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What determines whether faces are special?

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''Is face perception special?'' has become one of the most frequently asked questions among cognitive scientists. This issue has generated considerable debate and produced diversified rather than unified answers around the polarized ''yes–no'' positions. The ongoing confusion in this field now calls for a theoretical synthesis. The goal of this paper is to review and examine the conceptual basis of the contradictory claims and to offer a unified scheme for experimental inquiry. We argue that most differences in the stated claims can be traced to conceptual rather than empirical determinants. Assessment discrepancies arise prior to empirical investigations because of the use of unfounded assumptions. The key to resolving the current controversy will largely depend upon settling some conceptual issues. We propose to replace the commonly adopted approach of assessing a single criterion with one where the question is addressed along multiple dimensions that include comparison of face and object perception in terms of their innate specification, localization, and domain specificity using developmental, neuropsychological, and neurophysiological measures.

There has been much debate as to whether faces represent a special stimulus category that is treated differently from other objects by the brain (Farah, 1996; Nachson, 1995; Tovée, 1998). The impetus for this argument arose from a number of sources including the classical finding that inverted faces are disproportionately harder to recognize than inverted houses and other objects (Yin, 1969), the ontogenetic evidence that newborn babies pay greater attention to face-like patterns than non-face stimuli (Goren, Sarty, & Wu, 1976), and the identification of prosopagnosia as a selective deficit in face recognition (Bodamer, 1947). It has often been speculated that given the biological significance of faces to social species, it is quite plausible that the ability to recognize faces is driven by genetically hardwired mechanisms (Johnson & Morton, 1991). This

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hypothesis, combined with a large number of behavioural, neuropsychological, and neurophysiological findings, has produced much interest in the question—''is face perception special?''—among cognitive scientists. Although there has been considerable effort to resolve this issue, the answer nevertheless remains elusive. Some examples of this controversy are presented in Table 1.

Our aim here is to provide a brief review of this literature and to present a theoretical foundation for resolving this controversy. There is a legitimate worry as to the validity of the specialness question and what it can accom-

TABLE 1
Some examples of studies and reviews on whether faces are ''special''

Authors	*Quotes*	*Are faces special?*
Diamond & Carey (1986); Carey (1992)	''Faces are not special in the sense of posing unique problems for a pattern encoder, at least not as reflected in unique sensitivity to inversion'' (Carey, 1992, p. 99).	No
Johnson & Morton (1991)	''faces are only special because the infant is born with some structural information about the general characteristics of faces in a promitive pathway concerned with the control of orienting'' (p. 143).	Yes and no
Farah (1996); Farah et al. (1998)	''Face recognition and object recognition appear to depend on different systems, which are anatomically separate, functionally independent, and differ according to the degree of part decomposition used in representing shape'' (Farah, 1996, p. 189).	Yes
Moscovitch et al. (1997)	''face recognition normally depends on two systems: (1) a holistic, face-specific system that is dependent on orientation-specific coding of second-order relational features … and (2) a part-based object-recognition system … which contributes to face recognition when the face stimulus does not satisfy the domain-specific conditions needed to activate the face system (p. 555).	Yes
Tanaka & Gauthier (1997)	''contrary to the predictions of a strict modularity account, holistic recognition is not unique to faces in light of evidence demonstrating the holistic recognition of other nonface objects … experts differ from novices in their enhanced sensitivity to the configural properties of a stimulus'' (pp. 84–85).	No

(Continued)

TABLE 1
(Continued)

Authors	*Quotes*	*Are faces special?*
Ellis & Young (1989)	''Many object classes may be analyzed in similar ... ways [as faces] ..., but faces may be special simply because we all experience them so extensively and are continually required to make fine discriminations among them'' (p. 89).	Yes but not unique
Tovée (1998)	''The 'specialness' of the face processing system will rest upon the determination of whether the face processing cells in IT have no functional equivalent counterparts for object processing, either in IT or elsewhere'' (p. 1242).	Undecided
Allison et al. (1999)	''faces are processed by a dedicated subsystem of the ventral visual pathway known to be involved in object recognition'' (p. 415).	Yes
Kanwisher (2000)	''considerable evidence supports the domain-specific view: face perception seems to involve different cognitive and neural mechanisms from those involved in the recognition of nonface objects'' (p. 759).	Yes

plish. We wish to stress that a specialness rating by itself has little scientific merit; it is the reasons that lead to the rating that have the potential to contribute to our knowledge. In this context, the specialness evaluation is no more than a simplified label for the implicated theories. Thus the real goal of the question is to establish the reasons behind the specialness assessment and only after it is defined clearly, can it help to organize the theoretical foundation of this issue.

THE DETERMINANTS OF SPECIALNESS

A quick survey of the literature has led to our conviction that the main cause of the contradictions is conceptual rather than empirical, resulting largely from differences in definition and interpretation rather than fact. The problem is not unique to face and object recognition. We wish to draw attention to a striking similarity between the kinds of problems encountered by enquiries into whether faces are special and whether language is special. The importance of conceptual issues has also been shown in assessing the status of language. Bates (1994) has pointed out that the debates over the status of a ''linguistic organ'' confuse three logically separable issues—innateness, brain localization, and domain specificity. Once these issues are disentangled, all possible combinations of these three issues are possible. For example, because innateness can be separated from localization and domain specificity, neural systems that are domain specific and localized do not have to be innate because experience-dependent learning may give rise to these systems. Using this scheme, the question of whether language is special had to be assessed along a number of dimensions based on the logical combinations. This type of analysis, we believe, would be equally useful in assessing the controversial status of face recognition.

As in the case of language, innateness, localization, and domain specificity are acceptable markers for the ''special'' status and faces.[1] Innateness requires that at least part of the face recognition faculty be genetically hard-wired. Localization requires that face processing be localized to some specific regions of the brain. Domain specificity requires that the face module[2] be specialized for face processing. A multi-factorial approach would have the benefit of providing a more complete account of the problem because ''specialness'' may be found along one dimension but not others. The verdict in the current literature, however, is frequently based on a single factor. For example, a number of opinions are based on whether there is an innate face module, some on whether face perception is merely a matter of expertise, and some on whether different stimulus types—i.e., faces and objects—can be processed by the same module.

This lack of consistency suggests the need for a more rigorous definition of ''specialness''. An early effort was made by Hay and Young (1982) who defined ''special'' in terms of ''uniqueness'' and ''specificity''. They considered ''uniqueness'' of an extreme form of specificity where faces are not only handled by a separate system but are also processed differently from the system that deals with non-face complex objects. On the other hand, ''specificity'' only requires that faces be processed by a separate system where the mechanisms need not be qualitatively different from the other system. This distinction has been adopted in later studies for comparing face and non-face object types, e.g., Ellis and Young (1989) and Gauthier and Logothetis (2000). The advantage of the distinction is that it identifies two kinds of specificity and therefore offers a more precise evaluation of ''specialness''. In this paper, we argue that their framework, which is largely based on the dimension of domain specificity, may be further separable from innateness and localization. A careful analysis is therefore necessary to characterize how these various dimensions that are relevant to the judgement of ''specialness'' are interrelated.

[1] Of course, the debate in question is centred on perceptual, cognitive, and neurological processes. The specialness of faces in terms of social and biological significance is hardly a matter of debate.

[2] Note that the term ''system'' is often used interchangeably with ''module'' in the literature.

MODULARITY AND DOMAIN SPECIFICITY

Modularity is a critical concept in the current debate because the specialness question is typically judged by whether faces are processed by a specialized module. Fodor (1983) described a ''module'' as a specialized cognitive system that handles a specific type of information. He listed nine possible features for modules that included domain specificity, ontogenetic universals, pathological universals, encapsulation, speed, unconsciousness, localization, shallow output, and obligatory firing. Of these, domain specificity was considered to be the most important feature of modularity. A module with this feature deals exclusively with a specific information type, such as faces, language, etc.

Coltheart (1999) points out that Fodor did not attempt to define modularity other than associating it with a number of features. Nevertheless, features such as information encapsulation are widely misunderstood as necessary conditions for a system to be modular in Fodor's sense. Coltheart considers domain specificity as the only necessary condition for modular systems and has defined modularity solely in terms of specificity. For the other features of modularity on Fodor's list, Coltheart suggests that they be dealt with as empirical issues. For example, whether or not the proposed module is innate should be considered as an empirical rather than a priori question. Explicitly or implicitly, most researchers realize that other features on Fodor's list are not particularly relevant to assessing the special status of faces. Thus modularity is often used interchangeably with ''domain specificity'' or simply ''specificity'' in the literature.

The concept of specificity also requires careful scrutiny. It is more appropriate to treat specificity as a relative than an absolute term. It is conceivable that a module may handle more than a single type of information yet maintains some degree of domain specificity. For example, various types of objects, such as buildings, fruits, and animals, may well be handled by the same processing module and yet that module would still have some degree of domain specificity because it does not process other types of information, such as language, mathematics, and social interactions. However, the degrees of specificity may differ. If it should be the case that there exist two recognition modules, one for faces and another for non-face objects, then one should be able to assert that the face module has a far greater degree of specificity because it handles nothing but faces, whereas the object module processes multiple object types.

The boundary of an information type is often more difficult to identify than it first looks. Even such a seemingly uniform category as faces can be subdivided in a number of ways, such as real faces vs cartoon faces, human faces vs animal faces, male faces vs female faces, own-race faces vs other-race faces, etc. It can be a challenging task to decide whether all these forms of faces belong to the same information type. Using a relative measure makes it possible to assess the degree of specificity without being troubled by the problem of definition. For example, the degree of specificity can be estimated by checking the level and number of categories handled by a specialized module. Because fruit and furniture are superordinate categories, whereas face is a basic-level category, a module that handles fruit and furniture has a lower degree of specificity than one that handles faces.

INNATENESS AND DOMAIN SPECIFICITY

Innate endowment

Because the brain undergoes dramatic changes over development, the question of modularity can only be meaningfully addressed from a developmental perspective. Domain specificity can either be present at birth or developed over a period of time. Specificity may also be initially present in one domain but later adapted to different domains. Therefore, the question of whether faces are special can be broken down as to whether they are special at various stages of development.

Innateness is widely accepted as a legitimate criterion for specialness although the importance of this measure can be a matter of debate. If some mechanisms are genetically hardwired for face processing, but absent for other information types, then it would suggest a special status of face perception at an early stage of life. Innate mechanisms for face perception may be manifested in two forms: First, the presence of an innate module or modules that are exclusively dedicated to face stimuli. Second, the presence of a domain-general object module but one that is predisposed to developing face specialization prior to developing non-face object processing (i.e., superiority in the order of developmental sequence). In either case, if faces are processed at a greater proficiency than other non-face objects after birth, then a claim that faces are special can be made in terms of developmental onset.

Such assumptions have stimulated a number of studies on neonatal and infant face perception over the past few decades (see Nelson, 2001a for a recent review). Numerous experiments have shown that neonates are more tuned to face-like stimuli than other types. These include the remarkable finding that, within 30 minutes of birth, neonates track moving faces longer than other moving patterns of comparable complexity, contrast, and spatial frequency (Easterbrook, Kisilevsky, Hains, & Muir, 1999; Goren, Sarty, & Wu, 1976; Johnson, Dziurawiec, Ellis, & Morton, 1991; Valenza, Simion, Cassia, & Umiltà, 1996). Within a few days, infants can distinguish their mothers' faces from those of strangers (Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984). They also tend to look at attractive faces longer than less attractive ones (Langlois et al., 1987). Newborn babies less than 3 days old appear to be able to judge attractiveness based on the internal facial features and their sensitivity is restricted to the upright orientation (Slater, Bremner, Johnson, Hayes, & Brown, 2000; Slater et al., 1998). Based on these findings, Slater and

Quinn (2001) concluded that ''the infant enters the world with a detailed representation of the human face'' (p. 22).

A pattern of preference for conspecifics at birth is found in other species, such as chicks and ducklings. From a comparison of the parallels between chicks' and human newborns' recognition of conspecifics, Morton and Johnson (1991) proposed that infant face perception is accomplished by two systems, which they named ''CONSPEC'' and ''CONLERN''. CONSPEC is described as an innate, face-specific system. The human newborn's brain is believed to contain structural information about the visual characteristics of conspecifics, very much like a template of a face, that is similar to CONSPEC in chicks. Morton and Johnson speculated that this system is mainly mediated by subcortical mechanisms, a notion later supported by the study of Simion, Valenza, Umiltà, and Barba (1998).

Morton and Johnson (1991) argued that the function of the CONSPEC system is to regulate approach behaviour and to direct newborns' attention to face-like patterns. However, being a detector of facial pattern, CONSPEC does not allow individual level facial discrimination. They proposed that face discrimination instead is accomplished by CONLERN, a hypothetical domain general system achieving exemplar-level recognition through learning or experience. Unlike CONSPEC, this system is mediated by cortical mechanisms. Morton and Johnson proposed that faces are special for CONSPEC among newborns because this system is innate, whereas faces are not special for the developing CONLERN because face identification requires learning, as with any other object. De Gelder and Rouw (2001) have recently proposed a dynamical dual-route model of face recognition. According to this account, face recognition is accomplished by a *face detection system* that is largely experience independent or innate, and a functionally and anatomically different *face identification system* that requires extensive learning. Unlike CONSPEC, de Gelder and Rouw's detection system is presumed to spread over various cortical regions.

There is little dispute that certain face processing abilities appear early in ontogenetic history. However, the underlying mechanisms for the abilities remain largely speculative. Johnson and Morton's (1991) hypothesis about subcortical mechanisms for CONSPEC has been questioned on the basis that there is little evidence showing activation of subcortical structures during face processing (Nelson, 2001b). Most imaging studies to date are conducted on adults, whereas the CONSPEC mechanism is only present in early infancy. Johnson (2001) suggests that the pulvinar structure may be a key substrate for CONSPEC because it receives strong input from the superior colliculus, which is known to be important in controlling saccades toward salient stimuli (reviewed in Grieve, Acuna, & Cudeiro, 2000). Johnson also cites evidence that patients with brain damage seem to detect and orient to faces differently than to other stimuli (Vuilleumier, 2000).

Although there is much agreement that newborns' preferential response to faces is genetically determined, the level of genetic specification for the cortical mechanisms in CONLERN remains unclear. Developmental studies have shown that adult-level face recognition may take several years to develop (Carey, 1992). This developmental requirement provides evidence for CONLERN as an expert system. However, it is not clear how much the developmental changes occur as a result of learning versus being a genetically specified course of maturation. Due to this uncertainty, face recognition skills achieved over development may or may not rule out the possibility that CONLERN is also to some extent a genetically specified system. It is difficult to argue that a system is formed by learning only based on the fact that it requires repeated environmental stimulation because the same stimulation is necessary to trigger any innately hardwired system. For example, it is well known from studies of visual deprivation that a normal visual system can become dysfunctional without pattern vision during the critical period (see Daw, 1995, for a review). Few would argue that basic visual functions such as visual acuity, stereo-acuity, contrast sensitivity, etc. are solely the result of learning and independent of any normal maturational process.

It is difficult to separate learning from maturation, given that faces are constantly present during development in our species-typical environment. However, studies of children with early brain damage as well as visual deprivation offer certain hints. Farah, Rabinowitz, Quinn, and Liu (2000) have presented a case in which a child suffered brain damage at birth and subsequently displayed prosopagnosia. Although the onset of the damage was as early as 1 day after birth, his brain was unable to develop the neural circuits necessary for face recognition through a neuroplastic process. Farah et al. speculated that the human genome may contain sufficiently explicit information for encoding faces, raising the possibility that CONLERN may contain critical innate specification for face recognition. More recently, Le Grand, Mondloch, Maurer, and Brent (2001) have provided further evidence for the lack of neural plasticity for normal adult-level face perception. Their study showed that infants deprived of pattern vision for only 2–6 months due to dense bilateral congenital cataract were not able to develop normal configural processing ability for face stimuli. The 14 patients, aged between 9 and 21 at the time of test, were found to be severely impaired in their ability to discriminate faces that varied only by the relative positions of facial features. This result suggests a permanent deficit in their face processing ability, given the fact that even after more than 9 years' exposure to faces following their cataract removal, they were not able to reach normal levels of face recognition ability. However, they displayed no deficits in their ability to discriminate faces that varied by features or when the geometrical patterns differed by the location of an internal feature. The authors interpreted these results as suggesting separate systems for processing face and non-face objects.

These studies, however, require further confirmation. The case study by Farah et al. (2000) may be subject to an alternative explanation. In particular, they report that the child is not only impaired for face recognition but also impaired for visually similar object recognition. For example, he misidentified a cigar as a crayon, a broom as a spatula, and celery as rope. An alternative explanation would be that the child's deficit with faces may be the result of damage to part of his domain general system that is responsible for finer discrimination among visually similar objects rather than with faces *per se*. The Le Grand et al. (2001) finding may also be subject to a similar interpretation even though they have shown that configural processing with geometrical patterns may not be impaired in their patients. Sceptics may argue that geometrical patterns are not prototypical non-face objects. Thus, it remains possible that visually similar objects varying only by their configuration might create similar effects. If so, the result may be interpreted in terms of a configural process that is domain general, although a full development of this process would require early visual experience. Indeed, this would represent a potent argument for the expertise model of face recognition (Diamond & Carey, 1986; Tanaka & Gauthier, 1997).

Expertise

Although there is little dispute on the special status of faces in newborn infants, such an assessment is often made solely on the basis of long-term development. There has been a tendency to overlook developmental perspectives, particularly with regard to the issue of innateness, perhaps because a demonstrated innate mechanism appears too crude compared to a fully developed face recognition system. It is the very question of whether a mature face perception system is in anyway special where most of controversies occur.

The issue of the special status of face perception originally arose from behavioural data in adults. Based on the effect that inverted faces are more difficult to recognize than inverted objects, Yin (1970) proposed that faces might be a unique object class that requires qualitatively different mechanisms and dedicated neural substrates. However, researchers have subsequently shown that the effect is not specific to faces. Diamond and Carey (1986) demonstrated an inversion effect with images of dogs in experts who had years of experience in recognizing special breeds of dogs. Their results suggested that the inversion effect is not mediated by mechanisms that are domain specific to faces. Diamond and Carey argued that recognizing structurally similar stimuli required expertise. Adult face recognition is an expertise that is acquired over years of development. Indeed, as Carey (1992) pointed out, young children are profoundly deficient in face encoding. On some clinical tasks, they perform at a level that is diagnostic of brain damage in the right hemisphere of adults.

It is now generally accepted that fine discrimination among structurally homogeneous stimuli requires configural or holistic processing—a skill that involves encoding of spatial relations between facial features or relatively fewer part decompositions (Farah et al., 1998; Rhodes, 1988). It is believed that processing of this kind mediates the inversion effect. Researchers who consider face perception as an expertise argue that configural or holistic processing for any type of object requires years of experience or training (reviewed by Tanaka & Gauthier, 1997).[3] According to this view, face perception is not special because it requires the same amount of training to achieve the expert (adult) level of performance as it is required by expertise in discriminating other homogeneous types of objects or animals.

The expertise model is able to account for an impressive range of phenomena. What had originally been thought to be face-specific behavioural effects, such as the inversion effect, were later found in experts with different object domains. Other behavioural effects, such as the greater reliance on 3-D surface information shading, contrast polarity, spatial frequencies, etc. in face recognition than in object recognition (reviewed in Bruce & Humphreys, 1994; Liu, Collin, Burton, & Chaudhuri, 1999; Liu, Collin, Rainville, & Chaudhuri, 2000), and differential priming effects by face and object stimuli (Barry, Johnston, & Scanlan, 1998) may also be demonstrated as effects of expertise. However, a number of alternative explanations and objections have been raised with the expertise model. Before describing these arguments, it may be helpful to distinguish a strong version of the expertise model, in which faces are not special on all dimensions of assessments, from a weak version, which grants moderate special status on some of the dimensions but not on others. The strong version faces the problem of explaining the demonstrated innate advantage of face perception over object perception. In this regard, the weak version is more credible, though it is still problematic in a number of areas.

As noted earlier, in order to ascertain that adult-level face recognition is the result of expertise, it is necessary to separate maturation from learning. Although it is tempting to compare the length of development in face recognition to the length of expertise training in non-face object recognition, a direct comparison risks the problem of comparing learning in a premature developing brain to learning in a fully developed brain. Many aspects of vision, such as contrast sensitivity, require a prolonged period of maturation after birth to reach adult levels (Ellemberg, Lewis, Liu, & Maurer, 1999). Although factors that contribute to maturation may not be obvious in the case of face perception, because the task is more high level, there is no reason or

[3] Recently, there has been a suggestion that expertise may be acquired within a matter of days (Gauthier et al., 1999). The discrepancy between this and most of the earlier conclusions (Carey & Diamond, 1994) about the time required for expertise calls for further explanation. But this does not impact on the discussion here.

established evidence to rule out the possibility that high-level vision also requires maturation other than learning.

The second question related to the expertise model is whether the putative system responsible for configural processing is genetically designed to handle faces by default, whereas its handling of other types of object information is achieved by adaptation or plasticity. If true, it can provide a further basis for the specialness of faces. Pinker (1997) has pointed out that to call a module a face-recognizer does not imply that it can only handle faces. Rather, the module is simply best designed to distinguish members of geometrical features that are face-like. If non-face objects such as cars share some of these geometrical features, the module would have no choice but to process them. Clearly, cars are not likely to be automatically processed by the putative face module and would instead require a period of expertise training. The important question here is whether a module that processes faces has the potential for processing cars and other non-face objects. It has been suggested that most domain-specific mechanisms in human cognition have this potential (Sperber, 1994).

Another line of reasoning that may weaken a domain-general theory of face and object recognition is derived from a reinterpretation of the inversion effect with non-face objects. The inversion effect in dog experts (Diamond & Carey, 1986) has often been considered as definitive evidence against a domain-specific theory. However, Kanwisher (2000) argues that the effect is consistent with either a domain-general system for both faces and dogs or two domain-specific systems, one for faces and the other for dogs. Thus, further evidence is necessary to distinguish between these alternative explanations. A paradoxical effect for such argument is that if dogs are indeed handled by a dog module, then faces are no longer the only class of objects that is handled by a highly domain-specific mechanism, thus losing its ''specialness'' based on the criterion of domain specificity. But this argument may be defended if such modules are only limited to objects with expertise training.

A common defence for a unitary system is that impairment in face recognition is often accompanied by problems in identifying other non-face objects. However, Kanwisher (2000) points out this evidence is also consistent with the possibility that face and non-face objects are dealt with by different systems but that cortically adjacent regions are easily damaged together. Evidence on anatomically distributed systems will be addressed in a later section on localization.

The last, and perhaps the most difficult, requirement for the expertise model is to explain the extant neuropsychological data. It has been reported that impairment of face recognition (prosopagnosia) due to brain lesion can leave non-face object recognition relatively intact (De Renzi & di Pellegrino, 1998; Farah, Levinson, & Klein, 1995; McNeill & Warrington, 1993). This has been taken as evidence to support the hypothesis that face recognition is functionally distinct and separated from object recognition. An alternative hypothesis (or the ''individuation hypothesis'') suggests that prosopagnosic patients are simply impaired at tasks requiring finer discrimination among visually similar objects (Damasio, 1990). However, this hypothesis is at odds with the finding that some prosopagnosic patients are able to discriminate visually similar objects such as cars (Sergent & Signoret, 1992), sheep (McNeil & Warrington, 1993), or eye glasses (Farah et al., 1995). The most damaging evidence, however, comes from reports that some patients are unable to recognize objects (visual agnosia) but have little or no problem recognizing faces (Humphreys & Rumiati, 1998; Moscovitch et al., 1997). This evidence shows that prosopagnosia cannot be due simply to a greater visual difficulty in face discrimination. Also, because one of these patients was able to develop recognition of individual sheep after being diagnosed as a prosopagnosic (McNeil & Warrington, 1993), it is difficult to argue that prosopagnosia is an impairment to a domain general system that is involved in processing of visually similar objects or configural information. Indeed, the double dissociation between object and face recognition is frequently taken as convincing evidence that brain damage can selectively impair the face or object system (e.g., Farah, 2000; Kanwisher, 2000; Moscovitch et al., 1997).

The face-module hypothesis

The double dissociation discussed previously is often considered as the main support for the hypothesis of a face-specific module. Proponents of this hypothesis believe that the double dissociation results imply the existence of anatomically and functionally segregated systems for face and object recognition in which one system can function relatively independently without the other and that either system can be selectively impaired (Farah et al., 2000; Kanwisher, 2000; Moscovitch et al., 1997). Although this assumption remains unchallenged by the current neurological evidence, sceptics have suggested that a double dissociation may be created on a unitary system and simulated on artificial neural networks (e.g., Plaut, 1995; Shallice, 1988). This has often been used both as evidence against the face-module hypothesis and as a defence for the expertise hypothesis. However, this argument should not necessarily be used for either possibility but rather as another possible cause for double dissociation. The face-module hypothesis is not refuted by this possibility but rather needs a further validation by falsifying the alternative unitary explanation. By the same token, the expertise hypothesis is not validated by this possibility because double dissociation may or may not be subsumed by a unitary system.

The face-module hypothesis mainly relies on the assumption of domain specificity. We focus here on a number of conditions that need to be satisfied by this hypothesis. First, as noted earlier, innateness needs to be addressed separately from the issue of domain specificity because face perception may be innate but not domain specific or it may be domain specific but not innate, a point also acknowledge in Kanwisher (2000). This issue involves resolving the difficult question of whether the hypothetical face module requires a period of postnatal maturation or whether adult-level face perception depends solely on learning or expertise.

Second, it is necessary to establish proper controls to show that an effect is face specific. A typical criticism of studies that support the face-module hypothesis is that many of them have failed to use the right controls when recognition of faces and objects are compared (Gauthier & Logothetis, 2000; Tanaka & Gauthier, 1997). Clearly, face recognition requires exemplar-level discrimination, whereas non-face object recognition tasks only require discrimination at a higher level of categorization. Also, the absence of a sufficient control for the level of expertise has been questioned. That is, although all subjects are experts in face recognition, they may not have had the same level of expertise with the objects they were required to identify. A match-up in both level of categorization and expertise is therefore needed.

The same criticisms of studies on face-specific effects have been applied to studies of prosopagnosic patients whose face recognition is reported to be more impaired than object recognition. It has been pointed out that this result may have simply arisen because the studies failed to test the patients on discrimination of visually similar objects or on objects for which the patients were experts (Tarr & Gauthier, 2000). A resolution of these criticisms is therefore crucial for further advancing the face-module hypothesis.

The face recognition literature has shown that a perfect control stimulus for faces is difficult to find. As reviewed earlier, most studies, including the ones showing evidence of double dissociation, have attempted to take the level of categorization and expertise into consideration. For example, Moscovitch et al. (1997) have shown that their agnosic patient CK not only lost his ability to recognize ordinary objects, but also lost the ability to recognize visually similar aeroplanes and tin soldiers for which he had been an expert. A full control of expertise level for both normal and patient populations can be elusive. As pointed out earlier, expertise for face perception may involve intricate interactions with maturational processes. For this reason, expertise with other objects following the completion of maturation may be quite different from expertise with faces.

Finally, a problem common to both expertise and the face-module hypotheses is that both have considered localization as a determinant of domain specificity. We will show next that this may not be the case.

LOCALIZATION AND DOMAIN SPECIFICITY

Localization

The studies on brain lesion and cognitive deficits have often assumed that the functional architecture of the brain is based on anatomically distinct localization (Farah, 1994). According to this assumption, domain specificity occurs through activation of a distinct brain region when a specific type of information is processed. Although this may be a valid hypothesis, the neural substrates of a domain-specific behaviour do not always follow the locality assumption. Indeed, recent studies indicate that face processing engages anatomically distributed patches of cortex (Allison et al., 1999; Haxby, Hoffman, & Gobbini, 2000; Haxby et al., 2001; Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999; McCarthy, Puce, Belger, & Allison, 1999; Puce, Allison, Asgari, Gore, & McCarthy, 1996), suggesting that face processing may be more distributed than was previously thought. Probing the problem of localization using a molecular mapping method reveals an even more intriguing picture (Zangenehpour & Chaudhuri, in press). Preliminary data using a double-labelling technique have shown that neurons in the monkey temporal lobe responding to faces and objects are organized in the same area in an interleaved laminar and pseudo-columnar fashion. In addition to face or object selective cells, the technique also reveals cells that are co-responsive to both faces and objects. This result is consistent with earlier single-unit studies showing that face and non-face tokens are represented in a distributed manner (Tanaka, 1997). The representations for faces and objects in the monkey's brain may be found in segregated but closely adjacent layers much like the organization of columns for orientations in V1. If so, it may explain why it is so difficult to find a prosopagnosic monkey. Kanwisher (2000) has suggested that the reason why it is difficult to find a pure case of prosopagnosia without agnosia may be due to interleaved neurological organizations for the two systems. The preliminary result lends some support to this claim for monkeys. Note that this pattern of distributed representations is quite different from the functional magnetic resonance imaging (fMRI) studies because activation patterns are shown at the cellular level.

It is difficult to interpret these results in the context of human object vision due to obvious differences between the two species. However, one suggestion is that activation of the same brain area that is visualized with coarse resolution may not necessarily reveal a unitary system. For example, even if an MRI scan shows activation of a discrete area by both faces and objects, it may or may not show that these stimuli are processed by the same system. Similarly, an increased activity in this area due to experience or expertise with certain objects may or may not show that the same system that is specialized for faces is necessarily used to process non-face objects. Exactly how the cellular-level findings can be related to fMRI results that show faces and objects to engage different areas remains unclear. In any case, Cohen and Tong (2001) have rightly suggested that modular and distributed theories may not be mutually exclusive. A mixture of special purpose modules and distributed mechanisms is also possible. The current neuroimaging findings cannot uniquely discriminate among these possibilities.

The new findings in human and monkey studies thus far present a complex picture between modularity and localization. They reinforce the reason to separate the notions of localization and domain specificity although inferring one from another is still common. Conceptually, the distinction between them is not ambiguous; domain specificity represents the functional aspect of certain brain mechanisms, whereas localization concerns the anatomical locations in the brain that serve these functions.

To understand how functionally distinct processes are localized and separated in the brain, it is necessary to understand how brain mechanisms are related to their functions in the related regions. In the absence of this knowledge, it is difficult to ascertain whether a certain brain area involves functionally uniform or distinct processes. Unfortunately, the neurological mechanisms underlying face and object recognition are far from being understood at this stage. As Kanwisher and Moscovitch (2000) point out, it is not clear whether the fusiform face area is involved in the detection of faces (Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000), the structural encoding of faces (George et al., 1999), or the subordinate-level categorization of objects (Gauthier et al., 2000). Yet this kind of information is undoubtedly crucial for pin-pointing the actual system or systems involved in face and object recognition tasks. This is all the more apparent when our knowledge in this domain is compared to our knowledge about mechanisms involved in machine vision.

Functional localization is nevertheless an important step toward understanding recognition mechanisms. However, even complete knowledge of the brain regions involved in object recognition does not automatically provide knowledge about the actual mechanisms operating in those regions, without which the neurological substrates of specificity will remain elusive.

The evidence from localization studies does not offer a definitive measure of domain specificity for the following reason. On the one hand, faces and objects may be subsumed by the same system, yet their cortical representations occupy different areas. This may happen when distinct areas are used for storage but the same encoding and retrieval mechanisms are applied to all information types. On the other hand, they may be processed by different systems, yet their representations are found in the same brain area, as appears to be the case from our cellular-level functional imaging studies (Zangenehpour & Chaudhuri, in press). It is also possible that the representations are partly local with variable amount of overlap. That is, separate systems may or may not necessarily be localized to a single brain region and the issue of modularity therefore may be independent of the issue of localization. Given these considerations, we believe that localization should be cautiously interpreted if it is used as an indicator of modularity or domain specificity. Unless the relationship between localization and specificity is fully understood, findings in one area should not automatically produce insights in another. It is thus safer to treat localization and domain specificity as separate questions until their link is firmly established.

If domain specificity cannot be safely deduced from localization, what conclusion can then be made regarding the specialness of faces from the issue of localization? Perhaps one way to access the specialness question is through the characteristics of neural representations in the identified areas. Young and Yamane (1992) have suggested that face cells in the inferotemporal cortex use sparse coding, whereby each face cell represents whole faces rather than simple features of faces. A question related to specialness then follows—are faces the only objects that are represented in this fashion? In other words, do faces use sparse encoding whereas non-face objects use distributed encoding? There have been suggestions that non-face objects are represented in a distributed fashion (Tanaka, 1997). If so, it can be argued that faces do indeed have a special status in terms of neuronal representations. However, other studies have shown that cells in the monkey's brain can represent non-face objects in the same way as faces once the monkeys are trained to recognize objects (Kobatake, Wang, & Tanaka, 1998; Logothetis, Pauls, & Poggio, 1995). This suggests that expertise or experience may play an important role in forming sparse coding. The question of how sparse coding is related to domain specificity remains unknown. Kanwisher (2000) argues that since the cells that develop sparse coding are not the same cells that code for faces, the finding does not serve as a proof of domain general mechanisms. Nevertheless, it does serve as an evidence for the role on experience. The impact of experience on neural representations is well illustrated in the field of neural plasticity.

Plasticity

Similar to the complex relationship between specificity and innateness, the relationship between localization and innateness also requires careful examination. Although many anatomical structures and neural substrates of brain function may be genetically hardwired, there is substantial evidence that the brain is a highly plastic organ that is guided by environmental influence or experience. Much of the evidence shows that, contrary to previous views, neural reorganization may take place even in the mature human brain (e.g., Buonomano & Merzenich, 1998; Kujala, Alho, & Naatanen, 2000; Sterr et al., 1998).

Although neural plasticity is often taken as strong evidence against the innateness hypothesis, alternative interpretations may also be possible. For example, it may be important to consider whether there is a default setting in the genetic program that determines the priorities for brain development. It has been shown that although newborn chicks follow various moving objects as a substitute for their mother when absent, they nevertheless show a clear preference for moving hens to other objects when both stimuli are available (Johnson & Morton, 1991). In this instance, there may be a hierarchically defined preference in the genetic programme helping to cope with environmental variables in a more flexible manner such that the level of preferences may be highly correlated to the success for finding the mothers. It may be that the development of the human brain also follows some predetermined preference hierarchy. In this scenario, the default mapping of brain function is predetermined, although development of each default region can be highly plastic, e.g., blindness developed in an early age can cause the visual cortex to be recruited to somatosensory processing (Cohen et al., 1997).

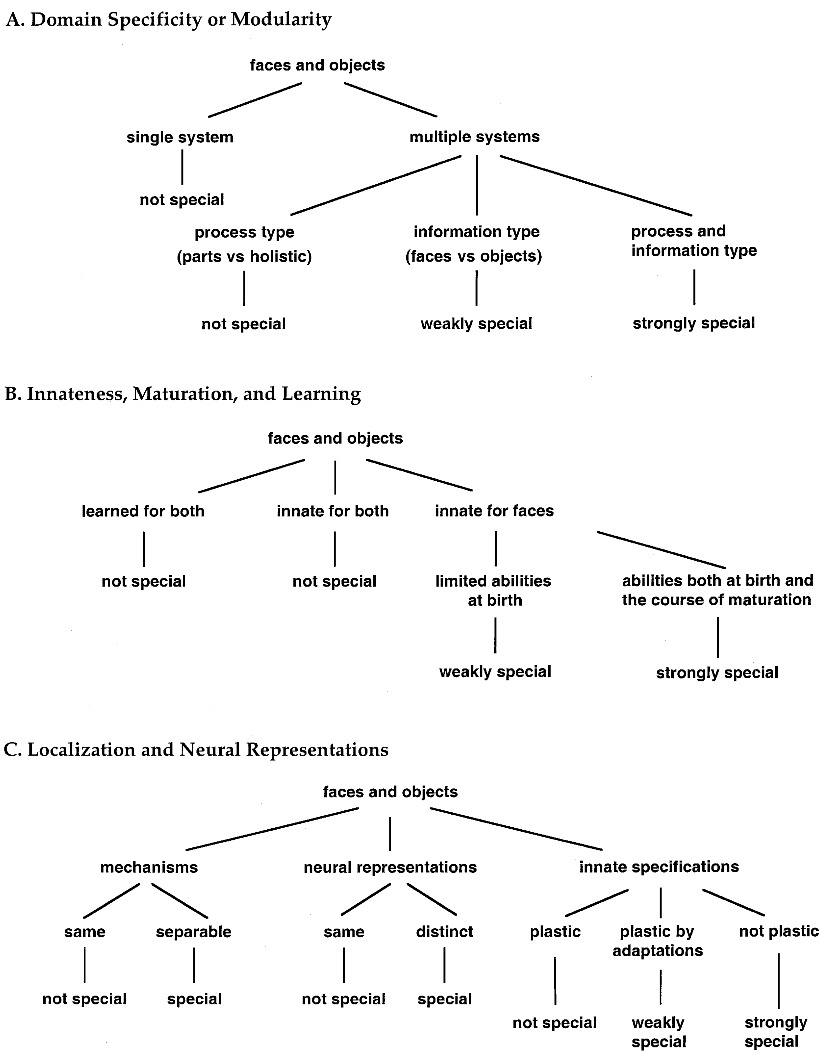
For the evaluation of facial specialness, a necessary task for neuroscientists is to determine whether faces are the preferred stimuli in a default setting for various related brain regions, such as the fusiform face area, or whether these regions are merely designated as a domain general learning system without any initial preference for the type of information. This is certainly a difficult task because there are few objects that can be compared to faces in terms of their importance in ontogenetic history. However, new directions in primate research and the potential utility of brain imaging techniques to observe human development profiles of face and object recognition may offer future advances.

A GENERAL FRAMEWORK FOR EVALUATING THE SPECIALNESS CLAIMS

We have described a number of dimensions that are relevant for assessing the specialness of face perception. A summary of the proposed framework that we have discussed is summarized in schematic form in Figure 1 (overleaf). The three panels in this figure show the possible ways of evaluating facial specialness along the dimensions of domain specificity, innateness, and localization. At each dimension, multiple levels of assessment are possible.

Figure 1A shows that the first level of evaluation for domain specificity concerns whether faces and objects are processed by a single or multiple systems. If they are processed by a single system, faces do not have any special status. If they are processed by different systems, the assessment is carried out at the next level at which the specialness decision depends upon the functional roles of these systems. If the roles differ in terms of processing type (such as part based vs holistic), faces do not have any special status. Diamond and Carey's (1986) expertise hypothesis would be consistent with either of these accounts. However, if the roles differ in terms of their information type (i.e., faces vs objects), then faces can be deemed special on the ground that this information type is treated by a dedicated module (e.g., Kanwisher, McDermott, & Chun, 1997; Kanwisher, Stanley, & Harris, 1999). A hybrid of this domain-specific system with a domain-general one is possible. For example, in de Gelder and Rouw's (2001) proposal, face recognition is accomplished by dynamic interactions between two systems—a face-specific detection system and an indentification system that partially overlaps with the object identification system. In this model, both faces and objects are subject to part-based and configural processing. An even stronger claim of specialness results when the two systems are believed to involve different mechanisms, e.g., the face system engages specialized holistic processing (Moscovitch et al., 1997).

It is conceivable that a separate module identified by information type be dedicated to other non-face objects. But when a multiplication of this happens, the specialness of faces can be significantly diluted or disappear. Because a proliferation of modules for an indefinite number of objects (chairs, cups, shoes, computers, etc.) may present a likely scenario, the finding that different objects uniquely stimulate different parts of ventral cortex has been interpreted in terms of distributed representations of objects rather than as evidence for different



modules (Haxby et al., 2001). However, either interpretation undermines the specialness claim.

Figure 1B illustrates that faces are not special if both face and object recognition requires equal amounts of learning for discrimination at equivalent levels of categorization, or if both are equipped with the same kind and quantity of innate mechanisms. Faces are special if additional innate mechanisms can be recruited for perception. This specialness is limited if innateness for face perception only shows some limited abilities, similar to that found at birth. However, the specialness argument is deemed to be strong if it can be shown that the major factors that determine the course of ontogenetic development of face recognition not only include innateness but also maturation. Alternatively, if maturation plays a minor role in development, adult-level face recognition may be simply the result of expertise, in which case faces have no special status. The developmental literature has shown a fairly clear evidence of early processing abilities of faces in comparison to a great number of visual stimuli, as well as

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Figure 1 (opposite). A general scheme for specialness evaluations of faces along three major dimensions.

A: Domain specificity or modularity. If faces and objects are processed by a single system, faces do not have any special status. If they are processed by different systems, the functions of these systems may differ in terms of processing type (such as one part-based and another for holistic processing), information type (such as one for faces and the other for objects), or a combination of the two. If both faces and objects are processed by the systems divided in terms of process type, then faces do not have any special status. However, if the systems differ in terms of their information type, then faces can be deemed special because they are processed by a dedicated module. But this specialness would be moderate if both faces and objects share the same or similar types of processing in comparison to the possibility that the face system mainly engages in holistic processing, whereas the object system mainly engages part-based processing.

B: Innateness, maturation, and learning. From a developmental perspective, if both face and object recognition require equal amounts of learning for discrimination at equivalent levels of categorization or both are equipped with the same kind and quantity of innate mechanisms, faces possess no special status. However, a special status can be claimed if relatively greater innate abilities are shown for face perception. If greater abilities are not only present at birth, but also manifest through the course of maturation, then even stronger special status can be given.

C: Localization and neural representations. The neural basis of specialness can be assessed by whether faces and objects are processed by the same or separable mechanisms. Only separable mechanisms lead to specialness. Furthermore, the assessment of specialness may be made at types of neural representations. Faces may be special if there are face selective cells but there are no chair or bird or other object selective cells. Finally, facial specialness can be regarded in terms of innate specifications and neural plasticity of the brain. If the mechanisms that mediate face and object recognition are not specifically hardwired to process a particular type of information, then faces cannot be considered to be special because such a system simply displays plasticity in developing any kind of expertise. Alternatively, there may be more innate resources initially designated to face processing, but these neural substrates may be highly plastic such that they can be adapted to process other information types. In this case, faces are special in the sense that they are designated as the default information type. Last, if they cannot be adapted to process non-face objects or cannot re-emerge in the presence of brain damage to the face area, faces would be considered strongly special.

evidence of great improvement of face processing abilities over the years of development (Nelson, 2001a). However, it is not clear how much of the later development may be accounted for by maturation.

Figure 1C shows that the neural basis of specialness is assessed by whether faces and objects are processed by the same or separable mechanisms. Face specialness cannot be attributed to the former but would be so for the latter. The current brain research on ventral cortex mainly produces knowledge about correlations between visual stimulation by images of various objects and patterns of activation in various brain locations. Because this knowledge currently provides limited clues to the functional roles of the activated areas (Kanwisher & Moscovitch, 2000), a debate built on highly speculative hypotheses about whether the relevant regions constitute a unitary or separate neural systems still appears premature.

The assessment of specialness may be made at less ambitious levels such as neural representations. Faces may or may not be special depending on whether they and expert-level object discrimination are mediated by neurons with the same type of coding. Evidence suggests that faces are not special in this sense because other non-face objects can also trigger single neurons (Logothetis et al., 1995). Finally, facial specialness can be regarded in terms of innate specifications and neural plasticity of the brain. If the mechanisms that mediate face and object recognition are not specifically hardwired to process a particular type of information, then faces cannot be considered to be special because such a system simply displays plasticity in developing any kind of expertise. Alternatively, there may be more innate resources initially designated to face processing, but these neural substrates may be highly plastic or flexible in the sense that they can be adapted to process other information types. In this case, faces are special in the sense that they are designated as the default information type.

Faces may be strongly special if the mechanisms responsible for face recognition are not plastic, in other words, if they cannot be adapted to process non-face objects or cannot re-emerge in the presence of brain damage to the face area. The evidence thus far has suggested some rudimentary innate neural mechanisms (Johnson & Morton, 1991), although the hypothesis that face detection is accomplished by an innate and specialized system in the right hemisphere remains highly speculative (de Gelder & Rouw, 2001). Very little is known about whether face processing in humans can be developed in an area other than the putative face area, though there is some evidence now to suggest a negative answer (Farah et al., 2000; Le Grand et al., 2001).

Thus, the question of whether faces are indeed special is quite complex, as evident from the scheme presented in Figure 1. A problem with the ongoing debate over the specialness question is that a conclusion has often been derived from a single dimension. Also, much of this debate may have stemmed from some questionable assumptions about the relationships between these dimensions, such as equating the issue of localization with domain specificity, or developmental changes with learning. A more fulfilling and complete approach would require, we believe, a careful examination of the multiple dimensions, their interrelationships, and how they are verified by empirical data.

REFERENCES

Allison, T., Puce, A., Spencer, D.D., & McCarthy, G. (1999). Electrophysiological studies of human face perception. I: Potentials generated in occipitotemporal cortex by face and non-face stimuli. *Cerebral Cortex*, *9*, 415–430.

Barry, C., Johnston, R.A., & Scanlan, L.C. (1998). Are faces ''special'' objects? Associative and semantic priming of face and object recognition and naming. *Quarterly Journal of Experimental Psychology*, *51A*, 853–882.

Bates, E. (1994). Modularity, domain specificity and the development of language. *Discussions in Neuroscience*, *10*, 136–149.

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

Bruce, V., & Humphreys, G.W. (1994). Recognizing objects and faces. In V. Bruce & G.W. Humphreys (Eds.), *Object and face recognition*. Hove, UK: Lawrence Erlbaum Associates Ltd.

Buonomano, D.V., & Merzenich, M.M. (1998). Cortical plasticity: From synapses to maps. *Annual Review of Neuroscience*, *21*, 149–186.

Bushnell, I.W., Sai, F., & Mullin, J.T. (1989). Neonatal recognition of the mother's face. *British Journal of Developmental Psychology*, *7*, 3–15.

Carey, S. (1992). Becoming a face expert. *Philosophical Transactions of the Royal Society of London B*, *335*, 95–103.

Carey, S., & Diamond, R. (1994). Are faces perceived as configurations more by adults than by children? *Visual Cognition*, *1*, 253–274.

Cohen, J.D., & Tong, F. (2001). The face of controversy. *Science*, *293*, 2405–2407.

Cohen, L.G., Celnik, P., Pascual-Leone, A., Corwell, B., Faiz, L., Dambrosia, J., Honda, M., Sadato, N., Gerloff, C., Catala, M.D., & Hallett, M. (1997). Functional relevance of cross-modal plasticity in blind humans. *Nature*, *389*, 180–183.

Coltheart, M. (1999). Modularity and cognition. *Trends in Cognitive Sciences*, *3*, 115–120.

Damasio, A.R. (1990). Category-related recognition defects as a clue to the neural substrates of knowledge. *Trends in Neurosciences*, *13*, 95–98.

Daw, N.W. (1995). *Visual development*. New York: Plenum Press.

De Gelder, B., & Rouw, R. (2001). Beyond localisation: A dynamical dual route account of face recognition. *Acta Psychologica*, *107*, 183–207.

De Renzi, E., & di Pellegrino, G. (1998). Prosopagnosia and alexia without object agnosia. *Cortex*, *34*, 403–415.

Diamond, R., & Carey, S. (1986). Why faces and and are not special: An effect of expertise. *Journal of Experimental Psychology: General*, *115*, 107–117.

Easterbrook, M.A., Kisilevsky, B.S., Hains, S.M.J., & Muir, D.W. (1999). Faceness or complexity: Evidence from newborn visual tracking of facelike stimuli. *Infant Behavior and Development*, *22*, 17–35.

Ellemberg, D., Lewis, T.L., Liu, C.H., & Maurer, D. (1999). Development of spatial and temporal vision during childhood. *Vision Research*, *39*, 2325–2333.

Ellis, H.D., & Young, A.W. (1989). Are faces special? In A.W. Young & H.D. Ellis (Eds.), *Handbook of research on face processing* (pp. 1–26). Amsterdam: North-Holland.

Farah, M.J. (1994). Neuropsychological inference with an interactive brain: A critique of the locality assumption. *Behavioral and Brain Sciences*, *17*, 43–104.

Farah, M.J. (1996). Is face recognition ''special''? Evidence from neuropsychology. *Behavioural Brain Research*, *76*, 181–189.

Farah, M.J. (2000). *The cognitive neuroscience of vision*. Malden, MA: Blackwell.
Farah, M.J., Levinson, K.L., & Klein, K.L. (1995). Face perception and within-category discrimination in prosopagnosia. *Neuropsychologia*, *33*, 661–674.
Farah, M.J., Rabinowitz, C., Quinn, G.E., & Liu, G.T. (2000). Early commitment of neural substrates for face recognition. *Cognitive Neuropsychology*, *17*, 117–123.
Farah, M.J., Wilson, K.D., Drain, M., & Tanaka, J.N. (1998). What is ''special'' about face perception? *Psychological Review*, *105*, 482–498.
Field, T.M., Cohen, D., Garcia, R., & Greenberg, R. (1984). Mother–stranger face discrimination by the newborn. *Infant Behavior and Development*, *7*, 19–25.
Fodor, J.A. (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: MIT Press.
Gauthier, I., & Logothetis, N. (2000). Is face recognition not so unique after all? *Journal of Cognitive Neuropsychology*, *17*, 125–142.
Gauthier, I., Tarr, M.J., Anderson, A.W., Skudlarski, P., & Gore, J.C. (1999). Activation of the middle fusiform ''face area'' increases with expertise in recognizing novel objects. *Nature Neuroscience*, *2*, 568–573.
Gauthier, I., Tarr, M.J., Moylan, J., Anderson, A.W., Skudlarski, P., & Gore, J.C. (2000). Does subordinate-level categorization engage the functionally-defined face area? *Cognitive Neuropsychology*, *17*, 143–163.
George, N., Dolan, R., Fink, G.R., Baylis, G.C., Russell, C., & Driver, J. (1999). Contrast polarity and face recognition in the human fusiform gyrus. *Nature Neuroscience*, *2*, 574–580.
Goren, C.C., Sarty, M., & Wu, P.Y.K. (1976). Visual following and pattern discrimination of face-like stimuli by new born infants. *Pediatrics*, *56*, 544–549.
Grieve, K.L., Acuna, C., & Cudeiro, J. (2000). The primate pulvinar nuclei: Vision and action. *Trends in Neuroscience*, *23*, 35–39.
Haxby, J.V., Gobbini, M.I., Furey, M.L., Ishai, A., Schouten, J.L., & Pietrini, P. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, *293* (5539), 2425–2430.
Haxby, J.V., Hoffman, E.A., & Gobbini, M.I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*, 223–233.
Hay, D.C., & Young, A.W. (1982). The human face. In A.W. Ellis (Ed.), *Normality and pathology in cognitive function*. London, UK: Academic Press.
Humphreys, G.W., & Rumiati, R.I. (1998). Agnosia without prosopagnosia or alexia: Evidence for stored visual memories specific to objects. *Cognitive Neuropsychology*, *15*, 243–277.
Ishai, A., Ungerleider, L.G., Martin, A., Schouten, J.L., & Haxby, J.V. (1999). Distributed representation of objects in the human ventral visual pathway. *Proceedings of the National Academy of Sciences of the United States of America*, *96*, 9379–9384.
Johnson, M.H. (2001). The development and neural basis of face recognition: Comment and speculation. *Infant and Child Development*, *10*, 31–33.
Johnson, M.H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*, 1–19.
Johnson, M.H., & Morton, J. (1991). *Biology and cognitive development: The case of face recognition*. Oxford, UK: Basil Blackwell Ltd.
Kanwisher, N. (2000). Domain specificity in face perception. *Nature Neuroscience*, *3*, 759–763.
Kanwisher, N., McDermott, J., & Chun, M.M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*, *17*, 4302–4311.
Kanwisher, N., & Moscovitch, M. (2000). The cognitive neuroscience of face processing: An introduction. *Cognition Neuropsychology*, *17*, 1–11.
Kanwisher, N., Stanley, D., & Harris, A. (1999). The fusiform face area is selective for faces not animals. *Neuroreport*, *10*, 183–187.

Kobatake, E., Wang, G., & Tanaka, K. (1998). Effects of shape-discrimination training on the selectivity of inferotemporal cells in adult monkeys. *Journal of Neurophysiology*, *80*, 324–330.

Kujala, T., Alho, K., & Naatanen, R. (2000). Cross-modal reorganization of human cortical functions. *Trends in neurosciences*, *23*, 115–120.

Langlois, J.H., Roggman, L.A., Casey, R.J., Ritter, J.M., Rieser-Danner, L.A., & Jenkins, V.Y. (1987). Infant preferences for attractive faces: Rudiments of a stereotype? *Developmental Psychology*, *23*, 363–369.

Le Grand, R., Mondloch, C.J., Maurer, D., & Brent, H.P. (2001). Early visual experience and face processing. *Nature*, *410*, 890.

Liu, C.H., Collin, C.A., Burton, A.M., & Chaudhuri, A. (1999). Lighting direction affects recognition of untextured faces in photographic positive and negative. *Vision Research*, *39*, 4003–4009.

Liu, C.H., Collin, C.A., Rainville, S.J.M., & Chaudhuri, A. (2000). The effects of spatial frequency overlap on face recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 956–979.

Logothetis, N.K., Paulsw, J., & Poggio, T. (1995). Shape representation in the inferior temporal cortex of monkeys. *Current Biology*, *5*, 552–563.

McCarthy, G., Puce, A., Belger, A., & Allison, T. (1999). Electrophysiological studies of human face perception. II: Response properties of face-specific potentials generated in occipitotemporal cortex. *Cerebral Cortex*, *9*, 431–444.

McNeil, J.E., & Warrington, B.K. (1993). Prosopagnosia: A face-specific disorder. *Quarterly Journal of Experimental Psychology*, *46A*, 1–10.

Morton, J., & Johnson, M.H. (1991). CONSPEC and CONLERN: A two-process theory of infant face recognition. *Psychological Review*, *98*, 164–181.

Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition. *Journal of Cognitive Neuroscience*, *9*, 555–604.

Nachson, I. (1995). On the modularity of face recognition: The riddle of domain specificity. *Journal of Clinical and Experimental Neuropsychology*, *17*, 256–275.

Nelson, C.A. (2001a). The development and neural bases of face recognition. *Infant and Child Development*, *10*, 3–18.

Nelson, C.A. (2001b). Response to critiques. *Infant and Child Development*, *10*, 35–38.

Pinker, S. (1997). *How the mind works*. New York: Norton.

Plaut, D.C. (1995). Double dissociation without modularity: Evidence from connectionist neuropsychology. *Journal of Clinical and Experimental Neuropsychology*, *17*, 291–321.

Puce, A., Allison, T., Asgari, M., Gore, J.C., & McCarthy, G. (1996). Differential sensitivity of human visual cortex to faces, letterstrings, and textures: A functional magnetic resonance imaging study. *Journal of Neuroscience*, *16*, 5205–5215.

Rhodes, G. (1988). Looking at faces: First-order and second-order features as determinates of facial appearance. *Perception*, *17*, 43–63.

Sergent, J., & Signoret, J.L. (1992). Varieties of functional deficits in prosopagnosia. *Cerebral Cortex*, *2*, 375–388.

Shallice, T. (1988). *From neuropsychology to mental structure*. Cambridge, UK: Cambridge University Press.

Simion, F., Valenza, E., Umiltà, C., & Barba, B.D. (1998). Preferential orienting to faces in newborns: A temporal-nasal asymmetry. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1399–1405.

Slater, A., Bremner, G., Johnson, S.P., Hayes, R., & Brown, E. (2000). Newborn infants' preference for attractive faces: The role of internal and external facial features. *Infancy*, *1*, 265–274.

Slater, A., & Quinn, P.C. (2001). Face recognition in the newborn infant. *Infant and Child Development*, *10*, 21–24.

Slater, A., von der Schulenburg, C., Brown, E., Badenoch, M., Butterworth, G., Parsons, S., & Samuels, C. (1998). Newborn infants prefer attractive faces. *Infant Behavior and Development*, *21*, 345–354.

Sperber, D. (1994). The modularity of thought and the epidemiology of representations. In L.A. Hirschfeld & S. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 37–67). Cambridge, UK: Cambridge University Press.

Sterr, A., Muller, M.M., Elbert, T., Rockstroh, B., Pantev, C., & Taub, E. (1998). Changed perceptions in Braille readers. *Nature*, *391*, 134–135.

Tanaka, J.W., & Gauthier, I. (1997). Expertise in object and face recognition. In R.L. Goldstone, P.G. Schyns, & D.L. Medin (Eds.), *Psychology of learning and motivation* (pp. 83–125). San Diego, CA: Academic Press.

Tanaka, K. (1997). Mechanisms of visual object recognition: Monkey and human studies. *Current Opinion in Neurobiology*, *7*, 523–529.

Tarr, M.J., & Gauthier, I. (2000). FFA: A flexible fusiform area for subordinate-level visual processing automatized by expertise. *Nature Neuroscience*, *3*, 764–769.

Tong, F., Nakayama, K., Moscovitch, M., Weinrib, O., & Kanwisher, N. (2000). Response properties of the human fusiform face area. *Cognitive Neuropsychology*, *17*, 257–279.

Tovée, M.J. (1998). Is face processing special? *Neuron*, *21*, 1239–1242.

Valenza, E., Simion, F., Cassia, V.M., & Umiltà, C. (1996). Face preference at birth. *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 892–903.

Vuilleumier, P. (2000). Faces call for attention: Evidence from patients with visual extinction. *Neuropsychologia*, *38*, 693–700.

Yin, R.K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, *81*, 141–145.

Yin, R.K. (1970). Face recognition by brain-injured patients: A dissociable ability? *Neuropsychologia*, *8*, 395–402.

Young, M.P., & Yamane, S. (1992). Sparse population coding of faces in the inferotemporal cortex. *Science*, *256*, 1327–1331.

Zangenehpour, S., & Chaudhuri, A. (in press). Focal clustering of face-selective neurons in monkey temporal lobe. *Society for Neuroscience Abstracts*.

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