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Understanding face recognition

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The aim of this paper is to develop a theoretical model and a set of terms for understanding and discussing how we recognize familiar faces, and the relationship between recognition and other aspects of face processing. It is suggested that there are seven distinct types of information that we derive from seen faces; these are labelled pictorial, structural, visually derived semantic, identity-specific semantic, name, expression and facial speech codes. A functional model is proposed in which structural encoding processes provide descriptions suitable for the analysis of facial speech, for analysis of expression and for face recognition units. Recognition of familiar faces involves a match between the products of structural encoding and previously stored structural codes describing the appearance of familiar faces, held in face recognition units. Identity-specific semantic codes are then accessed from person identity nodes, and subsequently name codes are retrieved. It is also proposed that the cognitive system plays an active role in deciding whether or not the initial match is sufficiently close to indicate true recognition or merely a 'resemblance'; several factors are seen as influencing such decisions.

This functional model is used to draw together data from diverse sources including laboratory experiments, studies of everyday errors, and studies of patients with different types of cerebral injury. It is also used to clarify similarities and differences between processes responsible for object, word and face recognition.

A human face reveals a great deal of information to a perceiver. It can tell about mood and intention and attentiveness, but it can also serve to identify a person. Of course, a person can be identified by other means than the face. Voice, body shape, gait or even clothing may all establish identity in circumstances where facial detail may not be available. Nevertheless, a face is the most distinctive and widely used key to a person's identity, and the loss of ability to recognize faces experienced by some neurological (prosopagnosic) patients has a profound effect on their lives.

During the last 20 years, many studies of face recognition have been carried out; the bibliography compiled by Baron (1979) lists over 200. However, as H. Ellis (1975, 1981) pointed out, this considerable empirical activity was not initially accompanied by developments in theoretical understanding of the processes underlying face recognition. It is only comparatively recently that serious theoretical models have been put forward (Bruce, 1979, 1983; Baron, 1981; H. Ellis, 1981, 1983, in press *a*; Hay & Young, 1982; Rhodes, 1985; A. Ellis *et al.*, in press).

In this paper we present a theoretical framework for face recognition which draws together and extends these recent models. This new framework is used to clarify what we now understand about face recognition, and also to point to where the gaps in our knowledge lie. It is also used to compare and contrast the recognition of people's faces with the recognition of other types of visual stimuli, and to explore ways in which mechanisms involved in human facial recognition relate to other types of face processing such as the analysis of expressions or the interpretation of lip and tongue movements in speech comprehension.

Our principal concern is to present a functional model to account for the perceptual and cognitive processes involved when people recognize faces. We use the term recognition here in a broad sense, covering the derivation of any type of stored information from faces. Thus we are also using face recognition to include what might well be called identification or retrieval of personal information. We develop the view that recognition in this sense is not a unitary event, and that it involves the interaction of a number of different functional components.

In the present paper we are concerned almost exclusively with evidence in favour of *functional* components in the human face processing system, without regard to whether or not these are localized to specific areas of the brain. The evidence of localization (and especially cerebral lateralization) of the component processes has been reviewed by H. Ellis (1983) and Rhodes (1985). Although we do not discuss the evidence for localization of function, we do, however, pay close attention to the functional deficits which can result from certain kinds of cerebral injury. Different patterns of breakdown can yield important information about what the functional components of the system are, and how they are organized. For this reason we pay attention not only to conventional experimental studies of face processing, but also to studies of the disorders of face processing caused by different types of cerebral injury. Temporary breakdowns of face processing also occur in everyone from time to time, and here too the patterns of breakdown yield important evidence. Therefore we also discuss studies of errors of recognition made by normal people both in everyday life and under laboratory conditions.

In understanding face processing a crucial problem is to determine what uses people need to make of the information they derive from faces. We argue here that there are at least seven distinct types of information that can be derived from faces; we describe these as different types of information *code*. We distinguish pictorial, structural, visually derived semantic, identity-specific semantic, name, expression and facial speech codes; this list can cover all of the uses of facial information of which we are at present aware. We assume that these codes are not themselves the functional components of the face processing system, but rather that they are the products of the operation of the functional components.

The idea of different ways of coding facial information provides a convenient set of terms for talking about face processing, particularly in the context of typical laboratory experiments on face recognition, where it is important to distinguish different sources of information which could mediate decisions about the earlier occurrence of faces (cf. Bruce, 1982). More importantly, though, it also makes clear what we need to understand about the human face processing system. It is clear that there are two major questions that we must address:

1. What different information codes are used in facial processing?
2. What functional components are responsible for the generation and access of these different codes?

An additional question of importance to the present discussion concerns which of the types of facial information are used in recognizing a familiar person in everyday life. As will become clear, our view is that recognition of familiar faces mainly involves structural, identity-specific semantic, and name codes, and that pictorial, expression and facial speech codes usually play no more than a minor role in recognition.

We deal in turn with each of the questions, before turning to compare our framework for face recognition with contemporary models of object and word recognition. We then consider some of the unresolved issues deriving from our functional model.

(1) What different codes are involved in face processing?

A photograph or other picture of a face will lead to the generation of a *pictorial code*. A pictorial code is a description of a *picture*. It should not be equated with view-specific information derived, and continuously updated, during early visual processing of moving faces (see later). Nor is it simply equivalent to the viewer-centred information derived when a picture is viewed, since what we term a 'pictorial' code is at a more abstract level, at which information from successive fixations has been integrated. The pictorial code may contain details of the lighting, grain and flaws in a photograph, as well as capturing the static pose and expression portrayed. A match at the level of the pictorial code can be used to mediate yes/no recognition memory decisions in many laboratory studies of episodic memory for faces, where the same pictures of previously unfamiliar faces are used as targets at presentation and test (Bruce, 1982; Hay & Young, 1982).

Even if our experience of faces were confined entirely to pictures of them, a pictorial coding system could not alone subserve the task of recognizing faces *despite* changes in head angle, expression, lighting, age or hairstyle. Yet we can readily cope with such transformations, at least across a certain range. Thus from a picture of a face, as well as from a live face, some yet more abstract visual representation must be established which can mediate recognition, despite the fact that in real life the same face will hardly ever form an identical image on successive occasions. Our ability to do this shows that we can derive *structural codes* for faces, which capture those aspects of the structure of a face essential to distinguish it from other faces.

The distinction between structural and pictorial codes is easily demonstrated in laboratory experiments. Bruce (1982), for instance, showed that episodic recognition memory for unfamiliar faces was impaired if views of faces were changed between presentation and test, with more impairment if both head angle and expression were changed than if only one change was made. More importantly, Bruce also showed that there was an effect of changing view even for episodic recognition of *familiar* faces, where recognition was significantly slower for changed compared with same views. Since structural codes must already be established for familiar faces, to allow their familiarity to be recognized, the effect of changing the view of familiar faces gives strong evidence for the additional retention of characteristics of a particular picture of a face in laboratory episodes. Further evidence for pictorial coding comes from the observation that subjects are better than chance at deciding whether a test picture is the same as, or different from, the picture of the person shown at presentation (Bruce, 1977).

We regard the pictorial code as a general code formed for any visual pattern or picture. It is a record of a particular, static, visual event. Studies of face memory which use the same pictures at presentation and test may tell us as much about picture memory generally as about face recognition. Pictorial coding is probably of little importance in everyday life, where faces are seldom encountered under identical conditions. The importance of pictorial coding lies in the interpretation of much of the research literature on face recognition, and in the design of future experiments.

It is the more abstract, structural codes which mediate everyday recognition of familiar faces. What can be said about the nature of such codes? Many studies (reviewed extensively by H. Ellis, 1975; Davies *et al.*, 1981) have shown that some areas of the face provide more information about a person's identity than other areas, and have led to the widespread view that face recognition is dependent on the arrangement of features with respect to each other (configuration) as much as the features themselves (e.g. Matthews, 1978; Sergent, 1984). While it is difficult to make a very clear-cut distinction between features and 'configuration', an emphasis on configural aspects of face processing may explain how we are able to identify celebrities' faces both from low spatial frequencies (blurred pictures in which all fine detail of features has been removed, see Harmon, 1973) and from caricatures, where individual features may be grossly distorted.

One important finding is that structural codes for familiar faces differ from those formed to unfamiliar faces. This is perhaps not too surprising as the formation of structural codes for unfamiliar faces will be limited by the conditions of initial exposure – whether the face is seen in one or many views, whether different expressions are seen, etc. H. Ellis *et al.* (1979) have shown that the internal features of familiar faces are differentially important for recognition, while internal and external features are equally important in the recognition of unfamiliar faces. This shows that structural codes for familiar faces emphasize the more informative and less changeable (cf. hairstyles) regions of the face. The finding has been replicated with Japanese subjects and Japanese faces (Endo *et al.*, 1984), and the differential salience of the internal features of familiar faces has also been demonstrated in a recognition task by Young (1984) and in a matching task by Young *et al.* (in press *a*). Young *et al.* (in press *a*) were able to demonstrate that the finding only arises when people match structural rather than pictorial codes.

There is evidence, then, demonstrating differences between the structural coding of familiar and unfamiliar faces. We will argue later that these differences probably arise because stored structural codes for known faces have become elaborated through frequent exposure, and represented within recognition units which are not present for unfamiliar faces. The precise nature of the structural codes used to recognize familiar faces remains, however, unknown. In thinking what form they might take it is probably useful to consider the idea of different levels of visual representation used by Marr (1982).

Marr distinguished three representational stages beyond the retinal image. The *primal sketch* makes explicit the intensity changes present in the image and groups these into larger structures. The *viewer-centred representation* (which Marr called the $2\frac{1}{2}$D sketch) describes the surface layout of a viewed scene relative to the viewer. Finally there is an *object-centred representation* (which Marr called the 3D model) allowing the recognition of objects from any viewpoint.

We assume that when a face is perceived, primal sketch and viewer-centred descriptions are constructed which describe, respectively, the layout of the image of the face, and the layout of the surfaces which gave rise to this image. What is less clear at the moment is what description, or set of descriptions, of the face is necessary before recognition can occur. Marr & Nishihara (1978) and Marr (1982) argued persuasively that the representational system used for recognizing objects must be based on an interlinked set of descriptions at different levels of detail. The description needed to recognize the shape of a human body cannot be sensitive enough to recognize the shape of a human hand simultaneously. Clearly different descriptions are needed, but these must be connected, so that recognizing a part of a body can facilitate recognition of the whole, and vice versa. In a similar way we argue that a familiar face is represented by an interconnected set of descriptions – some describing the configuration of the whole face, and some describing the details of particular features. Such a representational format could allow us to recognize a person's face both from distinctive features in isolation (e.g. Margaret Thatcher's eyes) and in situations where certain features are concealed (e.g. Margaret Thatcher wearing sunglasses). Therefore we propose that a familiar face is not represented by a single structural code, but by a set of codes. Can we say more about the nature of these descriptions?

While Marr & Nishihara (1978) and Marr (1982) argued that object-centred descriptions should form the basis of recognition, the specific (axis-based) representation which they proposed is not suitable to cope with the fine discriminations needed in face recognition, where similar three-dimensional structures hold for all members of the class of stimuli (i.e. for all faces). Moreover, the range of transformations of viewpoint across which we need to recognize faces in everyday life is considerably smaller than the range of transformations involved in object recognition, so that it is conceivable that object-centred descriptions are less important to face recognition. People usually stand with their heads more or less upright, and indeed face recognition is particularly prone to disruption when faces are inverted (Yin, 1969; Valentine & Bruce, in press). In addition, people will often look toward you, though recognition of profiles is of course quite possible. However, there are also transformations such as expression and hairstyle which apply only in the case of face (as opposed to object) recognition. While it seems unlikely that recognition of familiar faces is based on 'raw' viewer-centred descriptions, we think it possible that the face recognition system might make use of separate representations of discrete head angles, each in an expression-independent form. Our thinking here has been influenced by the work of Perrett and his colleagues (Perrett *et al.*, 1982; Perrett *et al.*, 1984, 1985) who have argued on the basis of properties of single cells in monkey infero-temporal cortex that the sensitivity of these cells to facial identity arises at the level of specific views of the individual. Further experimental and computational investigations are clearly needed to clarify these ideas, but for the moment we propose that a familiar face is represented via an interlinked set of expression-independent structural codes for distinct head angles, with some codes reflecting the global configuration at each angle and others representing particular distinctive features.

A face can be recognized as familiar when there is a match between its encoded representation and a stored structural code. However, we are generally not satisfied that we know a face until more than a sense of familiarity is achieved. We need to know to whom a face belongs.

Some information about the face's owner can be obtained even for unfamiliar faces. We can judge age and sex reasonably accurately, we can give to unfamiliar faces attributions like honesty or intelligence, and we can think of known individuals that faces remind us of. We will refer to this type of information as a *visually derived semantic code*.

Visually derived semantic codes are readily formed, and can be useful in remembering unfamiliar faces (Klatzky *et al.*, 1982*a*, *b*). Indeed attempts to apply the 'levels of processing' framework to face recognition can be described as attempts to influence the kind of visually derived semantic codes formed by subjects viewing unfamiliar faces (e.g. Bower & Karlin, 1974; Patterson & Baddeley, 1977). We contrast visually derived semantic codes with information in the form of an *identity-specific semantic code*. Identity-specific semantic codes might describe a familiar person's occupation, where he or she is usually encountered, who his or her friends are, and so on.

Not everyone makes this distinction between visually derived and identity-specific semantics. Rhodes (1985), for instance, suggests that there is a continuum of meaningfulness ranging from the once-viewed, unfamiliar face to the extremely familiar face of a friend or public figure, reflected in a continuum of strength of the semantic code. However, we prefer to think of qualitatively distinct kinds of associative coding, only some of which are available for the unfamiliar face.

One reason for this preference is the different relationships which hold between the physical form of a face and different aspects of its meaning. Judgements about sex, age, expression and so on are dependent upon physical 'features' (used neutrally here) of the perceived face. But the identity-specific semantics are not dependent upon surface form except in the loosest of ways. Although pop stars are likely to look different from politicians, in general the shape of a person's nose, mouth or hairstyle cannot tell you whether they are a politician, actor or secret agent. Thus identity-specific semantics bear a largely arbitrary relationship with the physical form of the face, rather like the relationship which holds between the semantics of a word in relation to its spelling. Other aspects of facial meaning are dependent on surface form, and may thus be more analogous to the relationship between an object's structure and its meaning. For objects, appearance alone would be sufficient to determine membership of many categories (Rosch *et al.*, 1976; Sperber *et al.*, 1979). For example, it would be possible to discriminate animals from items of furniture even in the case of unfamiliar members of each category, whereas reliable discrimination of unfamiliar politicians from unfamiliar stockbrokers could not be achieved on a purely visual basis.

A further reason for our distinction between different kinds of semantic code is that, for a familiar face, it is access of identity-specific semantic codes which gives the feeling that the person has been successfully recognized. A familiar face that we are struggling to 'place' nevertheless has meaning in terms of expression, resemblance to other faces, age, sex and so forth. But it is recovery of identity-specific semantic codes which resolves the 'feeling of knowing'.

In addition to the identity-specific semantic codes we also postulate a separate *name code*, holding the information that the person's name is Colin Smith, or whatever. We all have acquaintances who we know well enough to talk to, and to talk about to others, but whose names we may never have heard. Thus it is clearly possible to have an identity-specific semantic code for a person with no name code.

Name codes as here conceived are output codes which allow a name to be generated. It is thus important that they are distinguished from input codes used in recognizing written or spoken names. [See Morton (1979, 1984) for detailed reasons for distinguishing input from output codes.]

It would, of course, be possible simply to view names as a particular type of identity-specific semantic code, with rather different properties from other aspects of a person's identity. Someone's name is an essentially arbitrary label, and is relatively unimportant for guiding social interaction compared with other aspects of their identity. This alone might explain why names are particularly hard to remember (see below). However, we feel there are good empirical grounds for distinguishing names as a separate class of code. The experience of knowing who a person is without being able to recall their name is common in both everyday (Reason & Mycielska, 1982; Reason & Lucas, 1984; Young, Hay & Ellis, 1985) and laboratory (Yarmey, 1973; Williams & Hollan, 1981; Read & Bruce, 1982) studies of problems in recognizing people. Moreover, disorders of name retrieval (anomias) are also often seen in patients with cerebral injuries (Caramazza & Berndt, 1978; Goodglass, 1980; Ratcliff & Newcombe, 1982). Anomic disorders affect face naming (Warrington & James, 1967) and in some cases the anomia has even been reported as being restricted to proper names (McKenna & Warrington, 1980).

For both familiar and unfamiliar faces we are not only able to derive information concerning the person's likely age, sex and so on, but we are also able to interpret the meaning of their facial expressions. By analysing the relative shapes or postures of facial features we are able to categorize a person as looking 'happy', 'sad', 'angry', 'worried', etc. (Ekman & Oster, 1979). We will refer to this as the formation of an *expression* code. More recently, it has also been established that observation of a person's lip movements while speaking can affect speech perception of adults (McGurk & MacDonald, 1976; Campbell & Dodd, 1980) and infants (Dodd, 1979; Kuhl & Meltzoff, 1982; Mackain *et al.*, 1983). It seems that movements of the lips and tongue are used to derive a representation that shares at least some properties with representations derived from heard speech. We will describe the output of such analysis as a *facial speech code.*

At present, there is no evidence to suggest that expression codes (except, perhaps, for *characteristic* expressions) and facial speech codes are important in recognizing faces, which is our principal concern in this paper. Thus we largely restrict ourselves to briefly discussing how these codes might relate to the codes involved in recognition. As will be seen, we take the view that distinct functional components are involved in the generation of expression and facial speech codes. This is not surprising when thought is given to how heavily dependent they may be on analysis of *changes* in the shape and position of facial features across time.

(2) Functional components in the human face processing system

We can account for several aspects of face processing simply in terms of the different codes we have already outlined. Recognition memory experiments can be interpreted in terms of the formation and recovery of codes of different kinds (Bruce, 1982; Memon & Bruce, 1985), with performance better if many codes at test match those formed at presentation. To a certain extent, everyday recognition of familiar faces can be described in terms of the sequential access of different codes. However, there is a distinction to be drawn between the *products* of a process, or set of processes, and the processes themselves. To take Marr's work again as an example, his primal sketch is the product of a number of procedures which analyse the intensity changes in an image, while his $2\frac{1}{2}$D sketch results from the analysis of contours, depth, motion and shading.

Having emphasized the products of facial processing, we now turn to offer a suggestion about some of the procedures which generate and access the codes we have described. We here focus on the interrelationship of a number of broad functional components, though we also offer some more tentative suggestions about the fine-grained structure of these components. Our model is compatible with existing evidence derived from normal people's errors, descriptions of clinical conditions, and experiments involving normal and clinical subject populations.

The model is shown in the form of a box diagram in Fig. 1, which is a convenient way of representing what we consider to be involved in face processing, and how the different components are thought to relate to each other. In constructing this box diagram, we have adhered to the convention of similar models used in the related areas of word and object recognition. A 'box' represents any processing module, or store, which plays a distinct functional role, and whose operation can be eliminated, isolated or independently manipulated through experiment or as a consequence of brain damage. (The 'cognitive system', by convention, is somewhat cloudy.) Arrows between boxes variously denote the access of information, the conversion or recoding of information, and the activation of one component by another. We recognize that the differences in the statuses of the arrows and the boxes used in models of this type are problematic. However, the heuristic value of such models has been more than adequately demonstrated in other areas of research. In addition, use of a familiar format will allow us (see later) to draw explicit comparisons between the recognition of faces, objects and words.

Structural encoding produces a set of descriptions of the presented face, which include view-centred descriptions as well as more abstract descriptions both of the global configuration and of features. View-centred descriptions provide information for the *analysis of facial speech*, and for the *analysis of expression*. The more abstract, expression-independent descriptions provide information for the *face recognition units*. Each of these three components (analysis of facial speech, analysis of expression, and face recognition units) serves a different kind of perceptual classification function. The visible movements of the mouth and tongue are categorized in the analysis of facial speech, while the configuration of various features leads to categorization of expression. Facial speech codes and expression codes result, respectively, from these categorization processes. Beyond this, however, we will not speculate about the details of how such categorization is achieved. It is the third perceptual classification system – the face recognition units – which holds most interest here. Each face recognition unit contains stored structural codes describing one of the faces known to a person. When a face is seen, the strength of the

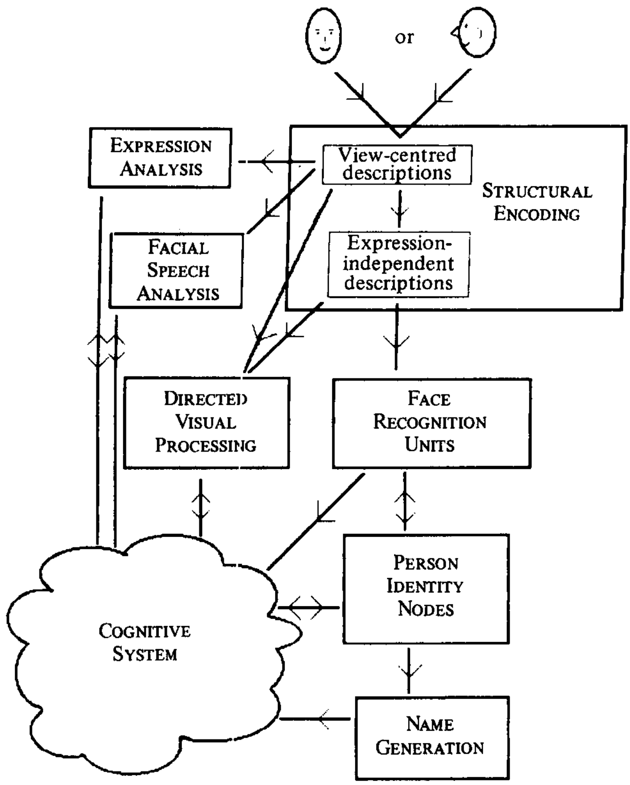

Figure 1. A functional model for face recognition.

recognition unit's signal to the cognitive system will be at a level dependent on the degree of resemblance between its stored description and the input provided by structural encoding. The basic level of activation of the recognition unit can also, however, be raised (primed) indirectly from the person identity node when we are expecting to see a particular person, or directly raised because that face has been recently seen (primed by recent use).

The face recognition units can access identity-specific semantic codes held in a portion of the associative memory which we term *person identity nodes*. The idea is that there is one person identity node for each person known, and that this contains the identity-specific semantic codes that allow us to feel we have successfully identified the person concerned. *Names* are accessed only via the person identity nodes. The distinction between face recognition units and person identity nodes is made clear when we consider the different inputs which each will respond to. A face recognition unit will respond when any view of the appropriate person's *face* is seen, but will not respond at all to his or her voice or name. The person identity node, in contrast, can be accessed via the face, the voice, the name or even a particular piece of clothing (only access via the face is shown in Fig. 1). It is the point at which *person* recognition, as opposed to face recognition, is achieved. It is clear that face recognition can break down whilst person recognition via other visual cues remains intact, since prosopagnosics become adept at using other visual cues (Hécaen, 1981). Moreover, disorders of visual and auditory recognition of people are dissociable, though they do co-occur in some cases (Assal *et al.*, 1981; Van Lancker & Canter, 1982).

The associative memory, to which the person identity nodes form an entry point, forms one component of the box we have labelled the 'cognitive system'. In Fig. 1 we have taken the person identity nodes 'outside' the rest of the cognitive system, in order to emphasize the logically distinct role that they play in person recognition. However, we must stress that person identity nodes are not seen as fundamentally different from other 'nodes' in semantic memory – they just serve a key role in the identification of people. The cognitive system includes or accesses all other associative and episodic information which falls outside the scope of our 'person identity nodes'. For example, occasionally people who had been asked to keep records of difficulties in person recognition (Young *et al.*, 1985*a*) reported that they had experienced difficulty retrieving some 'identity-specific' semantic information even after a face had been successfully named, though there was never any doubt that the person had been successfully identified. Invariably, the information sought concerned some precise detail, such as some of the films that a named actor had appeared in. It seems to us that there is a distinction to be drawn between such peripheral details, which blend imperceptibly into general knowledge about the film industry, literature and so on, and information which is essential to specify a person's identity. The latter we see as being accessed directly from the 'person identity nodes': all other information lies within the rest of associative memory.

A further function of the cognitive system is to direct attention to other components of the system. Just as we have taken the person identity nodes 'outside' the cognitive system, so too have we taken out a component which we label 'directed visual processing', since selective attention to the visual form of a face may play an important role in certain tasks. As well as 'passively' recognizing expressions, identities and so forth from faces, we also encode certain kinds of information selectively and strategically. For example, if we are going to meet a friend at the station, we will actively look out for faces sharing particular critical features with the friend. Alternatively, we may scrutinize a stranger's face to try to ensure we remember it in the future – carefully looking for distinctive features. We may make considerable use of such processes when asked to compare unfamiliar faces or to remember sets of unfamiliar faces in laboratory experiments. We thus contrast the processes used to compare and remember unfamiliar faces (via structural encoding and directed visual processing) from those which are used to identify familiar faces (via face recognition units). We assume that visual processing can be directed to any of the different representations produced by the structural encoding processes.

The analysis of facial speech, expression analysis, face recognition units, directed visual processes and person identity nodes all provide information to the rest of the cognitive system, which is in turn able to influence all these functional components. The cognitive system is also responsible for various decision processes, which we describe below.

In describing the functional model, we have mentioned components which generate structural, expression, facial speech, identity-specific semantic and name codes. The relationship between the functional model and the other two codes we described – pictorial and visually derived semantic – is not so clear-cut. Pictorial codes are by-products of some of the processes which we have housed within the 'structural encoding' component, but may also be enhanced by directed visual processing – for example when subjects in a face memory experiment pay attention to flaws in the photographs in an effort to remember them. We propose that the cognitive system is responsible for the generation of visually derived semantic codes, using information from the analysis of expression, structural encoding, directed visual processing, and the face recognition units. However, we note that future studies may allow the separation of 'visually derived semantic codes' into distinct types, produced by different routes. The classification of the sex and approximate age of a face, for example, may involve different processes from those involved in judging that a face appears honest, or resembles that of a particular relative (cf. H. Ellis, in press *a*, who suggests that categorization of age and sex occurs very early in the processing sequence).

This functional model is clearly related to those proposed by Hay & Young (1982) and H. Ellis (in press *a*), and we will not go through all of the evidence discussed in those papers. We will, however, look at some of the main lines of evidence in support of this type of model, and the principal unresolved issues that arise.

Consider first everyday difficulties in recognizing people that we all experience from time to time. These can be studied either by asking people to keep records of problems that they experience (Reason & Mycielska, 1982; Reason & Lucas, 1984; Young *et al.*, 1985*a*), or by examining errors and difficulties that arise when people are asked to identify a set of faces (Yarmey, 1973). These difficulties and errors can take a number of different forms, but two that are quite commonly reported are of particular interest here. The first involves knowing that a face is familiar, but being unable to recall any information about the person. In this case the face recognition unit has failed to access either the person identity node, and thereby the identity-specific semantic code, or a name code for the person seen.

The second type of difficulty involves the well-known 'tip-of-the-tongue' state in which we can identify the face's owner but cannot recall his or her name. This shows that identity-specific semantic codes can be accessed from structural codes without any need to proceed through an intervening name. Closer examination of tip-of-the-tongue states also suggests that the name code can only be accessed via an identity-specific semantic code, since one of the strategies that people use to guide their search for the name is to concentrate on the things that they know about the person (i.e. on the identity-specific semantic codes); they do not report trying to find the name by concentrating on the appearance of the face (which would be an appropriate strategy if name codes were accessed directly from structural codes).

Also of interest are types of error and difficulty that do *not* occur. In particular, if name codes could be accessed directly from the structural codes then it would be expected that there would be occasions on which people were able to put a name to a seen face but had no idea who the person was. In the studies of McWeeny (1985) and Young *et al.* (1985*a*), which between them involve a large corpus of errors and difficulties, this never happened. The only examples of such errors that we have been able to find are briefly mentioned in a report of cases of tuberculous meningitis by Williams & Smith (1954). One patient was able to name people from a photograph of the men on one of his former military training courses, but could give no indication as to when or where he had met them. However, such patients are in any case amnesic and often confused, so that it is difficult to know exactly how to interpret this error. In addition, the fact that all the pictured men share the same identity-specific semantics makes the task particularly tricky to interpret. We would wish to know whether such a patient was able to pick out his ex-colleagues from an array containing other familiar faces (e.g. politicians) before being persuaded of the lack of identity-specific semantic information.

Neuropsychological evidence is also consistent with our model (see also H. Ellis, in press *b*). The most relevant neuropsychological findings are the dissociation between disorders of familiar and unfamiliar face recognition, the dissociation between disorders of face recognition and analysis of facial expressions, and the dissociation between facial speech analysis and other aspects of facial processing.

The dissociation between disorders of familiar and unfamiliar face recognition was shown by Warrington & James (1967), who observed no correlation between these deficits for a group of patients with right cerebral hemisphere injuries. A number of findings consistent with the view of a dissociation between deficits of recognition of familiar and unfamiliar faces were subsequently obtained (see Benton, 1980). The strongest evidence comes from the two single case studies of prosopagnosic patients presented by Malone *et al.* (1982) who described one patient whose ability to match unfamiliar faces recovered whilst the severe recognition deficit for familiar faces persisted, and a second patient whose ability to recognize familiar people recovered whilst problems in matching unfamiliar faces persisted. Such dissociations would be expected from our model in which the recognition units and person identity nodes used in identifying faces that are already familiar form a route quite distinct from that used to temporarily store and recognize unfamiliar faces.

Clinical disorders of analysis of facial expressions also dissociate from disorders of face recognition. Although it is not unusual to find that prosopagnosic patients can neither identify faces nor understand their expressions (Bodamer, 1947), it is now known that some patients are able to interpret facial expressions correctly despite an almost complete inability to identify familiar faces (Shuttleworth *et al.*, 1982; Bruyer *et al.*, 1983). The opposite dissociation is seen in the work of Kurucz & Feldmar (1979) and Kurucz *et al.* (1979) who observed that patients diagnosed as having 'chronic organic brain syndrome' found it difficult to interpret facial emotions yet were still able to identify photographs of American Presidents. For these patients there was no correlation between performance on recognizing affect and identity from the face. Similarly, Bornstein (1963) described patients for whom there was some degree of recovery of ability to identify familiar faces whilst they remained unable to interpret facial expressions.

Neuropsychological studies of patients with impairments that severely affect the identification of familiar faces or the interpretation of facial expressions thus show that such impairments can dissociate from each other. Other neuropsychological evidence pointing to the conclusion that analyses of facial identity and facial expression proceed independently can be found in studies of patients with unilateral cerebral lesions (Cicone *et al.*, 1980; Etcoff, 1984; Bowers *et al.*, 1985) and in studies that have used brief lateral stimulus presentations to investigate cerebral hemisphere differences for face processing in normal subjects (Suberi & McKeever, 1977; Ley & Bryden, 1979; Hansch & Pirozzolo, 1980; Strauss & Moscovitch, 1981; Pizzamiglio *et al.*, 1983). These studies have shown that although the right cerebral hemisphere makes an important contribution to analyses both of facial identity and expression, the right hemisphere superiorities for identity and expression seem to be independent of each other. A review can be found in Etcoff (1985).

Finally Campbell *et al.* (in press) describe a dissociation between facial speech analysis and the recognition of faces and their expressions. The dissociation was observed in two patients. One was a severely prosopagnosic lady who failed to recognize faces or even to say what sex they were, and failed to categorize expressions correctly. She could, however, judge what phonemes were mouthed in photographs of faces and was susceptible to the McGurk & MacDonald (1976) illusion, where a mismatch between heard and seen (mouthed) phonemes results in the perceiver 'blending' the two. The second was an alexic patient who had no difficulties in recognizing faces or expressions, but who was impaired at phonemic judgements to face stimuli and was not susceptible to the McGurk & MacDonald illusion.

Support for our model also derives from laboratory experiments. Such studies support the view that structural codes lead to the access of identity-specific semantic codes before name codes. Young *et al.* (in press *b*) showed that decisions requiring access only to structural codes (deciding whether or not a face was familiar) were more quickly made than semantic decisions that required access to an identity-specific code (deciding whether or not a face was a politician). Young *et al.* (in press *b*) also showed that the use of familiar stimuli drawn from a homogeneous semantic category could speed up semantic decisions without affecting familiarity decisions. Thus semantic decisions can be affected by factors that do not influence familiarity decisions, a finding consistent with the view that a structural code is sufficient to determine familiarity whereas an identity-specific semantic code must be accessed from the structural code in order to determine category membership.

Although semantic decisions are usually made more slowly than familiarity decisions, they are made much more quickly than responses that require faces to be named, even when the set of possible faces occurring in the experiment is quite small (Young *et al.*, in press *c*). Thus access to a name code from a face takes longer than access to an identity-specific semantic code, a finding consistent with the view that name codes are accessed via the person identity nodes.

There is good evidence, then, that names are accessed via the identity-specific semantic codes available at the person identity nodes. This is by no means a trivial conclusion. As we will see later, direct links between structural codes and name codes certainly do seem to exist for visually presented words (including people's names).

Experiments have also provided some support for the 'face recognition unit' component. Bruce & Valentine (1985) found that recognition of a face as familiar was facilitated by earlier presentation of the same picture, and to a lesser extent by a different picture of the same person's face, but was not facilitated by earlier presentation of the person's name. If it is thought that seen names can access the same identity-specific semantic codes as seen faces, then this priming effect must clearly be located in an earlier component than the person identity nodes. However, Bruce & Valentine also found that the amount of priming in the different picture condition was not correlated with the rated visual similarity between the two different pictures used. Hence, though re-presenting the same picture confers additional benefit (presumably via a match at the level of the pictorial code), the results of Bruce & Valentine's (1985) experiment are not consistent simply with a visual memory effect. The effect of a different picture can instead be explained as mediated by residual activation in a face recognition unit which responds when any view of a face is seen.

In our (Fig. 1) model, we have suggested, like Hay & Young (1982), that face recognition units can be primed by the presence of an appropriate context, and some evidence consistent with this has also been obtained (Bruce, 1983; Bruce & Valentine, 1986). Bruce & Valentine found that the familiarity decisions to faces were speeded if each face was preceded by a related face (e.g. Stan Laurel followed by Oliver Hardy), compared with preceding the face by a neutral or unrelated familiar face. This facilitation occurred even when the interval between onset of prime and target faces was as little as 250 ms which rules out an explanation in terms of conscious expectancy. Thus we have an apparent example of interpriming of face recognition units for people associated with each other.

The findings of Bruce (1979) also fit well with the model. Her tasks involved searching for familiar faces (politicians) in sequences of familiar and unfamiliar faces. She showed that search for the faces of four politicians could be affected by the presence of visually or semantically similar distractor faces. Distractors rated as visually similar to the targets and distractors who were other familiar politicians took longer to reject than visually dissimilar and non-politicians' faces respectively, and these effects of visual and semantic similarity were additive. This led Bruce to argue that in visual search tasks involving faces visual and semantic analyses can proceed in parallel, with both providing information that can be employed in making a decision. Our (Fig. 1) model allows semantic analysis via the person identity nodes to occur in parallel with directed visual processing, which in Bruce's task would involve a careful, feature-by-feature visual analysis of each face for remembered features of the target faces. Both components could then send outputs to decision processes set up by the cognitive system.

In a task such as Bruce's (1979), in which *particular* targets are to be found, there is an obvious need for some kind of decision mechanism. Experiments on episodic memory for familiar and unfamiliar faces can also be analysed in this way (Bruce, 1982). However, we feel that decision processes may have a more general role to play in everyday face recognition. Some kind of decision-making machinery seems necessary to account for a number of rather striking errors in Young *et al.*'s (1985*a*) diary study of difficulties and errors in everyday recognition. Such errors included, for instance, uncertainty as to whether or not a seen person was a particular friend, and thinking that a seen person must be someone unfamiliar who looked remarkably like the person it actually was!

Young *et al.* (1985*a*) also found that a common experience, which is in no sense an error, is to notice that someone bears a striking resemblance to someone else. This 'resemblance' experience also illustrates the importance of decision processes since it is most readily accounted for by proposing that the recognition unit fires and accesses the appropriate person identity node and via this the name code, but a decision has been taken that this firing is not to be seen as sufficient evidence that it is that person (often because the context is wrong for such an encounter). We do not think that it would be adequate to try to account for all such experiences simply by postulating a threshold of recognition unit firing, above which the level of firing would be taken to indicate recognition and below which it would be taken to indicate resemblance, since the experience can occur even to very strong resemblances (lookalikes).

The role of decision processes in recognition would clearly repay further investigation. In our (Fig. 1) model, such decisions are assigned to the cognitive system component, which can be seen as evaluating the strength of activity in various components of the system.

Comparisons between face, object and word recognition

Our theoretical framework allows us to draw parallels as well as highlighting differences between the recognition of faces and the recognition of other objects and words.

In broad outline, our model shares much in common with recent functional models of word and object recognition, such as those of Nelson *et al.* (1977), Seymour (1979) and Warren & Morton (1982). In particular, our account of face recognition shares the 'recognition unit' metaphor which has previously been used in theories of word recognition (logogens) and object recognition (pictogens) (Morton, 1969, 1979; Seymour, 1979). The advantage of this idea is that it sidesteps the difficult issue of the nature of the structural codes used to effect recognition, and concentrates attention onto questions about the interrelationship of different coding processes – questions that are more amenable to investigation using current experimental techniques.

Hay & Young (1982) first put forward the explicit suggestion that the same idea might help in understanding face recognition. They proposed that face recognition units mediate between the establishment of a facial representation and the access of 'person information' concerning a person's identity. The same recognition unit would respond when any view of a known individual's face was seen, and a different face recognition unit would be constructed for each known person's face. Much the same conception of face recognition units has been used in the present paper, except that we have followed the emphasis placed by Young *et al.* (1985*a*) and A. Ellis *et al.* (in press) on recognition units giving a graded signal of degree of resemblance to a familiar face, rather than acting as simple triggers. Thus we have modified the original analogy with the 'logogen' concept, used by Hay & Young (1982), and the recognition units described in this paper function more like the 'cognitive demons' in a Pandemonium type of system, signalling degree of resemblance by the intensity with which they shout to a decision demon (see Lindsay & Norman, 1977).

Several authors have proposed a similar sequence of accessing semantic and name codes from objects to that proposed here for faces (Potter & Faulconer, 1975; Nelson & Reed, 1976; Warren & Morton, 1982). For recognition of visually presented words, however, existing evidence favours something more complex in which recognition units are able to access name codes directly as well as via the semantic representations (Warren & Morton, 1982; A. Ellis, 1984). These arrangements are shown in Fig. 2. The diagram of visual word

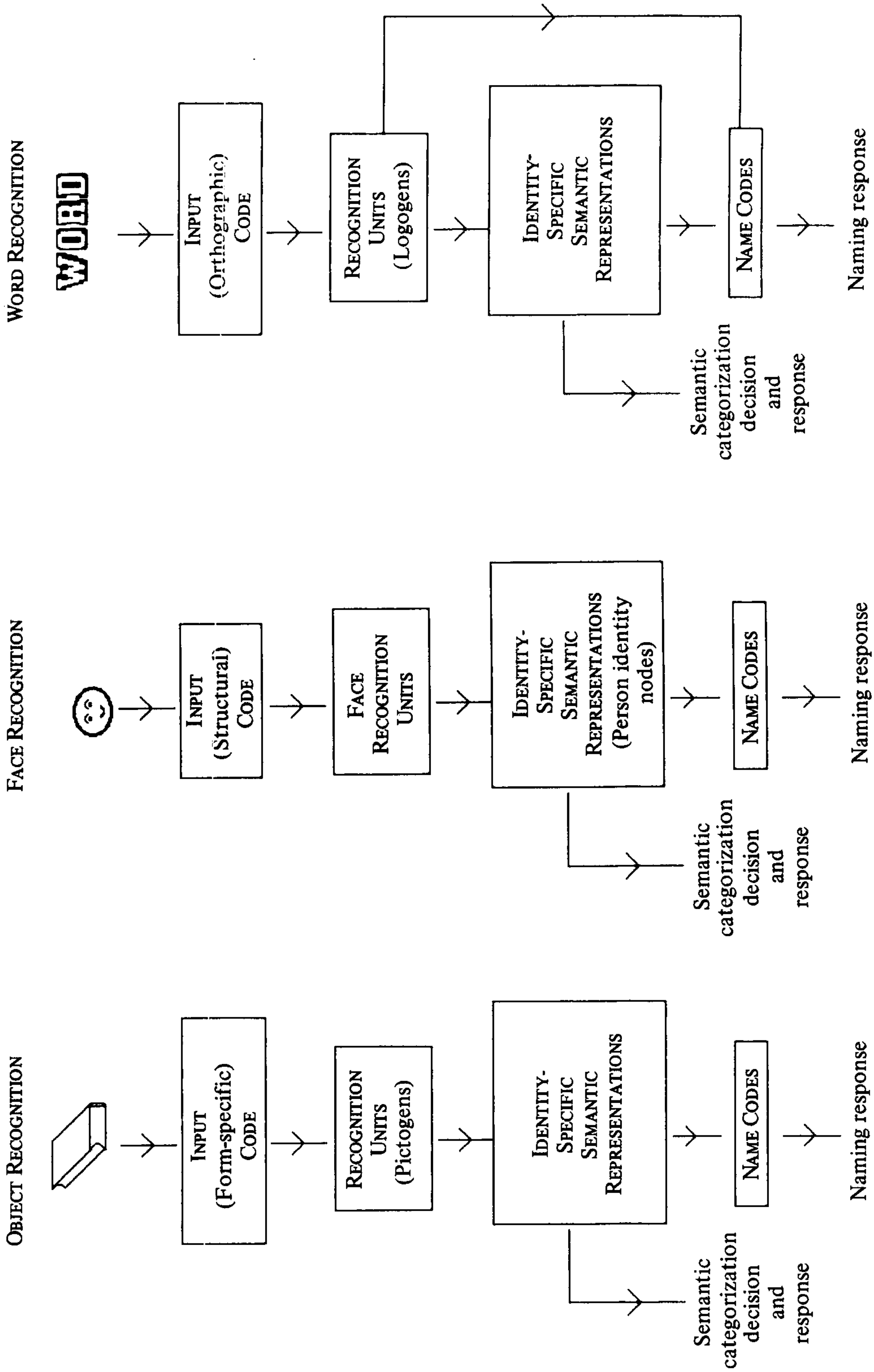

Figure 2. A comparison of the routes involved in recognition and naming of objects, faces and words.

recognition would, of course, be more complex still if it also included the possibility of using spelling–sound correspondences.

Reasons for postulating a more complex arrangement for visual word recognition include the descriptions by Schwartz *et al.* (1979, 1980) of a patient who was able to read single words that she could not classify on a semantic basis. Moreover, this patient could correctly name irregular words such as 'leopard', which showed that she did not rely on spelling–sound correspondences. This phenomenon of correct naming without understanding has not been observed in the case of disorders of object recognition (Ratcliff & Newcombe, 1982) and, we have argued, it has yet to be clearly established for disorders of face recognition.

In some types of experiment, objects and words also show different properties that can be interpreted in terms of the arrangements shown in Fig. 2. Objects can, for instance, often be semantically categorized more quickly than they can be named, whereas words can be named more quickly than they can be categorized (Potter & Faulconer, 1975). Faces share with objects this property of being semantically categorized more quickly than they can be named (Young *et al.*, in press *c*). Moreover, by using categories of faces that do not differ visually from each other, Young *et al.* (in press *c*) were able to show that the rapid categorization of faces is not entirely due to the use of visually derived semantic codes.

In interference experiments the presence of irrelevant printed words will interfere with naming depicted objects, whilst irrelevant pictures of objects do not interfere much with word naming (Rosinski *et al.*, 1975; Glaser & Düngelhoff, 1984). This interference effect reverses in categorization tasks, where irrelevant pictures of objects will interfere more with word categorization (Smith & Magee, 1980; Glaser & Düngelhoff, 1984). In comparisons of interference between faces and written names of familiar people, photographs of faces produce interference effects corresponding to those found for pictures of objects and people's names produce interference effects corresponding to those found for words (Young, Flude, Ellis & Hay, in press; Young, Hay & Ellis, in press).

In semantic categorization, naming and interference tasks, faces behave rather like objects whereas people's names and other types of word behave differently. If we shift to examining each system at a different (earlier) level, however, object, face and word recognition findings are similar to one another. The results of Bruce & Valentine (1985, 1986), for example, supporting the hypothesis of face recognition units by identity priming and associative priming, are similar to findings that have pointed to object and word recognition units. Likewise Bruce (1981) was able to show that visual and semantic analyses involved in searches for words appeared to proceed in the same parallel fashion as those involved in searches for faces (Bruce, 1979).

What these similarities and differences between object, face and word recognition relate to is the way in which what might be considered analogous functional components in each system are arranged with respect to each other. However, when we turn to consider the *demands* placed on these functional components in each case it becomes clear that some of the apparent similarities may be only superficial.

In recognizing objects, for instance, we usually rely on analysis to a level at which objects belong to broad categories that maximize the functional and visual similarities of the objects within each category (dogs, tables, houses, etc.). Rosch (1978) and Rosch *et al.* (1976) refer to these as 'basic level' categories, and a considerable body of evidence has accumulated indicating their primacy in object recognition. However, although the members of these basic level categories may be more visually similar to each other than to members of other categories (i.e. different dogs are more like each other than they are like tables or houses), the task facing the perceptual system is nonetheless one of assigning different stimuli (different dogs, different tables, different houses) to the same category (dog, table or house). For face recognition, the task is quite different. First, functional semantic categories such as actors, politicians or television newsreaders are often not visually distinct. Indeed, we suspect that visually derived semantics may be much more important to object than to face processing. Second, with people's faces we want to identify the actual individuals. In Rosch's terms 'faces' are themselves a kind of basic level category; what we have to do is to discriminate *within* this rather homogeneous visual category to determine which of the already known exemplars a face actually is. In some cases the visual differences between different people might only be very slight.

When these requirements are taken into consideration it is clear that face recognition units are really doing a rather different job from pictogens, and the clinical observations of object agnosia without prosopagnosia and of prosopagnosia without object agnosia become less surprising (see also Hécaen, 1981; Damasio *et al.*, 1982; Blanc-Garin, 1984; Jeeves, 1984). In fact, the requirements for face recognition, of discrimination within a class of rather homogeneous stimuli on the basis of any difference in individual features or their arrangement, are more reminiscent of the requirements of word than of object recognition units. With written words, however, the range of potential distinguishing features is limited to the set of letters in the language and the crucial spatial arrangement is in the form of a sequence. Word recognition disorders can, of course, dissociate perfectly from both object agnosia and prosopagnosia.

In making our comparisons between face, word and object recognition we have been touching on the question of whether specialized mechanisms are involved in face processing. Hay & Young (1982) suggested that this question can in turn be broken down into that of whether some components of the face-processing system are qualitatively different from those involved in the processing of other visual stimuli (the question of face uniqueness) or whether some of the components are used only for faces despite similarities to equivalent components used in processing other visual stimuli (the question of face specificity). The present paper is not directly addressed to such issues. However, the clinical dissociations mentioned clearly suggest that there are at least some face-specific components. Moreover, the preceding discussion of the requirements of object, face and word recognition, together with our earlier comments on the particular demands made by expression codes and facial speech codes, should make it clear why we are inclined to think that some of the components are unique to faces (see also Young, in press, for evidence concerning innate specification of some components).

Unresolved issues

A reasonably detailed functional model is clearly valuable in accounting for existing findings and clarifying the issues that need to be addressed in future work. In this final section we draw attention to these issues. In doing this we hope to stimulate the research that will lead to an improvement of the model. Three main issues will be addressed. These involve the breadth of specification of functional components, the question of whether faces must first be classified *as faces*, and the roles of contextual information.

(*a*) *Breadth of specification of functional components*

Not all of the components have been specified with the same degree of precision. Face recognition units are, for instance, more narrowly and precisely specified than structural encoding, which is in turn more narrowly and precisely specified than the cognitive system. Our view is that as more evidence is gathered this will lead to the division of some of the components shown in Fig. 1.

For example, while we have offered suggestions about the nature of structural codes for familiar face recognition, these ideas will become further refined through experimentation.

A computational approach to face recognition is also likely to prove fruitful in this respect, and we note the possibility that it may prove feasible to account for the properties of face recognition units in terms of distributed representations (e.g. McClelland & Rumelhart, 1985). In addition, careful investigation of the neuropsychological symptom of 'metamorphopsia', in which faces appear distorted to certain patients (Hécaen & Angelergues, 1962; Whiteley & Warrington, 1977; Hécaen, 1981), may give us further clues about the nature of visual representations used in face recognition. Further experimental, computational and neuropsychological investigations will also allow us to specify more details of the analyses of expressions and facial speech.

The broadest component in our (Fig. 1) model at present is the cognitive system. This serves to catch all those aspects of processing not reflected in other components of our model. Such a component is a common one in other functional models of human memory. For example, the cognitive system in Morton's (1969, 1979) logogen model of word recognition is directly analogous to the same component in our own model, and Baddeley & Hitch (1974) include a similar 'catch-all' component in the 'central executive' of their working memory model. In the future we aim to specify in more detail the finer structure of this component. As described here, the cognitive system has at least three distinct functions. The first of these functions is to house the associative memory, and the second to take decisions on the basis of information received from other components of the system. The third is to direct attention to various other components of the system, as in the directed visual processing which plays an important role in perception of unfamiliar faces. The details of each of these aspects of the cognitive system, and their interactions, should be made clearer through further experimental studies, and simulation could provide a further way of exploring this.

(b) Is the input first classified as a face?

When we look at a face, we know that we are seeing a face rather than some other object. As we discussed above, it may be the *object* classification system which allows us to make this basic level judgement, and it is possible that such a judgement *precedes* further analysis of who the face belongs to (H. Ellis, 1981, 1983). Prosopagnosic patients can, for instance, recognize faces as such even though they do not know whose face they are seeing (Bodamer, 1947; Bruyer *et al.*, 1983; Jeeves, 1984).

H. Ellis (1981, 1983) argued that without such a classification faces could not be treated differently from any other visually presented stimulus. However, we have not included this 'classification as a face' stage as an explicit component in our model for three reasons. First, it prejudges the issue of whether faces actually do require a special type of analysis. We do not want to do this at present, even though we (like Ellis) now strongly suspect that specialized processes are involved. Second, even if face-specific analyses do occur, it is not clear to us that an explicit face 'switch' is needed. Appropriate analysers might just pick up the input to which they are attuned, thereby classifying the input implicitly. Third, we are uncertain about the level of visual information processing at which the decision to classify an input as a face is taken (see Young, Hay & McWeeny, 1985*b*). It could be that classification as a face is an essential first step that must be taken before processing is directed to other components in our system, or it might be that classification as a face is achieved on the basis of a very general global structural description simultaneous with the classification of particular faces on the basis of more detailed local information. Future studies examining which disorders of structural encoding are or are not specific to faces should help to answer such questions. In the meantime we assume that if classification of the input as a face is necessary it occurs as part of the structural encoding component.

(c) The roles of contextual information

The semantic priming experiments of Bruce (1983) and Bruce & Valentine (1986) illustrate the way in which one kind of context can affect the recognition of familiar faces. A face is easier to recognize if accompanied by an appropriate partner (e.g. Stan Laurel with Oliver Hardy). This effect can be compared with that of facilitation of word recognition by appropriate accompanying words in lexical decision (Meyer & Schvaneveldt, 1971) or facilitation of object naming by the presence of semantically related objects (Sperber *et al.*, 1979).

However, contextual information might also include the place where a face is usually seen. We might expect to find the recognition of, say, Margaret Thatcher, to be more difficult if she were shown against a picture of a launderette than if she were shown along with a picture of the Houses of Parliament, although the difficulty of producing a range of distinctive visual contexts for celebrities makes it unlikely that such an experiment will be conducted. However, we note that Palmer (1975) found that appropriate scenic contexts (e.g. a kitchen) facilitated the recognition of objects appropriate to that context (e.g. loaf of bread).

The kinds of contextual effects we have described above could be explained in terms of the 'priming' of face recognition units for familiar people. However, when we turn to the episodic recognition of unfamiliar faces, for whom we assume face recognition units have not been formed, context effects also abound. Episodic recognition of unfamiliar faces is facilitated if faces are retested along with the same partners that accompanied them at presentation (Winograd & Rivers-Bulkeley, 1977), or if they are retested against the same distinctive background context with which they were originally presented (Beales & Parkin, 1984; Memon & Bruce, 1983). There have even been claims (e.g. Wagstaff, 1982) that performance on a photo-lineup task is improved if this is conducted in the same room in which a staged incident occurred.

Such contextual effects both in the recognition of familiar faces and in episodic recognition of unfamiliar faces scarcely seem surprising when we consider the relationship between identity-specific semantic codes and context. Even for familiar celebrities, part of their meaning is where they live, who their associates are and so on. Thus we would expect the person identity node for Stan Laurel to include a strong link to that for Oliver Hardy, and we would expect the person identity node for Margaret Thatcher to be associated with '10 Downing St', however temporarily.

For less familiar, and less 'public' figures, their identity is even more bound up in the contexts with which they are associated. In Young *et al.*'s (1985*a*) diary study, for instance, a commonly reported way of trying to resolve the irritating 'I know that face' feeling was to try to think where the person was usually encountered. For many people that we know, their identity goes together with where we know them from, and the role we ourselves play when we see them. This is particularly clearly seen in Young *et al.*'s (1985*a*) example of a person who thought for a long time that one of her somewhat casual acquaintances was two different people because she met him in two different places. We have yet to examine closely the relationship between categorical aspects of a person's identity (e.g. their occupation) and aspects more closely tied to time or place of occurrence.

Our ability to link faces to a context may explain why faces are often remarkably resistant to forgetting in laboratory experiments, despite all the 'real-world' faces, which include newspaper and television photographs, seen between presentation and test. Yet striking interference can be obtained retroactively from a later set of faces (Deffenbacher *et al.*, 1981) or from distractors within a test series (Laughery *et al.*, 1974). Thus, much more interference seems to be obtained from faces seen in the same laboratory context than from those seen in a different context.

We suggested above that certain of these contextual effects could be seen as resulting from the priming of face recognition units via the person identity nodes, but noted that this explanation was not satisfactory for the effects in episodic memory for unfamiliar faces. The most common explanation offered in the literature is some variant of Tulving's encoding specificity theory (Tulving & Thomson, 1973). Recognition will be easier the greater the overlap between retrieval cues at test and features of the encoded trace. Although it is difficult to translate the terminology of encoding specificity into that of our own framework, which is not designed specifically to account for episodic memory, Memon & Bruce (1985) argue that by considering the different codes derived from faces, we can provide a better account of contextual effects in face recognition than that given by theories borrowed directly from the verbal memory literature.

One recent theory attempts, like us, to explain people's difficulties in remembering names, and certain contextual effects in remembering. The headed records framework (Morton *et al.*, 1985) copes well with such phenomena which are difficult for traditional associative network conceptions of long-term memory. Headed records is an 'episodic' theory, in which information about a person's identity would be discovered by accessing the appropriate record via the access key contained in the heading. Headings themselves cannot be retrieved, and Morton *et al.*, explain the particular difficulty in recalling names by suggesting that these often form the headings to records containing details of person information. Morton *et al.*'s model, unlike our own, does not address the relationship between perceptual classification and access of semantic information, and would have difficulty accommodating some of the clinical evidence we have discussed.

Overview and conclusions

We have presented a functional framework for face recognition, in which a number of components are distinguished. Different processes are involved in the generation and storage of different kinds of information, or 'codes'. We have described seven codes that can be distinguished in face processing, which we label pictorial, structural, identity-specific semantic, visually derived semantic, name, expression and facial speech codes. The last two of these are not directly involved in face *recognition*, though they are clearly important for other aspects of face *perception*, and pictorial codes are probably only of major importance in laboratory experiments of a certain kind. Everyday face recognition is seen as involving use of structural codes to access identity-specific semantic information and names, where available, in that order.

Our functional model is compatible with existing evidence drawn from a wide range of sources, including laboratory experiments, studies of everyday errors, and studies of patients with different types of cerebral injury. For many of the components, these different areas provide converging evidence for the organization we propose. For some components, evidence is currently available from only one source (e.g. the proposal that facial speech analysis is independent of expression analysis and person identification rests entirely on clinical evidence at present).

The fact that the model can encompass such diverse types of evidence is one example of its usefulness. Another example comes from the way such a model can be used to clarify the similarities and differences between processes responsible for object, word and face recognition. However, the true measure of the value of an explicit model of this type lies in its capacity to stimulate the research that will lead to further improvements in our understanding. In this respect the model presented here makes several obvious predictions concerning the results of conventional laboratory experiments, and the types of disorder that should be found in brain-injured patients. In addition, we have devoted some space to spelling out areas which we see as important for future research.

As we said in our introduction, the account we have presented is a synthesis and extension of several current models of face recognition. Together with other authors we feel that this kind of approach will prove fruitful for understanding how we identify people from their faces, and why face recognition sometimes fails.

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References

Assal, G., Aubert, C. & Buttet, J. (1981). Asymétrie cérébrale et reconnaissance de la voix. *Revue Neurologique*, **137**, 255–268.

Baddeley, A. D. & Hitch, G. J. (1974). Working memory. In G. Bower (ed.), *The Psychology of Learning and Motivation*, vol. 8. New York: Academic Press.

Baron, R. J. (1979). A bibliography on face recognition. *The SISTM Quarterly Incorporating The Brain Theory Newsletter*, **II** (3), 27–36.

Baron, R. J. (1981). Mechanisms of human facial recognition. *International Journal of Man–Machine Studies*, **15**, 137–178.

Beales, S. A. & Parkin, A. J. (1984). Context and facial memory: The influence of different processing strategies. *Human Learning*, **3**, 257–264.

Benton, A. L. (1980). The neuropsychology of facial recognition. *American Psychologist*, **35**, 176–186.

Blanc-Garin, J. (1984). Perception des visages et reconnaissance de la physionomie dans l'agnosie des visages. *L'Année Psychologique*, **84**, 573–598.

Bodamer, J. (1947). Die Prosop-Agnosie. *Archiv für Psychiatrie und Nervenkrankheiten*, **179**, 6–53.

Bornstein, B. (1963). Prosopagnosia. In L. Halpern (ed.), *Problems of Dynamic Neurology*, pp. 283–318. Jerusalem: Hadassah Medical School.

Bower, G. H. & Karlin. M. B. (1974). Depth of processing pictures of faces and recognition memory. *Journal of Experimental Psychology*, **103**, 751–757.

Bowers, D., Bauer, R. M., Coslett, H. B. & Heilman, K. M. (1985). Processing of faces by patients with unilateral hemisphere lesions: 1. Dissociation between judgements of facial affect and facial identity. *Brain and Cognition*, **4**, 258–272.

Bruce, V. (1977). Processing and remembering pictorial information. Unpublished PhD thesis, Cambridge University.

Bruce, V. (1979). Searching for politicians: An information-processing approach to face recognition. *Quarterly Journal of Experimental Psychology*, **31**, 373–395.

Bruce, V. (1981). Visual and semantic effects in a serial word classification task. *Current Psychological Research*, **1**, 153–162.

Bruce, V. (1982). Changing faces: Visual and non-visual coding processes in face recognition. *British Journal of Psychology*, **73**, 105–116.

Bruce, V. (1983). Recognizing faces. *Philosophical Transactions of The Royal Society of London, Series B*, **302**, 423–436.

Bruce, V. & Valentine, T. (1985). Identity priming in the recognition of familiar faces. *British Journal of Psychology*, **76**, 373–383.

Bruce, V. & Valentine, T. (1986). Semantic priming of familiar faces. *Quarterly Journal of Experimental Psychology*, **38A**, 125–150.

Bruyer, R., Laterre, C., Seron, X., Feyereisen, P., Strypstein, E., Pierrard, E. & Rectem, D. (1983). A case of prosopagnosia with some preserved covert remembrance of familiar faces. *Brain and Cognition*, **2**, 257–284.

Campbell, R. & Dodd, B. (1980). Hearing by eye. *Quarterly Journal of Experimental Psychology*, **32**, 85–99.

Campbell, R., Landis, T. & Regard, M. (in press). Face recognition and lipreading: A neurological dissociation. *Brain*.

Caramazza, A. & Berndt, R. S. (1978). Semantic and syntactic processes in aphasia: A review of the literature. *Psychological Bulletin*, **85**, 898–918.
Cicone, M., Wapner, W. & Gardner, H. (1980). Sensitivity to emotional expressions and situations in organic patients. *Cortex*, **16**, 145–158.
Damasio, A. R., Damasio, H. & Van Hoesen, G. W. (1982). Prosopagnosia: Anatomic basis and behavioral mechanisms. *Neurology*, **32**, 331–341.
Davies, G., Ellis, H. & Shepherd, J. (1981). *Perceiving and Remembering Faces*. London: Academic Press.
Deffenbacher, K. A., Carr, T. H. & Leu, J. R. (1981). Memory for words, pictures and faces: Retroactive interference, forgetting and reminiscence. *Journal of Experimental Psychology: Human Learning & Memory*, **7**, 299–304.
Dodd, B. (1979). Lipreading in infants: Attention to speech presented in- and out-of-synchrony. *Cognitive Psychology*, **11**, 478–484.
Ekman, P. & Oster, H. (1979). Facial expressions of emotion. *Annual Review of Psychology*, **30**, 527–554.
Ellis, A. W. (1984). *Reading, Writing and Dyslexia: A Cognitive Analysis*. London: Erlbaum.
Ellis, A. W., Young, A. W. & Hay, D. C. (in press). Modelling the recognition of faces and words. In P. E. Morris (ed.), *Models of Cognition*. London: Wiley.
Ellis, H. D. (1975). Recognizing faces. *British Journal of Psychology*, **66**, 409–426.
Ellis, H. D. (1981). Theoretical aspects of face recognition. In G. Davies *et al.* (eds), *Perceiving and Remembering Faces*. London: Academic Press.
Ellis, H. D. (1983). The role of the right hemisphere in face perception. In A. W. Young (ed.), *Functions of the Right Cerebral Hemisphere*. London: Academic Press.
Ellis, H. D. (in press *a*). Processes underlying face recognition. In R. Bruyer (ed.), *The Neuropsychology of Face Perception and Facial Expression*. Hillsdale, NJ: Erlbaum.
Ellis, H. D. (in press *b*). Disorders of face recognition. In K. Poeck (ed.), *Neurology: Proceedings of the 13th World Congress of Neurology*. Berlin: Springer-Verlag.
Ellis, H. D., Shepherd, J. W. & Davies, G. M. (1979). Identification of familiar and unfamiliar faces from internal and external features: Some implications for theories of face recognition. *Perception*, **8**, 431–439.
Endo, M., Takahashi, K. & Maruyama, K. (1984). Effects of observer's attitude on the familiarity of faces: Using the difference in cue value between central and peripheral facial elements as an index of familiarity. *Tohoku Psychologica Folia*, **43**, 23–34.
Etcoff, N. L. (1984). Selective attention to facial identity and facial emotion. *Neuropsychologia*, **22**, 281–295.
Etcoff, N. L. (1985). The neuropsychology of emotional expression. In G. Goldstein & R. E. Tarter (eds), *Advances in Clinical Neuropsychology*, vol. 3. New York: Plenum.
Glaser, W. R. & Düngelhoff, F. J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception & Performance*, **10**, 640–654.
Goodglass, H. (1980). Disorders of naming following brain injury. *American Scientist*, **68**, 647–655.
Hansch, E. C. & Pirozzolo, F. J. (1980). Task relevant effects on the assessment of cerebral specialisation for facial emotion. *Brain and Language*, **10**, 51–59.
Harmon, L. D. (1973). The recognition of faces. *Scientific American*, **229**, 70–82.
Hay, D. C. & Young, A. W. (1982). The human face. In A. W. Ellis (ed.), *Normality and Pathology in Cognitive Functions*. London: Academic Press.
Hécaen, H. (1981). The neuropsychology of face recognition. In G. Davies, H. Ellis & J. Shepherd (eds), *Perceiving and Remembering Faces*. London: Academic Press.
Hécaen, H. & Angelergues, R. (1962). Agnosia for faces (prosopagnosia). *Archives of Neurology*, **7**, 92–100.
Jeeves, M. A. (1984). The historical roots and recurring issues of neurobiological studies of face perception. *Human Neurobiology*, **3**, 191–196.
Klatzky, R. L., Martin, G. L. & Kane, R. A. (1982*a*). Influences of social-category activation on processing of visual information. *Social Cognition*, **1**, 95–109.
Klatzky, R. L., Martin, G. L. & Kane, R. A. (1982*b*). Semantic interpretation effects on memory for faces. *Memory and Cognition*, **10**, 195–206.
Kuhl, P. K. & Meltzoff, A. N. (1982). The bimodal perception of speech in infancy. *Science*, **218**, 1138–1141.
Kurucz, J. & Feldmar, G. (1979). Prosopo-affective agnosia as a symptom of cerebral organic disease. *Journal of the American Geriatrics Society*, **27**, 225–230.
Kurucz, J., Feldmar, G. & Werner, W. (1979). Prosopo-affective agnosia associated with chronic organic brain syndrome. *Journal of the American Geriatrics Society*, **27**, 91–95.
Laughery, K. R., Fessler, P. K., Lenorovitz, D. R. & Yoblick, D. A. (1974). Time delay and similarity effects in facial recognition. *Journal of Applied Psychology*, **59**, 490–496.
Ley, R. G. & Bryden, M. P. (1979). Hemispheric differences in processing emotions and faces. *Brain and Language*, **7**, 127–138.
Lindsay, P. H. & Norman, D. A. (1977). *Human Information Processing*. New York: Academic Press.
McClelland, J. L. & Rumelhart, D. E. (1985). Distributed memory and the representation of general and specific information. *Journal of Experimental Psychology: General*, **114**, 159–188.
Mackain, K. S., Studdert-Kennedy, M., Spieker, S. & Stern, D. (1983). Infant intermodal speech perception is a left hemisphere function. *Science*, **219**, 1347–1349.
McGurk, H. & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, London*, **264**, 746–748.
McKenna, P. & Warrington, E. K. (1980). Testing for nominal dysphasia. *Journal of Neurology, Neurosurgery and Psychiatry*, **43**, 781–788.

McWeeny, K. H. (1985). Face processing: An investigation of everyday problems in learning and recognising faces and names. Unpublished MPhil thesis, Lancaster University.
Malone, D. R., Morris, H. H., Kay, M. C. & Levin, H. S. (1982). Prosopagnosia: A double dissociation between the recognition of familiar and unfamiliar faces. *Journal of Neurology, Neurosurgery and Psychiatry*, **45**, 820–822.
Marr, D. (1982). *Vision*. San Francisco: Freeman.
Marr, D. & Nishihara, K. (1978). Representation and recognition of the spatial organisation of three-dimensional shapes. *Proceedings of the Royal Society of London, Series B*, **200**, 269–294.
Matthews, M. L. (1978). Discrimination of identikit constructions of faces: Evidence for a dual processing strategy. *Perception and Psychophysics*, **23**, 153–161.
Memon, A. & Bruce, V. (1983). The effects of encoding strategy and context change on face recognition. *Human Learning*, **2**, 313–326.
Memon, A. & Bruce, V. (1985). Context effects in episodic studies of verbal and facial memory. *Current Psychological Research and Reviews*, **4**, 349–369.
Meyer, D. E. & Schvaneveldt, R. W. (1971). Facilitation in recognising pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, **90**, 227–234.
Morton, J. (1969). Interaction of information in word recognition. *Psychological Review*, **76**, 165–178.
Morton, J. (1979). Facilitation in word recognition: Experiments causing change in the logogen model. In P. A. Kolers, M. Wrolstad & H. Bouma (eds), *Processing of Visible Language*. New York: Plenum.
Morton, J. (1984). Naming. In S. Newman & R. Epstein (eds), *Dysphasia*. Edinburgh: Churchill Livingstone.
Morton, J., Hammersley, R. H. & Bekerian, D. A. (1985). Headed records: A model for memory and its failures. *Cognition*, **20**, 1–25.
Nelson, D. L. & Reed, V. S. (1976). On the nature of pictorial encoding: A levels of processing analysis. *Journal of Experimental Psychology: Human Learning & Memory*, **2**, 49–57.
Nelson, D. L., Reed, V. S. & McEvoy, C. L. (1977). Learning to order pictures and words: A model of sensory and semantic encoding. *Journal of Experimental Psychology: Human Learning & Memory*, **3**, 485–497.
Palmer, S. E. (1975). The effects of contextual scenes on the identification of objects. *Memory and Cognition*, **3**, 519–526.
Patterson, K. E., & Baddeley, A. D. (1977). When face recognition fails. *Journal of Experimental Psychology: Human Learning & Memory*, **3**, 406–417.
Perrett, D. I., Rolls, E. T. & Caan, W. (1982). Visual neurones responsive to faces in the monkey temporal cortex. *Experimental Brain Research*, **47**, 329–342.
Perrett, D. I., Smith, P. A. J., Potter, D. D., Mistlin, A. J., Head, A. S., Milner, A. D. & Jeeves, M. A. (1984). Neurones responsive to faces in the temporal cortex: Studies of functional organisation, sensitivity to identity and relation to perception. *Human Neurobiology*, **3**, 197–208.
Perrett, D. I., Smith, P. A. J., Potter, D. D., Mistlin, A. J., Head, A. S., Milner, A. D. & Jeeves, M. A. (1985). Visual cells in the temporal cortex sensitive to face view and gaze direction. *Proceedings of the Royal Society of London*, **B223**, 293–317.
Pizzamiglio, L., Zoccolotti, P., Mammucari, A. & Cesaroni, R. (1983). The independence of facial identity and facial expression recognition mechanisms: Relationship to sex and cognitive style. *Brain and Cognition*, **2**, 176–188.
Potter, M. C. & Faulconer, B. A. (1975). Time to understand pictures and words. *Nature*, **253**, 437–438.
Ratcliff, G. & Newcombe, F. (1982). Object recognition: Some deductions from the clinical evidence. In A. W. Ellis (ed.), *Normality and Pathology in Cognitive Functions*. London: Academic Press.
Read, D. J. & Bruce, D. (1982). Longitudinal tracking of difficult memory retrievals. *Cognitive Psychology*, **14**, 280–300.
Reason, J. T. & Mycielska, K. (1982). *Absent-minded? The Psychology of Mental Lapses and Everyday Errors*. Englewood Cliffs, NJ: Prentice-Hall.
Reason, J. T. & Lucas, D. (1984). Using cognitive diaries to investigate naturally occurring memory blocks. In J. Harris & P. E. Morris (eds), *Everyday Memory, Actions and Absentmindedness*. London: Academic Press.
Rhodes, G. (1985). Lateralized processes in face recognition. *British Journal of Psychology*, **76**, 249–271.
Rosch, E. (1978). Principles of categorization. In E. Rosch & B. Lloyd (eds), *Cognition and Categorization*. Hillsdale, NJ: Erlbaum.
Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M. & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology*, **8**, 382–439.
Rosinski, R. R., Golinkoff, R. M. & Kukish, K. S. (1975). Automatic semantic processing in a picture–word interference task. *Child Development*, **46**, 247–253.
Schwartz, M. F., Marin, O. S. M. & Saffran, E. M. (1979). Dissociations of language function in dementia: A case study. *Brain and Language*, **7**, 277–306.
Schwartz, M. F., Saffran, E. M. & Marin, O. S. M. (1980). Fractionating the reading process in dementia: Evidence for word-specific print-to-sound associations. In M. Coltheart, K. Patterson & J. C. Marshall (eds), *Deep Dyslexia*. London: Routledge & Kegan Paul.
Sergent, J. (1984). An investigation into component and configural processes underlying face perception. *British Journal of Psychology*, **75**, 221–242.
Seymour, P. H. K. (1979). *Human Visual Cognition*. London: Collier Macmillan.
Shuttleworth, E. C. Jr, Syring, V. & Allen, N. (1982). Further observations on the nature of prosopagnosia. *Brain and Cognition*, **1**, 307–322.

Smith, M. C. & Magee, L. E. (1980). Tracing the time course of picture–word processing. *Journal of Experimental Psychology: General*, **109**, 373–392.
Sperber, R. D., McCauley, C., Ragain, R. & Weil, C. (1979). Semantic priming effects on picture and word processing. *Memory and Cognition*, **7**, 339–345.
Strauss, E. & Moscovitch, M. (1981). Perception of facial expressions. *Brain and Language*, **13**, 308–332.
Suberi, M. & McKeever, W. F. (1977). Differential right hemispheric memory storage of emotional and non-emotional faces. *Neuropsychologia*, **15**, 757–768.
Tulving, E. & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, **80**, 352–373.
Valentine, T. & Bruce, V. (in press). The effect of race, inversion and encoding activity upon face recognition. *Acta Psychologica*.
Van Lancker, D. R. & Canter, G. J. (1982). Impairment of voice and face recognition in patients with hemispheric damage. *Brain and Cognition*, **1**, 185–195.
Wagstaff, G. F. (1982). Context effects in eyewitness reports. Paper presented at the Law and Psychology Conference, Swansea, Wales.
Warren, C. & Morton, J. (1982). The effects of priming on picture recognition. *British Journal of Psychology*, **73**, 117–129.
Warrington, E. K. & James, M. (1967). An experimental investigation of facial recognition in patients with unilateral cerebral lesions. *Cortex*, **3**, 317–326.
Whiteley, A. M. & Warrington, E. K. (1977). Prosopagnosia: A clinical psychological and anatomical study of three patients. *Journal of Neurology, Neurosurgery and Psychiatry*, **40**, 395–403.
Williams, M. D. & Hollan, J. D. (1981). The process of retrieval from very long-term memory. *Cognitive Science*, **5**, 87–119.
Williams, M. & Smith, H. V. (1954). Mental disturbances in tuberculous meningitis. *Journal of Neurology, Neurosurgery and Psychiatry*, **17**, 173–182.
Winograd, E. & Rivers-Bulkeley, N. J. (1977). Effects of changing context on remembering faces. *Journal of Experimental Psychology: Human Learning & Memory*, **3**, 397–405.
Yarmey, A. D. (1973). I recognise your face but I can't remember your name: Further evidence on the tip-of-the-tongue phenomenon. *Memory and Cognition*, **1**, 287–290.
Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, **81**, 141–145.
Young, A. W. (1984). Right cerebral hemisphere superiority for recognizing the internal and external features of famous faces. *British Journal of Psychology*, **75**, 161–169.
Young, A. W. (in press). Subject characteristics in lateral differences for face processing by normals: Age. In R. Bruyer (ed.), *The Neuropsychology of Face Perception and Facial Expression*. Hillsdale, NJ: Erlbaum.
Young, A. W., Hay, D. C. & Ellis, A. W. (1985*a*). The faces that launched a thousand slips: Everyday difficulties and errors in recognizing people. *British Journal of Psychology*, **76**, 495–523.
Young, A. W., Hay, D. C. & Ellis, A. W. (in press). Getting semantic information from familiar faces. In H. D. Ellis, M. A. Jeeves, F. Newcombe & A. W. Young (eds), *Aspects of Face Processing*. The Hague: Martinus Nijhoff.
Young, A. W., Hay, D. C. & McWeeny, K. H. (1985*b*). Right cerebral hemisphere superiority for constructing facial representations. *Neuropsychologia*, **23**, 195–202.
Young, A. W., Flude, B. M., Ellis, A. W. & Hay, D. C. (in press). Interference with face naming. *Acta Psychologica*.
Young, A. W., Hay, D. C., McWeeny, K. H., Flude, B. M. & Ellis, A. W. (in press *a*). Matching familiar and unfamiliar faces on internal and external features. *Perception*.
Young, A. W., McWeeny, K. H., Hay, D. C. & Ellis, A. W. (in press *b*). Access to identity-specific semantic codes from familiar faces. *Quarterly Journal of Experimental Psychology*, **38A**.
Young, A. W., McWeeny, K. H., Ellis, A. W. & Hay, D. C. (in press *c*). Naming and categorisation latencies for faces and written names. *Quarterly Journal of Experimental Psychology*, **38A**.

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