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Cognitive models of familiar people recognition and hemispheric asymmetries

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1. ABSTRACT

The aim of the present review consists in reviewing data inconsistent with assumptions made by modular cognitive models of familiar people recognition. In particular, some of these inconsistencies are due to the failure to consider hemispheric specialization as an important variable in familiar people recognition. Indeed, hemispheric asymmetries exist between familiar faces and voices, underpinned by the right hemisphere, and names, subsumed by the left hemisphere. Furthermore, before the level of the person identity nodes (PINs), cross-communication exists between the perceptual channels for faces and voices, but not the channel for faces. Additionally, familiarity judgements are generated at the level of the modality-specific recognition units, with a right hemisphere dominance in the generation of face and voice familiarity feelings and PINs should not be considered as a simple gateway to a semantic system, storing information about people, but as structures involved in person-specific information retrieval processes. These data show that person-specific representations are mainly based on perceptual (face and voice) information in the right hemisphere and on verbal information in the left hemisphere.

2. INTRODUCTION

In each social species, particularly in humans, identification of individuals belonging to a social group and with whom we are personally acquainted or who are simply well known for their achievements or specific abilities, is a fundamental biological function. A complex, multimodal recognition system has, therefore, evolved in the brain, to quickly and efficiently accomplish this complex individual identification. Although this recognition system is mainly based on visual (face), auditory (voice) and verbal (name) recognition channels, other types of information, including biological motion signals and body shapes, might be useful in identifying people. Different models have been proposed to explain how this process is achieved within each recognition modality, how these modalities interact and how the biographical information of each person is accessed and organized.

The most influential cognitive model of familiar people recognition is Burton *et al.'s* (1) Interaction Activation and Competition (IAC) model, which was derived from the first influential model of face recognition, constructed by Bruce and Young (2). Further developments and modifications of this model were proposed, among others, by Bredart *et al.* (3, 4), Valentine *et al.* (5), and Burton *et al.* (6). These models tend to be modular and sequential in nature, but the IAC model allows both processing of information in a cascade-like manner, sensu McClelland and Rumelhart (7), and allows extensive parallel bottom-up and top-down processing . This feature has been used, for instance, by Burton *et al.* (8) to model covert face recognition in prosopagnosia. Furthermore, these models do not take into account possible processing differences, related to the hemispheric specialization and are based on the distinction between some lower level perceptual processes, a locus of convergence of the output of these processes and a unitary store of higher level cognitive or semantic representations. The perceptual processes concern the visual and auditory channels through which a seen face and a heard voice are mapped onto the corresponding invariant representation within specific recognition units for faces (FRUs) and voices (VRUs). The output of these modality-specific recognition units converge into person-identity nodes (PINs), which allow the identification of a person characterized by a given face and voice, giving access to the corresponding semantic (biographical) information. In addition to the perceptual channels for faces and voices, the output of a different modality of people identification (their name), also converge into the PINs, after it has been mapped onto the corresponding invariant representation in a name recognition unit (NRU). The name, however, does not belong to the perceptual system, but rather to the semantic system, where name information is stored, together with semantic information units, in a unitary person-specific semantic system.

As all of these models are strictly modular, they assume that the channels of familiar people recognition are domain specific and encapsulated. According to these principles, a modality-specific processing system (e.g. the visual channel that processes faces) should not communicate with the voice or the name processing systems before the level of the corresponding PINs. Furthermore, no continuity should exist between the lower level perceptual channels and the higher level familiar people representations, which are stored in the unitary, person-specific semantic system. This last claim is consistent with the postulates of more general modular cognitive models (e.g. 9-17), which are based on two main assumptions. The first is that the hierarchical stages of perceptual analysis proceed up to the level of a three-dimensional structural description (corresponding to the FRUs and VRUs), which includes a complete perceptual specification of objects prior to their meaningful recognition. The second is that, after this stage, no trace of the previous sensory-motor mechanisms should persist, because the format of semantic representations, accessed through these structural descriptions (or the corresponding recognition units), is abstract and amodal. Following this line of thought, Ellis *et al.* (18) postulated a cognitive model that consists of two processing modules working in parallel and corresponding to the auditory and visual modalities. Each processing system includes homologous stages: a step for "structural encoding" (auditory and visual) followed by modality-specific "recognition units" for faces (FRU) and voices (VRU). These two pathways converge in a "person identity node" (PIN), which stores semantic information.

Besides these modular characteristics, which are shared by the IAC and Bruce et Young's (2) models, there are important differences between Bruce et Young's (2) model of familiar faces recognition and models that address the more general problem of familiar people recognition. These differences concern: (a) the locus in which familiarity feelings for the addressed person are generated and (b) the structure in which person-specific information is stored. As to the first point, Bruce et Young's (2) model assumesthat familiarity feelings could be generated in the modality-specific recognition units where (for instance) the structural description of a seen face is compared to the familiar faces stored in the FRUs. By contrast, the IAC model assumes that the locus of familiarity decisions is the PINs,, where familiarity is signalled when PINs reach a given activation threshold. As for the second point, the Bruce and Young's (2) model assumes that PINs store semantic information, whereas the IAC model maintains that PINs do not store semantic information, but provide a modality-free gateway to a single semantic system, where information about people is stored in an abstract format.

In recent years some clinical and experimental data have questioned both the strictly modular approach of all the above mentioned cognitive models and the specific statements of the IAC model. These new data have shown: (a) that all the steps of stimulus processing and semantic representation taken into account in the above mentioned cognitive models are not equally represented at the level of the right and left hemisphere and that, therefore, these models should be reformulated by trying to explain these hemispheric asymmetries; (b) that a communication between the visual and auditory channels of person recognition probably exists before the level of the corresponding PINs; (c) that the loci of emergence of familiarity feelings are the modality-specific recognition units rather than the PINs; (d) that PINs are directly linked to semantic information, and do not provide a modality-free gateway to a single semantic system, where information about people is stored in an abstract format.

The aim of the present position paper will was to review some of these open questions, by considering data which suggest the following: :

(a) that important hemispheric asymmetries exist between the recognition of familiar faces and voices, which are mainly underpinned by the right hemisphere and names, which are mainly subsumed by the left hemisphere;

(b) that a cross-communication between channels of person recognition probably exists before the level of the PINs, but concerns only the perceptual channels that process faces and voices and not the linguistic channel concerning people's name;

(c) that familiarity judgements might be generated at the level of the modality-specific recognition units rather than at the PINs level, with a right hemisphere dominance in the generation of face and voice familiarity feelings;

(d) that the PINs should not be considered simply as a modality-free gateway to a single semantic system, where information about people is stored in an amodal format, but might be much more strictly involved in processes of retrieval of person-specific information;

(e) that the format of person-specific representations might be mainly based on perceptual (face and voice) information in the right hemisphere and on language-mediated information in the left hemisphere.

3. HEMISPHERIC ASYMMETRIES IN THE RECOGNITION OF FAMILIAR FACES, VOICES AND NAMES

A growing body of evidence suggests that a different hemispheric specialization exists for different modalities of person identification, with a prevalent right hemisphere (RH) lateralization of the sensory-motor systems allowing face and voice recognition and a prevalent left (LH) lateralization of the verbal name recognition system. Data concerning the right hemisphere (RH) lateralization of the sensory-motor systems subsuming face and voice recognition mainly come from clinical studies because in brain-damaged patients familiar face recognition disorders, called 'prosopagnosia' by Bodamer, (19), are provoked either by bilateral or right-sided lesions (20-22) and are very rarely observed in left brain-damaged patients (see 23 for a recent review). Analogously, voice recognition disorders, which were more rarely described in a condition called 'phonagnosia' by Van Lancker and Canter (24), are usually due to bilateral or right temporal lesions (24-26). It is more difficult to distinguish defects in personal names recognition from general lexical recognition disorders in aphasic left brain-damaged patients, but investigations conducted in normal subjects, to evaluate laterality effects in recognition of familiar personal names by Schweinberger *et al.* (27-31) and by Tsukiura *et al.* (32-34) have provided strong evidence for left temporal lobe involvement in personal name recognition and in proper name retrieval. Furthermore, results of a recent review (35) of investigations that evaluated laterality effects in the recognition of familiar names, faces and voices in normal subjects reported that: (a) recognition of familiar faces and voices shows a prevalent right hemisphere lateralization and recognition of familiar names, a left hemisphere lateralization; (b) the right hemisphere prevalence is greater in tasks involving familiar than unfamiliar faces and voices, and the left hemisphere superiority is greater in the recognition of familiar than unfamiliar names. Taken together, these data suggest that hemispheric asymmetries in the recognition of faces, voices and names are not limited to their perceptual processing, but also extend to the domain of their cortical representations.

4. COMMUNICATION BETWEEN THE PERCEPTUAL CHANNELS PROCESSING FACES AND VOICES BEFORE THE 'PIN' LEVEL

Schweinberger *et al.* (36) provided the first unequivocal evidence that a communication exists between face and voice channels of person recognition before the level of the corresponding PINs. These authors observed that famous faces, but not famous names, caused a long term repetition priming effect in famous voice recognition. They concluded that these findings might be tentatively related to ``perceptual links" between faces and voices. In a later study, Schweinberger *et al.* (37), provided converging evidence, by demonstrating systematic costs and benefits in the identification of familiar voices that were accompanied by time-synchronized articulating faces of non-corresponding or corresponding speakers, respectively. These findings were reported in a often-cited review of the integration of faces and voices in person perception (38). However,the most impressive data, showing that a communication exists between face and voice channels of person recognition before the level of the corresponding PINs havebeen obtained by von Kriegstein *et al.* (39-40), with functional magnetic resonance imaging (fMRI). Using the same methodology, previous investigations had shownthat face sensitive areas could be found, especially in the right hemisphere, in the middle fusiform gyrus (FFA) (41-43) and on the lateral surface of the occipital lobe (OFA) (43-44) ; moreover, a voice-sensitive cortical area was found along the superior bank of the superior temporal sulcus (STS) (45-46). Starting from these data, von Kriegstein *et al.* (39-40) have provided evidence of cross-modal neural activation of face-specific regions in the context of voice identification. These studies, which measured brain activity during identification tasks, in which subjects focused on either the speaker's voice or the verbal content of sentences, showed that familiar persons' voices activated the FFA when the identification task was to focus on the speaker's identity. Functional connectivity between FFA and STS during familiar speaker recognition was also obtained. This led to the conclusion that interactions between the person familiarity assessments resulted from direct information sharing between auditory voice and visual face regions and did not engage the supramodal cortical regions underlying person identity information (PINs). Subsequently,the hypothesis of an early perceptual integration of facial and vocal identity was confirmed by several authors withboth event-related potentials (ERP) studies, which allowed researchers to determine when the brain first registers the correspondence or non-correspondence of audiovisual stimuli, and with direct studies of the structural connections between voice- and face-processing cortical areas.

The first of these research strategies was adopted in some recent ERP studies, that investigated audiovisual integration (AVI) in speaker recognition. In one of these studies Gonzalez *et al.* (47) reported ERP evidence for early (~200 ms) face-voice integration, by combining static faces with voices in a familiarity detection task. Similar results were obtained in another study on sequential face-voice matching that used dynamic facial videos (48) . With this strategy, a crossmodal priming effect concerning personal identity was observed as early as 100 ms, i.e. in the time range of the auditory N1. Finally, Schweinberger *et al.* (49) used an experimental paradigm in which the voice is combined with a time-synchronised articulating face of corresponding or non-corresponding speaker identity. These authors showed that the ERPs of both audiovisual conditions led to a much earlier onset of frontocentral negativity than those of unimodal conditions, with maximal differences around 50-80 msec. All these data suggest that the assessment of person familiarity can lead to direct information sharing between voice and face sensory systems from the early processing stages, before access to the person identity nodes (PINs).

The second research strategy was followed by Blank *et al.* (50), who looked for evidence of direct structural connections between voice- and face-processing cortical areas by combining functional and diffusion magnetic resonance imaging. They localized, at the individual subject level, three voice-sensitive areas in anterior, middle, and posterior superior temporal sulcus (STS) and face-sensitive areas in the fusiform face area (FFA). Using probabilistic tractography, they showed that the FFA is structurally connected with voice-sensitive areas in STS, and that these connections are very strong with the middle and anterior areas of the STS, which are particularly responsive to voice identity. This specific structural connectivity pattern indicates that direct links between face-and voice-recognition areas could be used to optimize human person recognition. But a recent study by O'Mahony and Newell (51) reported that an interaction similar to that found between faces and voices was not observed between faces and names. This result suggests that the channels which process perceptual data are more closely integrated than those which process perceptual and semantic data respectively. The IAC model postulated a distinction between the perceptual systems containing FRUs and VRUs and the semantic systems, containing NRUs and semantic information units, but also assumed that the two perceptual systems were connected only via the PINs and not at an earlier processing stage, which all the above mentioned data clearly suggest. Since, as I have already said, there is increasing evidence of a prevalent RH lateralization of the sensory-motor systems allowing face and voice recognition and a prevalent LH lateralization of the verbal name recognition system, it is likely that the presence of an integration between the channels processing faces and voices, but not between faces and names, is due to the fact that the former are processed by the same (right) hemisphere, whereas the latter are processed by different hemispheres.

5. CONTROVERSIES ABOUT THE LOCUS OF GENERATION OF FAMILIARITY JUDGEMENTS

In a review of the patterns of famous people recognition disorders found in patients with right and left anterior temporal lobe (ATL) lesions, Gainotti (52) suggested, in partial agreement with results of a previous study by Snowden *et al.* (53), that laterality of lesion could have a twofold influence on familiarity decisions about famous people. According to the Gainotti's (52) review, familiarity feelings were overall more impaired in right than in left ATL patients, and this impairment was modality-specific in right, but not in left ATL patients. The former obtained significantly lower scores on faces than names, whereas the latter obtained relatively good scores on both faces and names. At partial variance with Gainotti's (52) findings , Snowden *et al.* (53) reported a double dissociation regarding familiarity judgements: patients with more left hemisphere atrophy showed greater familiarity for faces than names, whereas patients with more right sided atrophy showed the reverse. This double dissociation occurred despite the 'normal' bias towards better familiarity for names. This is theoretically relevant because it argues against the possibility that the right hemisphere may have a special status with regards to familiarity. In spite of the above noted differences, data obtained by Snowden *et al.* (53) and by Gainotti (52) consistently show that familiarity feelings are modality-specific, at least in patients with right anterior temporal lesions. They are, therefore, at variance with the IAC model, which assumes that familiarity judgments are evoked at the supra-modal PIN's level. These claims are tempered by the fact that the IAC model´s architecture is not incompatible with modality-specific impairments of familiarity feelings, because the latter are modelled by impaired links between modality-specific recognition units and PINs. Regardless of these theoretical controversies, the right hemisphere might be prevalent in the generation of modality-specific face familiarity feelings because this hemisphere plays a major role in face processing; nevertheless, this prevalence could also be due to a methodological bias.

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The first interpretation was suggested, by the following reasons: (a) both the FFA and the OFA are larger in the right than the left hemisphere. (41, 43-44); (b) the right lateralization of the ERP repetition priming effect peakof |250 ms ('N250r') was obtained by Schweinberger *et al* (54-55) in an investigation of face familiarity processing and (c) the special role of right hemisphere lesion in the pathophysiology of prosopagnosia (20-23).

The second interpretation was suggested by the Haslam et *al.'s* (56) observation that in normal subjects familiarity judgements are more accurate in response to names than to faces, because this variable had not been taken into account systematically in studies considered in our review. To check if differences observed in Gainotti's (52) review between patients with right and left ATL atrophy were due to a methodological bias, i.e. to the 'normal' differences about familiarity judgements in response to names and faces reported by Haslam *et al.* (56), Gainotti *et al* (57) undertook a new investigation. In this research they made use of two very well controlled normative studies of face and name recognition and identification, recently carried on by Bizzozero *et al.*(58-59) on Italian participants. The Bizzozero *et al.'s* (58-59) tests were administered to two patients, showing a selective mild difficulty of familiar people identification and naming due to a predominantly right and left ATL atrophy, to see if the conclusions of Gainotti's (52) review were confirmed even with this highly controlled material. Data obtained in the right ATL patient confirmed the results of Gainotti's (52) previous review, because this patient showed a very impaired familiarity for faces, contrasting with a spared familiarity for names. This confirms that familiarity judgments are generated at the level of modality-specific recognition units and not of a supramodal PIN. Results consistent with this general view were also obtained in a recent survey of face and voice recognition disorders in patients with right temporal lesions (26). In this review, double dissociations were observed between some patients who showed a moderate face familiarity impairment but were unimpaired in voice recognition, and other patients who showed a severe defect in voice recognition but were only moderately impaired in face familiarity judgments. These data also suggest that familiarity feelings are generated in modality-specific recognition units and not at the PIN level.

6. ACCESS TO PERSON-SPECIFIC SEMANTIC KNOWLEDGE

In the introductory section of this survey, we saw that an important difference between the IAC and the Bruce et Young's (2) model, concerned the access to person-specific semantic knowledge. The Bruce and Young's (2) model assumes that PINs store semantic information, whereas the IAC model maintains that PINs simply provide a modality-free gateway to a single semantic system, where information about people is stored in an amodal format. The IAC position, , which assumes the existence of a single common body of person-specific semantic information equally accessible from all modalities through the PINs, was been first challenged by Haslam *et al.* (60) in a patient diagnosed as herpes simplex encephalitis who at the MRI showed a bilateral lesion of the anterior temporal lobes, mainly involving the medial temporal regions, but extending on the right to the temporal pole and the lateral cortex. These authors showed (a) that the patient accessed more information about famous people when cued with names than with faces; (b) that the same pattern of results emerged when knowledge about people known personally to the patient was taken into account. Results consistent with Haslam *et al.*'s (60) objections to the IAC model were obtained in a group of investigations conducted in normal subjects by Hanley *et al.* (61), Damjanovic and Hanley (62), Bredart *et al.* (63), Hanley and Damjanovic (64) and Barsics and Brédart (65-66) and in Gainotti's (52) above mentioned review of the patterns of famous people recognition disorders shown by patients with right and left anterior temporal lesions. Hanley *et al.* (61) examined in detail the situation in which a subject finds a face or a voice familiar, but is unable to retrieve any biographical information about the person ("familiar-only experiences"), asking undergraduate students to identify a set of celebrities, from either their voices or their faces.. They found that in the voice condition subjects made significantly more "unfamiliar" decisions and gave significantly more familiar-only responses than the subjects in the face condition. These results created problems for the IAC model because if PINs provide a modality-free gateway to a single system storing semantic information about people, and if familiar-only responses reflect a block between the PINs and this semantic store, there would be no reason to expect that the number of familiar-only responses would be greater for voices than for faces. Hanley and Turner (67) tried to account for these unexpected findings, by hypothesizing that the poorer recall of semantic information from voices than from faces considered as familiar might have been due to the overall lower level of familiarity in the voice than in the face conditions. However, subsequent studies (62-66) confirmed and extended Hanley *et al's.* (61) results ,showing that even if the overall level of recognition is matched in the face and voice condition by presenting blurred faces, subjects still recall significantly less episodic and semantic information from familiar voices than from blurred familiar faces. Furthermore Barsics and Brédart (66) have shown that the advantage of faces over voices can be confirmed comparing the participants' ability to associate semantic information with newly learned faces and voices in very well-controlled conditions..

The prediction made on the basis of the IAC model in the Gainotti's (52) review was that, if PINs provide a modality-free gateway to a single amodal person-specific semantic system, then a similar amount of semantic information should be retrieved in response to face and name cues in right and left temporal lobe patients showing a relatively intact familiarity judgment, because these patients should also have an intact PIN. Results of the review showedthat, on the contrary, right ATL patients exhibited a selective difficulty in accessing person-specific information from faces, regardless of the level of impairment of their familiarity feelings. The same dissociation between an impaired ability to access person-specific information from faces and an intact ability to access the same information from names, in spite of a relatively intact face familiarity judgment, wasalso reported by Anaki *et al.* (68) in a patient (DBO) who showed an associative form of prosopagnosia as a consequence of a left occipital infarct.

Thus, the results of all these investigations, conducted in normal subjects and in patients with focal brain lesions areat variance with models which assume that PINs provide a modality free gateway to a single system in which semantic information about people is stored. These results, indeed, consistently show: (a) that in normal subjects access to PINs is more difficult from familiar voices than from equally familiar faces and (b) that right ATL patients show a selective difficulty in accessing person-specific information from faces, even if their familiarity judgments are intact.

7. FORMAT OF PERSON-SPECIFIC KNOWLEDGE IN RIGHT AND LEFT TEMPORAL LOBES

As we saw in the introductory section of this survey, according to general modular cognitive models (e.g. 9-17), the format of semantic representations (which are accessed through the structural descriptions), is abstract and amodal, with no trace of the previous sensory-motor experiences. Alternative theoretical models of the functional bases of conceptual activity (e.g. 69-71), countered the notion of abstract and amodal semantic representations, and suggested that conceptual knowledge "keeps the flavour" of the sensory-motor information through which it has been acquired. One of the cornerstones of the debate between supporters of these two general cognitive models turned around the hypothesis that dissociations in access to the semantic representation through the visual and the verbal modalities might be due to the 'perceptual affordances' of objects, namely to the perceptual features that might "suggest" which actions can be performed with the seen objects (72), allowing 'privileged accessibility' from vision to part of the semantic representation (16). In Snowden *et al.'s* (53) previously mentioned paper, , the authors argued that a fine-grained investigation of the person-specific semantic impairment obtainable from visual (face) and verbal (name) stimuli in patients with degenerative lesions of the right and left ATL could contribute to clarifying the debate concerning the 'unitary'(abstract-amodal) or 'non-unitary' (concrete multisensory vs verbally-coded) format of semantic representations. These authors reasoned that, since people's faces and names are arbitrary, studying person-specific semantic information obtainable from visual (face) and verbal (name) stimuli in patients with degenerative lesions of the right and left ATL might be a valuable way of addressing the unitary vs non-unitary semantic systems controversy, ruling out the possible influence of the perceptual affordances of objects. Results of their study showed that semantic information accessed through face and name are different depending on the prevalent side of atrophy and that an important overlap exists between results obtained with famous people and with categories of objects. Semantic dementia patients with predominantly left temporal lobe atrophy identified faces better than names and performed better on the picture than on the word version of the semantic memory 'Pyramids and Palm Trees' test (73), whereas patients with right temporal lobe atrophy showed the opposite pattern of performance. These data were considered as incompatible with a unitary abstract model of semantic memory. One problem with this study, however, was that due to the rarity of this disease the number of patients reported by Snowden *et al.* (53) was relatively small, thus paired comparisons between patients with right and left ATL atrophy seldom reached significance.. In the previously mentioned review of the patterns of famous people recognition disorders shown by patients with right and left anterior temporal lesions, Gainotti (52) confirmed the Snowden *et al.*'s (53) hypothesis This author found that the ratio between the amount of person specific information available from faces and names was more imbalanced in right than in left ATL patients. To be sure, the loss of personal information was greater from faces than from names in about 60% and equal across modalities in 30% of the right ATL patients; by contrast, within the left ATL patients, the loss of semantic information was greater from name in less than 30% and equal across modalities in more than 50%. An argument that could be raised against these results (and the results of the same review concerning the prevalence of the right hemisphere in the generation of modality-specific face familiarity feelings) was the observation of Haslam *et al.* (56) that in normal subjects access to biographical information as well as familiarity judgements is more accurate in response to names than to faces. As a similar trend was also observed in in Snowden *et al.'s* (53) control subjects , this problem too was taken into account in the study in which Gainotti *et al.* (57) administered the Bizzozero *et al.*'s (58-59) tests to two patients, showing a selective mild difficulty of familiar people identification and naming due to a predominantly right and left ATL atrophy. In Bizzozero *et al.*'s (58-59) study, the semantic interviews aimed to assess the person identification were restricted to the faces and names correctly judged as familiar by the patient and therefore to people whose PINs should have been unimpaired. Therefore, discrepancies between results obtained from faces and names with this procedure shouldpoint to a different format of the semantic representation accessed through these different channels and could not be explained on the basis of methodological inconsistencies. Data obtained in the right ATL patient by Gainotti *et al.* (57) confirmed the results of Snowden *et al.* (53) and of the previous Gainotti's (52) review, because this patient showed was prevalently impaired on person specific information available from faces rather than from names also for people who (being recognized as familiar from their face and name), should be normally represented at the PINs level. Taken together, data obtained by Snowden *et al.* (53) and our results strongly suggested that semantic knowledge of famous people is not represented in an 'amodal format' in both temporal lobes, but in a pictorial format in the right and in a verbal format in the left temporal lobe. Furthermore the Snowden *et al.*'s (53) observation that semantic dementia patients with predominantly right temporal lobe atrophy perform worse on the picture than on the word version of the semantic memory 'Pyramids and Palm Trees' test (73) suggest that this different format is not limited the semantic representation of famous people, but also extends to other conceptual domains. This suggestion is supported by both behavioural and neuroimaging data, that I will not take into account here, because they are not directly relevant to the specific topic of this review and were surveyed in a recent paper (74).

8. GENERAL DISCUSSION

Data summarized in the previous sections of this review clearly show that strictly modular models in general, and the IAC model of familiar people recognition in particular are unable to account for experimental and clinical data, showing that: (a) cross-communications exist between channels of person recognition before the level of the PINs; (b) these cross-communications concern only the perceptual channels processing faces and voices and not the linguistic channel concerning people's name; (c) familiarity feelings are not generated at the PIN's level, but are modality-specific and prevail at the level of the right hemisphere; (d) PINs are critical for the retrieval of person-specific semantic information, and do not simply provide a modality-free gateway to a single semantic system, where information about people is stored in an amodal format; (e) person-specific knowledge, accessed through the modality-specific recognition units is not stored in a unitary, amodal semantic system, but in a sensory-based format in the right ATL and in a verbal format in the left temporal lobe. Furthermore, the data reported in this review demonstrate the existence of important asymmetries between the right and the left hemisphere with respect to the following points:

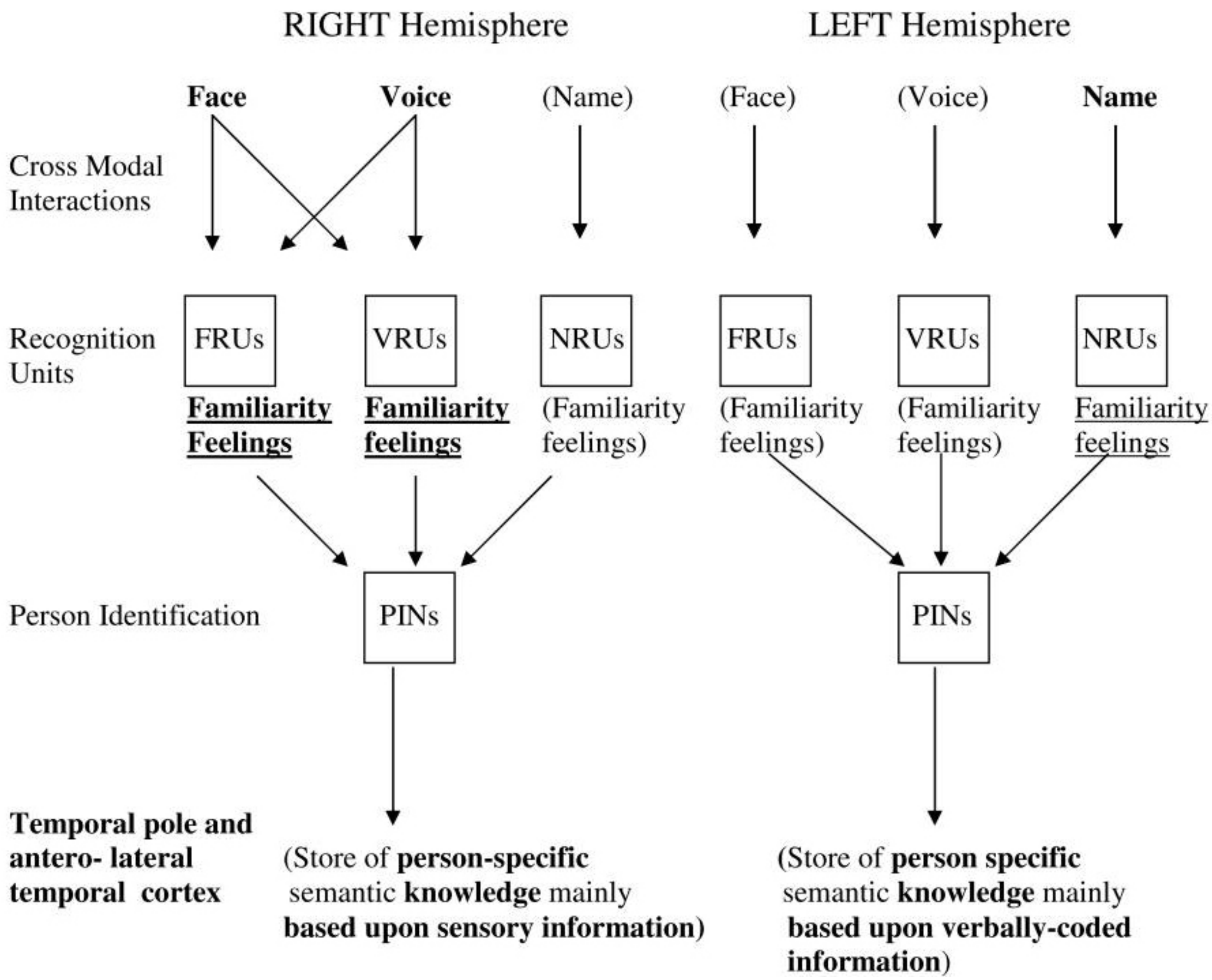

Figure 1. Main differences between the right and left hemisphere with respect to the communications between different channels of person recognition, the locus of generation of modality-specific familiarity feelings and the format of person-specific semantic information.

(1) the existence of communications between face and voice channels of person recognition before the level of the corresponding PINs in the right hemisphere; (2) the generation of modality-specific familiarity feelings for faces and voices in the right hemisphere ; (3) the format of person-specific semantic knowledge, which is mainly based on visual-auditory integration in the right hemisphere and on verbally-coded information in the left hemisphere. All these inter-hemispheric difference are reported schematically in Figure 1.

In this figure bi-directional arrows from the modality-specific recognition units to the PINs have been depicted to explain the highly consistent findings of cross-modal face-name semantic/associative priming effects observed in familiarity judgment tasks by Young *et al.* (75), and by Schweinberger (76).

Taken together, these data seem to suggest that strictly sequential and modular cognitive models cannot explain the complexity and the heterogeneity of the brain processing of perceptual information and of the construction of conceptual representations.

In particular, data summarized in this review are inconsistent with two important assumptions of the cognitive models: (a) the modular assumptions of domain specificity and encapsulated nature of the channels of familiar people recognition; (b) the assumption of a complete discontinuity between the lower level perceptual channels and the higher level person-specific representations, which are stored in a unitary, amodal, person-specific semantic system. The first assumption is at variance with data gathered by several authors (e.g. 39-40, 47-51), who showed the existence of communication between face and voice channels of person recognition before the level of the corresponding PINs. The second assumption is at variance with results of investigations (e.g. 52-53, 74, 77) which have shown that the semantic information accessed through faces and names in SD patients is different depending on the prevalent side of atrophy and that an important overlap exists between results obtained with famous people and with categories of objects.

More in general, the current cognitive models of familiar people recognition do not take into account the differences that exist between the right and the left hemisphere in both the perceptual and the conceptual domains. The former plays a leading role in the more basic sensory-motor activities, (78), in the automatic generation of familiarity feelings (79) and in the construction of a sensory-motor conceptual knowledge mainly based on the perceptual attributes of objects and on the actions performed with them (77). The latter is dominant for language and shapes, through this powerful tool, the previously acquired sensory-motor conceptual knowledge (80-82), allowing concepts to lose their surface similarities to be generalized on the basis of verbally acquired abstract criteria.

These characterizations of the right and left hemisphere processing mechanisms can explain some of the previously mentioned clinical and experimental data that cannot be explained by current cognitive models of familiar people recognition.

Thus, the existence of cross-communications before the PINs level between the channels that process faces and voices, but not faces and names, can be explained by assuming: (a) that language may be important for the full development of the PINs; (b) that an integration between faces and voices may contribute to this development in the pre-linguistic period, during our earliest experiences with personally relevant people; (c) that this integration may be built in the right hemisphere because it matures before the left hemisphere from both the structural and the functional point of view (83- 85). In this perspective, the prevalent sensory-motor organization of the right hemisphere and of the corresponding cross-modal integrations could be considered as a consequence of the 'First come, first served' principle (84), according to which, the right and left hemispheres tend to remain linked in later stages of processing to the mechanisms in which they had played a dominant role in earlier stages of the human development.

In a similar manner, the fact that familiarity feelings are modality-specific and prevail at the level of the right hemisphere is consistent with the above mentioned model of a rather primitive, sensory-motor organization of the right hemisphere. The generation of familiarity feelings is, indeed, an automatic process, elicited by the implicit recognition of a significant stimulus and contributing to its further processing. Its prevalence in the right hemisphere is in keeping with the right hemisphere dominance of two other important automatic mechanisms: (a) the exogenous component of the spatial orienting of attention, which plays a crucial role in the most important right hemisphere syndrome, namely unilateral spatial neglect (86-88); (b) the automatic, unconscious processing of spontaneous emotions, for which the dominance of the right hemisphere has been repeatedly stressed (89-91).

The final results that I would stress here (because they are also consistent with the different organization of the right and left hemisphere that I have just proposed), are those obtained by Snowden *et al.* (53) and Gainotti (52 and 57), studying the different semantic information accessed through faces and names in SD patients whose ATL atrophy prevailed on the right or left side. These results show, indeed, in keeping with the proposed characteristics of the right and left hemisphere functional organization, that the format of person specific and general knowledge represented in the right and left ATLs is different and is mainly based upon perceptual (facial and vocal) features at the right hemisphere level and upon more abstract, verbally coded information in the left hemisphere semantic-lexical knowledge.

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