN to famous names, NFF to non-famous faces, NFN to non-famous names, SF to scambled faces (famous and/or non-famous, as appropriate) and CS to consonant strings (common names, and/or famous and/or non-famous names, as appropriate).

Contrast 1a. Conjunction analysis indicating areas common to face conditions compared with the respective name conditions: [FF – FN] + [NFF – NFN].

Contrast 1b. Conjunction analysis indicating areas common to name conditions compared with the respective face conditions: [FN – FF] + [NFN – NFF].

Contrast 2a. Main effect of faces relative to scrambled faces: [FF + NFF – SF].

Contrast 2b. Main effect of names relative to consonant strings: [FN + NFN – CS].

Contrast 3. Main effect of all stimuli relative to controls: [FF + NFF + FN + NFN – SF – CS].

Contrast 4. Conjunction analysis showing areas common to each stimulus type relative to respective controls: [FF – SF] + [NFF – SF] + [FN – CS] + [NFN – CS].

Contrast 5. Conjunction analysis showing areas for famous versus non-famous for both faces and names: [FF – NFF] + [FN – NFN].

Contrast 6a. Interaction between modality and type of stimulus indicating areas more active for famous faces: [FF – NFF] – [FN – NFN].

Contrast 6b. Interaction between modality and type of stimulus indicating areas more active for famous names: [FN – NFN] – [FF – NFF].

Experiment 2

The contrasts for Experiment 2 were as follows.

Contrast 7. Conjunction analysis indicating areas common to double names relative to the corresponding consonant strings: [famous proper names – CS] + [double object names – CS].

Contrast 8a. Interaction between modality and type of stimulus showing areas more active for famous proper names: [famous – single proper names] – [double – single object names].

Contrast 8b. Interaction between modality and type of stimulus showing areas more active for single proper names: [single – famous proper names] – [single – double object names].

Contrast 8c. Interaction between modality and type of stimulus indicating areas more active for double object names: [double – single object names] – [famous – single proper names].

Contrast 8d. Interactions between modality and type of stimulus indicating areas more active for single object names: [single – double object names] – [single – famous proper names].

Significant interactions (Contrasts 2, 6, 7 and 8) were analysed conventionally and the simple main effects within each area of interaction are also presented (see Tables 1–8).

Results

The results of the two experiments are described separately.

Behavioural data

Experiment 1

Post-scanning questioning of the subjects confirmed that at least one of the two celebrities of famous pairs was familiar to them. Subjects also reported that they spontaneously named most of the famous faces. Furthermore, they stated that in the control condition for names, i.e. consonant strings, they performed the task by checking the strings letter-by-letter. The accuracy of performance was close to 100% for all conditions. Subjects gave a key press response during scanning sessions, and reaction times were recorded. We tested for differences between reaction times in the four experimental conditions (famous and non-famous, and faces and names), using a one-way ANOVA (analysis of variance). No significant effect was found (Table 1). When the same analysis was performed for all six conditions, i.e. including the controls (scrambled faces and consonant strings), a significant effect was found ($P <$ 0.0001). A *post hoc* Scheffe's test showed that each control condition had significantly longer reaction times compared with each experimental condition ($P < 0.001$). Only in the consonant strings was a significant difference found between 'same' and 'different' pairs ($P < 0.001$). The longer responses to 'same' pairs indicates that subjects were checking the strings letter by letter, stopping only when a difference was found.

Experiment 2

The accuracy of performance was again close to 100% for all conditions. Subjects gave a key press response, and reaction times were measured (Table 2). A one-way ANOVA was performed on the four experimental conditions, and a significant effect was found ($P < 0.001$). A *post hoc* Scheffe's test showed a significant effect of length, i.e. double words longer than single words ($P < 0.01$), but there was no significant effect of category, i.e proper versus common names. As in the first experiment, the consonant strings had significantly longer reaction times than the word conditions ($P < 0.001$) and an effect of length was also present, with reaction times to the double strings being significantly longer ($P < 0.05$). Again, there was a significant effect of 'same' versus 'different' pairs, only for the consonant string conditions ($P < 0.001$), i.e. not for the word conditions.

Activations: Experiment 1

We discuss the results of Experiment 1 in two sections. In the first section we identify areas that are specific to face or proper-name processing by comparing the two face conditions (famous and non-famous) directly with the corresponding name conditions. In the second section we identify areas that are activated by all four conditions above control levels and within these regions we outline the modulations due to different contributions from famous and non-famous stimuli for faces or names.

Areas specific to face and name processing

Faces versus names (Fig. 3; Table 3). When famous or non-famous faces were directly compared with the

Table 1 *Experiment 1: reaction times (ms)*

Task	All pairs	'Same' pairs	Different pairs
Scrambled faces	1742 ± 673	1887 ± 677	1485 ± 599
Non-famous faces	1454 ± 613	1394 ± 645	1548 ± 554
Famous faces	1399 ± 768	1360 ± 879	1458 ± 563
Consonant-letter strings	2290 ± 980	2537 ± 903	1003 ± 821
Non-famous names	1375 ± 331	1393 ± 322	1346 ± 347
Famous names	1372 ± 373	1343 ± 382	1415 ± 599

Values are given as means ± SDs.

Table 2 *Experiment 2: reaction times (ms)*

Task	All pairs	'Same' pairs	Different pairs
Single consonant-strings	1913 ± 581	2026 ± 622	1728 ± 456
Single common names	1157 ± 675	1153 ± 355	1164 ± 200
Single proper names	1263 ± 451	1210 ± 391	1274 ± 530
Double consonant-strings	2165 ± 975	2500 ± 988	1662 ± 711
Double common names	1312 ± 422	1298 ± 413	1334 ± 439
Double famous person names	1428 ± 471	1397 ± 474	1475 ± 469

Values are given as means ± SDs.

Table 3 *Faces versus names (areas also activated relative to corresponding controls)*

Area (BA)	Conjunction (famous and non-famous)				Famous faces versus famous names				Non-famous faces versus non-famous names			
	x	*y*	*z*	*Z*-value	*x*	*y*	*z*	*Z*-value	*x*	*y*	*z*	*Z*-value
Right lingual gyrus (18)	18	–74	–8	7.0	16	–74	–8	5.1	18	–74	–8	6.0
	18	–56	–2	4.1	16	–60	–2	2.8	18	–56	–2	3.1
Right fusiform gyrus (19/37/20)	46	–78	–18	7.1	46	–78	–18	5.2	44	–74	–18	6.2
	44	–54	–22	6.4	44	–54	–22	3.4	44	–54	–22	6.1
Left fusiform gyrus (19/37)	–34	–70	–10	4.1	–36	–76	–10	3.1	–30	–70	–12	3.7
	–36	–56	–14	3.9	–36	–56	–14	2.9	–32	–58	–12	3.0

Table 4 *Names versus faces (areas also activated relative to corresponding controls)*

Area (BA)	Conjunction (famous and non-famous)				Famous faces versus famous names				Non-famous faces versus non-famous names			
	x	*y*	*z*	*Z*-value	*x*	*y*	*z*	*Z*-value	*x*	*y*	*z*	*Z*-value
Left posterior middle temporal gyrus (21/37)	–52	–58	8	4.8	–58	–56	4	4.3	–62	–58	8	3.8
	–58	–52	16	3.9	–52	–50	14	2.4	–60	–52	18	3.3
Left superior temporal sulcus (22/21)	–58	–8	–2	3.8	–54	–10	0	2.5	–62	–2	–2	4.0
	–58	–24	0	3.0	–46	–34	12	3.0	–56	–32	6	4.3

Table 5 *Areas of significant activity common to all four conditions versus controls*

Area (BA)	Famous faces versus controls				Non-famous faces versus controls				Famous names versus controls				Non-famous names versus controls			
	x	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*
Right inferior anterior temporal pole (38)	28	6	–24	3.6	28	6	–22	4.4	24	4	–26	3.1	24	6	–28	3.9
Left inferior anterior temporal pole (38)	–40	6	–26	3.6	–40	6	–26	3.4	–42	–2	–24	3.6	–40	–2	–24	3.4
Medial frontal lobe (10)	–4	44	–14	4.5	–4	44	–14	3.0	–2	44	–14	3.5	2	48	–6	3.3
	–2	60	4	4.4	4	64	4	3.1	–2	56	6	3.5	8	60	0	4.1
Precuneus/posterior cingulate cortex (23/31)	–2	–62	30	4.2	–16	–56	30	3.2	–16	–62	30	3.4	–14	–56	30	3.5
	–8	–56	14	3.4									–14	–46	36	4.2

corresponding name conditions (Contrast 1a), there was widespread activation across the striate and extrastriate cortices and this was more extensive in the right hemisphere. Of these regions, only the bilateral fusiform gyri [Brodmann area (BA) 19/37/20] and right lingual gyrus (BA 18) were more active than in the scrambled face (Contrast 2a) condition.

Table 6 *Areas of activity for famous versus non-famous stimuli, common to faces and names, and simple main effects relative to controls*

Area (BA)	Conjunction: famous versus non-famous				Famous faces versus controls				Non-famous faces versus controls				Famous names versus controls				Non-famous names versus controls			
	x	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*
Left temporoparietal junction (39)	–54	–56	30	3.6	–50	–58	30	3.3	Not significant				–48	–62	32	4.2	–50	–64	26	3.6
Left middle inferior temporal gyrus (21/20)	–54	–8	–26	3.5	–54	–8	–26	4.1	–58	–12	–22	1.7	–54	–10	–24	3.3	–56	–10	–20	2.4
	–62	–20	–14	3.4	–64	–12	–18	4.4	–64	–12	–18	2.2	–64	–12	–18	3.2	–60	–10	–14	2.5
Medial frontal lobe (9/10/11)	–14	46	–16	3.5	–10	48	–12	3.9	–10	48	–14	1.7	–12	46	–14	3.3	–16	48	–12	2.5
	–6	54	22	3.2	–10	46	28	3.7	8	56	20	2.7	0	54	22	3.5	–6	54	18	2.1
Precuneus (7/31)	–4	–66	36	3.1	0	–64	36	3.7	6	–64	32	2.1	0	–60	32	3.1	–8	–66	32	2.4

Table 7 *Areas where activation is higher for famous versus non-famous faces than for famous versus non-famous names*

Area (BA)	Interaction: fame and stimulus type				Famous faces versus controls				Non-famous faces versus controls				Famous names versus controls				Non-famous names versus controls			
	x	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*	*x*	*y*	*z*	*Z*
Left lateral anterior middle temporal gyrus (21)	–60	2	–24	3.5	–54	4	–30	5.0	–56	4	–28	1.7	–56	–2	–22	2.2	–56	0	–28	2.3

Table 8 *Areas of activity common to both famous and common double names, relative to controls, and simple main effects*

Area (BA)	Conjunction: familiar double names				Double famous proper names versus controls				Double common names versus controls			
	x	*y*	*z*	*Z*-value	*x*	*y*	*z*	*Z*-value	*x*	*y*	*z*	*Z*-value
Left temporoparietal junction (39)	–64	–52	8	4.1	–66	–48	6	4.2	–56	–56	10	2.5
	–60	–60	20	3.8	–56	–62	–18	2.9	–60	–60	20	2.3
Right anterior inferior temporal pole (38)	38	8	–26	3.5	40	6	–28	3.4	–54	–16	–28	3.6
Left anterior inferior temporal pole (38/20)	–48	–16	–28	3.8	–46	–16	–22	3.5	–54	–16	–28	3.6
	–36	12	–32	3.6	–36	12	–32	3.2	–34	20	–30	1.8
Precuneus/posterior cingulate cortex (23/31)	–10	–50	18	4.0	–8	–50	–16	2.9	–10	–48	18	3.4
	2	–48	22	3.6	4	–48	22	3.6	–2	–50	22	2.0

The face-specific activation in the fusiform gyri extended from the posterior occipital region (y = –78/76) into the temporal cortices (y = –54/56) and was more marked in the right hemisphere, spreading laterally from the lingual to the fusiform gyrus. The focus of the activation in the right lingual gyrus was confined to the occipital lobe.

Names versus faces (Table 4). When famous or non-famous names were directly contrasted with the corresponding faces conditions (Contrast 1b), a large area of activation in the left hemisphere was observed, which spread from the superior temporal gyrus to the angular and supramarginal gyri. However, when the contrast was confined to regions activated by names relative to controls (Contrast 2b), only two foci remained significantly active: one in the superior temporal sulcus (BA 22) and the other in the posterior middle temporal gyrus, at the temporoparietal junction at a level of $z = +8$ (BA 21/37).

Areas common to faces and names

Famous and non-famous versus control stimuli (Fig. 4A). The main effect of all types of stimuli (Contrast 3), irrespective of modality, relative to controls revealed an extensive area of activation that spreads from the temporoparietal junction (BA 39) to the anterior temporal region on the left hemisphere (BA 21/38) and the temporal pole on the right hemisphere (BA 38). Areas on the medial surface of the parietal (BA 23/31) and frontal lobes (BA 10/11) were also activated.

In many of these areas there were interactions between modality and familiarity. We therefore distinguish between areas common to all face and name conditions (Contrast 4), areas more active for famous than for non-famous stimuli (Contrast 5) and areas specific for famous faces or names (Contrasts 6a and b).

Areas common to all conditions relative to controls (Fig. 4B; Table 5). Areas that were significantly and equally activated by all four experimental conditions relative to controls (Contrast 4) were observed in the more medial portions of the temporal poles bilaterally (BA 38), the medial frontal lobe (BA 10) and in the medial parietal cortex (precuneus) spreading to the posterior cingulate cortex (BA 23/31).

Famous versus non-famous stimuli (Fig. 4C; Table 6) First, we consider areas common to faces and names. When famous faces or names were directly compared with the corresponding non-famous conditions (Contrast 5), activation was observed in the anterior part of the left middle temporal gyrus (BA 21) and the left temporoparietal junction (BA 39). These areas have previously been associated with semantic processing (Vandenberghe *et al*., 1996; Price *et al.*, 1997). In addition, there were two foci of activation in the precuneus (BA 31) and the medial frontal lobe (BA 9/10/11). These regions were also identified in the contrast of all conditions relative to controls (see above), but activation was more extensive for the famous stimuli.

Secondly, we consider areas specific to famous faces (Fig. 4D; Table 7). The interaction (Contrast 6a) between modality (faces and names) and type of stimulus (famous and non-famous) revealed an area in the left lateral anterior middle temporal gyrus (BA 21) that was more active for famous faces than any other condition (Contrast 6a).

Finally, there were no areas in which activation was specific to famous names (Contrast 6b).

Activations: Experiment 2

First, we identified areas that were common to double-barrelled proper and common names and then areas that were specific for double-barrelled famous proper names (e.g. John Major) relative to all other conditions, i.e. double common names (e.g. compact disc) single proper names (e.g. David) and single common names (e.g. table).

Double names versus controls (Table 8)

Areas activated by double-barrelled words (irrespective of category of stimulus) relative to control stimuli (Contrast 7) were identified in the posterior middle temporal cortex

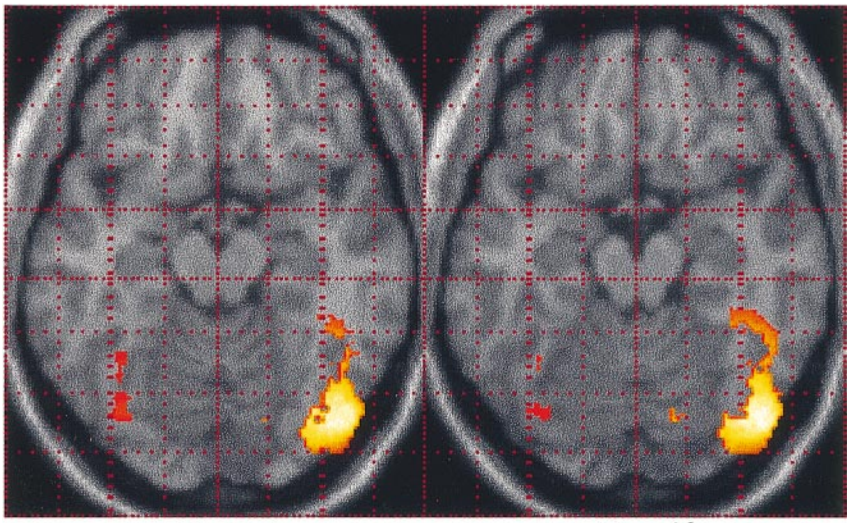
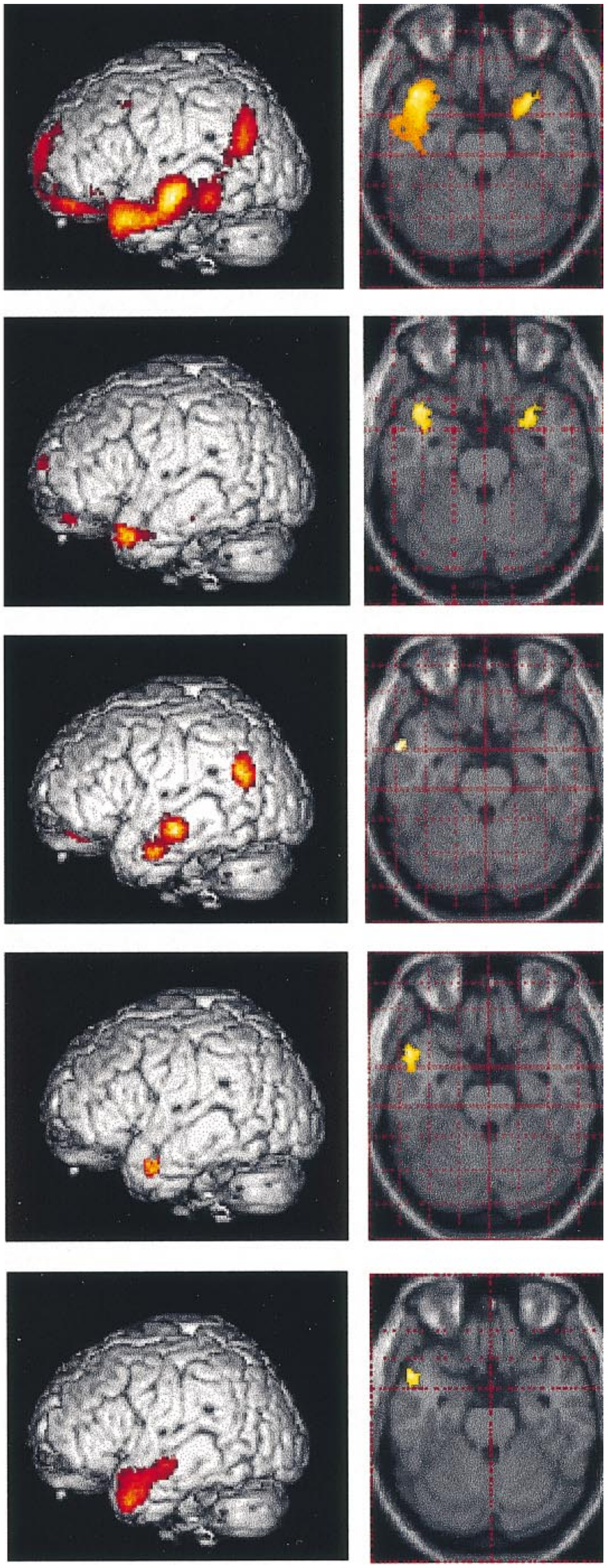


Fig. 3 Areas of significant activation specific to faces relative to names, irrespective of the type of stimuli. The activations in this figure are superimposed on slices from the Montreal Neurological Institute standard brain (Evans *et al.*, 1994). The colours of the activations in the figure do not correspond to differences in the *Z*-scores which are given on the tables.

Fig. 4 (**A**) The areas activated when all the face and name conditions are compared with controls (main effect of stimuli versus controls). Within these regions, some areas were equally activated by all the stimuli versus controls (**B**) whilst others showed modulations: in **C**, areas that were more active for famous stimuli irrespective of modality; in **D**, the area which was more active for famous faces than for any other condition. In **E**, areas that were more active for famous double proper names than for any other condition in Experiment 2. The slices shown on the right are at a level of 26 mm below the AC–PC (anterior–posterior commissure) line. The activations in this figures are superimposed on a 3D reconstruction and on slices from the Montreal Neurological Institute standard brain (Evans *et al.*, 1994).

(A)
(B)
(C)
(D)
(E)



spreading from the precuneus to the temporoparietal junction, extending from $z = +8$ to $z = +20$ (BA 39), also in the medial parietal lobe spreading to the posterior cingulate cortex (BA 23/31) and bilateral temporal poles (BA 38/21). This system was remarkably similar to that identified for famous versus non-famous faces and names (Experiment 1).

Areas specific to famous names (Fig. 4E)

Areas that were more active for famous proper names than in all other conditions (Contrast 8a) were observed in the left anterior middle and superior temporal gyri (BA 21) (*Z*-score = 4.0 at coordinates *x, y, z* = –52, 12, –30; *Z*-score = 3.6 at *x, y, z* = –62, –12, –14) close to the area found to be specific for famous faces (relative to famous names) in Experiment 1.

There were no areas that were specific to single proper names (which carry no specific associations) (Contrast 8b) but the supplementary motor cortex (*Z*-score = 4.8 at *x, y, z* = –4, 6, 76) showed greater activation for single common names than for single proper names (Contrast 8d).

Discussion

The two experiments reported in this study make a contribution to the identification of the neural system involved in face, proper-name and common-name processing. Segregation of structural and semantic/biographical processing was achieved by comparing the effects of faces and names of familiar and unfamiliar persons with each other and with baseline conditions that controlled for the task and components of visual input (spatial frequencies). We discuss first the differential activations associated with face or name processing, irrespective of familiarity, and then the areas associated with recognition of a person.

Processing of faces relative to names resulted in enhanced activity bilaterally in the fusiform gyri (particularly in the right) and in the right lingual gyrus. The same areas were also more active with the processing of faces relative to the scrambled face condition. These activations could be explained by low level visual differences between the stimuli (i.e. luminance). However, many previous functional imaging studies have linked the fusiform and lingual gyri with perceptual, pre-semantic analysis of faces (Haxby *et al*., 1994; Grady *et al*., 1996; Puce *et al*., 1996; Dolan *et al*. 1997), even when they were compared with complex visual stimuli such as houses (Kanwisher *et al*., 1997). Sergent *et al*. (1992) found the fusiform gyri to be more active on a semantic categorization task with familiar faces relative to a gender decision on unfamiliar faces, and proposed that the right fusiform gyrus ‘performs perceptual operations particulary well adapted to the process of facial identity’. In our study, the activations in the fusiform gyri were common to familiar and unfamiliar faces suggesting that perceptual analysis is equivalent when subjects perform the same task on both type of stimuli. Therefore, it appears that task demands rather than the types of stimuli (famous or not famous) are the most important determinants of fusiform activation.

Processing of names relative to faces resulted in enhanced activity in two regions in the left temporal cortex, irrespective of the familiarity of the persons. These results are in accord with previous studies showing that the left posterior middle temporal gyrus and the left superior temporal sulcus are particulary responsive to written words. For instance, Howard *et al.* (1992) found greater activation in the left posterior temporal cortex for reading words aloud relative to repetition of auditorily presented words and they associated this area with the visual word form system. Vandenberghe *et al*. (1996) also reported greater activations in the left superior temporal sulcus for semantic decisions on words relative to the same decisions on objects.

In contrast to these modality input differences, both faces and names (famous and non-famous) activated a common system of regions relative to their respective controls, which included the medial portions of the temporal poles bilaterally, two regions on the medial surface of the superior frontal cortex and the medial parietal lobe spreading to the posterior cingulate cortex. For famous stimuli (both faces and names), the activation in the medial frontal cortex and precuneus was more extensive. These regions are involved in a range of cognitive tasks including unfamiliar face matching (Grady *et al*., 1996), visual imagery (Fletcher *et al*., 1996) and listening to ‘theory of mind’ stories (Fletcher *et al*., 1995). Their specific role is still uncertain and will be discussed elsewhere. Activation in the temporal poles extended posteriorly to the middle temporal gyrus (BA 21) for famous relative to non-famous stimuli and more laterally to the anterior temporal cortex for famous faces (see Table 6). Another region that specifically responded when semantic information was present, i.e. with famous relative to non-famous faces and proper names, was the left temporoparietal cortex (BA 39). Since these areas responded to both famous faces and famous proper names, the model of face identification indicates a role in biographical knowledge. Furthermore, concurrent activation of the same left extrasylvian temporal regions (BA 39, 21 and 38) has previously been associated with a variety of semantic tasks (Demonet *et al*., 1992, 1994; Vandenberghe *et al*., 1996; Mummery *et al*., 1997; Price *et al*., 1997). These findings indicate that semantic knowledge of objects and personal identity involve the same anatomical regions. The possibility that these areas are involved in phonology can be discounted because phonology is present in all three written name conditions and would therefore not be expected to characterize the famous versus non-famous name contrast (or the names relative to consonant strings contrast, because subjects reported naming the letters in the baseline condition).

In the second experiment we wanted to address the question whether, within these ‘semantic areas’, there is a region(s) particularly specialized for the storage of unique biographical information about known people relative to the more general and shared knowledge about common names of objects. We used written names rather than faces and objects, in order to avoid visual processing confounds. Our hypothesis was that such a 'people-specific area' should be more active for proper names than any other condition, i.e. for 'Marilyn Monroe' more than double barelled common names ('compact disc') single proper names ('David') and single common names ('table'). Only famous proper names carry constant, specific and unique biographical information about a single individual. The results revealed that both proper and common names, relative to controls, engaged the same semantic areas as above (left temporoparietal junction: BA 39, bilateral temporal poles and posterior cingulate cortex), but the activation in the left anterior middle temporal region extended more laterally for famous proper names than for common names (see Results section). Interestingly, this was the same area found to be more active for famous faces in Experiment 1. Since phonology was involved in all conditions and the visual input was always letters, the area specific to famous proper names appears to be enhanced by semantic processing of person knowledge. This conclusion contrasts with that of Damasio *et al.* (1996) who associated the left anterior temporal cortex with a face-dedicated lexical retrieval system. However, the association of left anterior temporal activity with knowledge of personal identity is consistent with recent lesion studies (Hodges and Graham, 1998).

Together, the findings from Experiments 1 and 2 are consistent with a distributed semantic system in the left anterior and posterior extrasylvian temporal cortex, which can be accessed by faces, objects and words. This does not exclude the existence of modality- and category-specific connections within the network, or the possibility that within the system some areas are differentially involved in specific types of processing. The most interesting demonstration of functional segregation in this study was in the left lateral anterior middle temporal cortex, which responded more to famous faces than to famous names (Experiment 1) and to famous names more than to common object names (Experiment 2). Further experiments are required to determine whether this area is specialized for the semantic attributes of known people or whether it becomes more involved when stimuli with many visually similar neighbours are linked to unique and complex semantic associations. This latter property contrasts with other object categories such as mammals which share both visual and semantic features.

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Appendix 1 *Experiment 1**

Famous faces/names		Non-famous names	
Bob Geldof	Prince Charles	Arnold Turner	Rob Glover
Princess Margaret	Michael Barrymore	Albert Sanderson	Jeff Clifford
The Queen	Woody Allen	Sue Richards	Gary Stock
Tina Turner	Eddie Murphy	Meryl Prutton	Cindy Martin
Elvis Presley	Eric Morecombe	Sara Randall	Tony Morgan
John Smith	John Major	Joan Peterson	Edie Lancaster
John F. Kennedy	Joan Collins	Nick Kesselman	Jim Conway
Madonna	Mel Gibson	Neal Smith	Mick Jordan
Princess Diana	Bill Clinton	Elizabeth	Margaret Russel
Noel Edmonds	Rowan Atkinson	Julia Tucker	Valerie
Richard Branson	Arnold Schwarzenegger	Caroline Nettelton-Jones	George Steel
Albert Einstein	Sean Connery	Josephine Murfitt	Sam Gibbons
Steve Davis	Twiggy	Kevin Swann	Terry Bannister
Julia Roberts	Prince Andrew	Michael Gardiner	Terry Harrison
John Travolta	Esther Rantzen	Martin Davidson	John Kendall
Margaret Thatcher	Sara Ferguson	Sean McKenzie	Bill Edwards
Cilla Black	Cliff Richard	Mark Sharp	Andrew Price
Prince Andrew	Princess Anne	Jonny Moore	Edmond Prece
Tony Hancock	Tom Cruise	Joanna Pearson	Lucy Tomlinson
Neal Kinnock	Michael Heseltine	Liz May	Cathy Marlett
Ronald Reagan	Queen Mother	Esther Hall	Philip Brennan
Nelson Mandela	Mikail Gorbachov	Tina Hutchinson	Robert Garret
Terry Wogan	Paul McCartney	Heather Fitzpatrick	Paul Connelly
Ringo Starr	Michael Caine	Steven White	Bob Davis
Marylin Monroe	Luciano Pavarotti	Robin Thomas	Sandra Webster
Terry Waite	Tony Blair	Camilla Elliot	John Clark
Gary Lineker	Martina Navratilova	Tommy Hopkins	Julie Bell
Virginia Bottomley	Meryl Streep	Michael Jones	Tom Peterson

*When the names were used as stimuli they were written in capital letters; first names and surnames were arranged on two lines.

Appendix 2 *Experiment 2: common names**

Double	Single	Double	Single
Seat belt	Bottle	Record player	Fork
Mobile phone	Mirror	Video recorder	Folder
Dinner jacket	Camera	Microwave oven	Napkin
Remote control	Button	Ironing board	Engine
Rear-view mirror	Guitar	Rubber band	Knife
Alarm clock	Balloon	Traffic light	Pencil
Food processor	Fridge	Kitchen table	Plate
Frying pan	Flute	Cake tin	Blanket
Light bulb	Sweater	Picture book	Pillow
Personal computer	Envelope	Washing machine	Piano
Answering machine	Bicycle	Can opener	Racket
Credit card	Anchor	Fire extinguisher	Wallet
Football helmet	Diary	Paper towel	Stereo
Compact disc	Stapler	Wall paper	Wagon

*When the common names were used as stimuli they were written in capital letters.