WHICH COMPONENTS OF FAMOUS PEOPLE RECOGNITION ARE LATERALIZED? A STUDY OF FACE, VOICE AND NAME RECOGNITION DISORDERS IN PATIENTS WITH NEOPLASTIC OR DEGENERATIVE DAMAGE OF THE RIGHT OR LEFT ANTERIOR TEMPORAL LOBES

ABSTRACT

We administered to large groups of patients with neoplastic or degenerative damage affecting the right or left ATL, the ‘Famous People Recognition Battery’ (FPRB), in which subjects are required to recognize the same 40 famous people through their faces, voices and names, to clarify which components of famous people recognition are lateralized. At the familiarity level, we found, as expected, a dissociation between a greater impairment of patients with right ATL lesions on the non-verbal (face and voice) recognition modalities and of those with left ATL lesions on name familiarity. Equally expected were results obtained at the naming level, because the worse naming scores for faces and voices were observed in left-sided patients. Less foregone were, for two reasons, results obtained at the semantic level. First, no difference was found between the two hemispheric groups when scores obtained on the verbal (name) and non-verbal (face and voice) recognition modalities were account for. Second, the face and voice recognition modalities showed a different degree of right lateralization. All group of patients showed, indeed, both at the familiarity and at the semantic level, a greater difficulty in the recognition of voices regarding faces, but this difference reached significance only in patients with right ATL lesions, suggesting a greater right lateralization of the more complex task of voice recognition. A model aiming to explain the greater right lateralization of the more perceptually demanding voice modality of person recognition is proposed.

1. INTRODUCTION

A fundamental biological function of human beings is the identification of individuals belonging to their social group or who are simply well known for their achievements or specific abilities. A complex, multicomponent and multimodal recognition system, mainly based on visual (face), auditory (voice), and verbal (name) recognition channels, has, therefore, evolved in the brain, to quickly and efficiently allow this individual identification. The first papers which investigated neuropsychological aspects of individual person recognition were published after the 1980s and usually focused on faces (e.g. Glass et al., 1985; Young et al., 1985; Vokey & Read, 1992). In those years Malone et al (1982) published the first paper dissociating familiar and unfamiliar cognitive phenomena in a neurological context, as manifest in face processing and Van Lancker (1991) reviewed the main observations on the status of personal relevance (familiarity itself) in brain processing. As for voice recognition disorders, Van Lancker. & Canter (1982) published the first paper identifying this selective defect and coined for it the term "phonagnosia". Subsequent papers comparing familiar and unfamiliar voice processing were published by Van Lancker & Kreiman (1987). Much more recently Kreiman & Sidtis (2011) described a full-blown model of voice processing in the normal brain and Stevenage (2018) published a review of neuropsychological, clinical and empirical findings allowing to distinguish familiar from unfamiliar voice processing.

Cognitive models of familiar people recognition: The most influential cognitive models of familiar people recognition (e.g. Bruce and Young, 1986; Burton et al. 1990; Bredart et al. 1995; Valentine et al., 1996 and Burton et al., 1999) make a distinction between some lower level perceptual processes, leading to the formation of modality-specific representations, a locus of convergence of the output of these processes, and a store of the corresponding semantic (biographical) information and of the related proper name. The perceptual processes concern the visual and auditory channels through which a seen face, a heard voice and a (oral or written) name are mapped onto the corresponding invariant representations within specific recognition units for faces (FRUs) voices (VRUs) and names (NRU). The brain structures involved in the early stages of face recognition are located in the inferior occipito-temporal cortices [occipital face area ('OFA' of Gauthier et al., 2000) and fusiform face area (‘FFA’ of Kanwisher et al., 1997)], whereas the structures involved in the first stages of voice recognition, namely the so-called temporal voice areas (TVAs), are located in the superior temporal sulcus and gyrus (e.g. Belin et al., 2000; Belin et al., 2002, Pernet et al., 2015). 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, voice and name, giving access to the corresponding semantic information. From the subjective and behavioural point of view, the first marker of an ongoing process of person recognition is represented by the generation of a ‘familiarity feeling’, which arises, according to Bruce and Young (1986), when a perceived face (or voice or name) matches a representation, stored in the corresponding RU or, according to Burton et al. (1990), when PINs reach a given activation threshold.

Localization and lateralization of brain structures involved in people recognition: Several data (e.g. Sergent et al., 1992; Tranel et al., 1997; Sugiura et al., 2001; Belin & Zatorre, 2003; Gainotti, 2007a; Gainotti & Marra, 2011; Blank et al., 2014; Collins & Olson, 2014; Liu et al., 2016) have shown that the anterior temporal lobes (ATLs) are the locus of convergence of modality-specific information allowing person recognition and of the corresponding semantic information.

A growing body of experimental and clinical evidence have suggested that a different hemispheric specialization exists for different modalities of person identification, with a prevalent right hemisphere (RH) lateralization of face and voice recognition and a prevalent left (LH) lateralization of (verbal) name recognition. Furthermore, 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. For instance, experimental studies (e.g.

Kanwisher et al.,1997 and McCarthy et al., 1997) have shown that fusiform activation for faces is greater in the right than in the left hemisphere, but clinical and experimental studies (e.g. Sergent et al., 1992; Tranel et al., 1997; Belin & Zatorre, 2003; Gainotti, 2007a; Gainotti & Marra, 2011; Blank et al., 2014; Collins & Olson, 2014; Liu et al., 2016) have also shown that multimodal person recognition disorders are usually due more to right than to left ATL lesions. Several studies, conducted either in subjects with temporal lobe epilepsy (TLE) or in patients with semantic dementia (SD) have tried to clarify the meaning of these hemispheric asymmetries, distinguishing different kinds of person recognition defects in patients with damage of the right and left temporal lobes. More precisely, investigations conducted on patients with TLE took mainly into account the distinction between face recognition and people naming, whereas research carried out in SD patients with predominant left or right temporal lobe atrophy chiefly contrasted knowledge of famous faces and names. Results of all these studies were, however, rather inconsistent. Most investigations dealing with TLE patients (e.g. Seidenberg et al., 2002; Glosser et al., 2003; Drane et al., 2008 and 2013) claimed, in fact, that left anterior temporal lesions disrupt access to the names of known people, whereas right ATL lesions impair recognition of familiar faces, but different results were reported by other researchers. Thus, Viskontas et al. (2002) showed that patients with right TLE are impaired at recognizing famous individuals by their faces but not by their names and are impaired at face familiarity judgments, whereas both right and left TLE patients are impaired at naming famous faces and providing semantic information about famous people. On the other hand, Griffith et al. (2006), who examined the correlations between metabolic measures of the temporal poles and performance on the Famous Faces Task (Greene & Hodges, 1996) showed that the left temporal pole is associated with lexical and semantic retrieval of knowledge of famous people, whereas correlations with the right temporal pole were not significant. Finally, Rice et al. (2018), using a methodology very similar to that of Drane et al. (2008 and 2013), showed that left post-surgical TLE patients were less accurate at naming people, whereas both left and right TLE patients were equally impaired at recognizing famous faces compared with control participants. The interest of these investigations is, however, mitigated by the fact that persons with TLE typically have other or extensive brain damage.

As for studies conducted in patients with SD, Snowden et al. (2004) compared knowledge of famous faces and names in 10 patients with a predominant atrophy of the left temporal lobe and in 3 patients in whom right temporal atrophy predominated. The left > right atrophy group identified faces better than names and reported more familiarity for faces than for names, whereas patients with right > left atrophy showed the converse pattern (but the latter paired-comparisons did not reach statistical significance because of the very small group size). Gainotti et al. (2010) administered tests of face and name recognition and identification to two patients (VL and StG), showing a selective atrophy of the anterior parts of the right (VL) and left (StG) temporal lobes. The first patient (VL) showed a very impaired familiarity for faces, contrasting with a spared familiarity for names, and an impairment of semantic retrieval greater from faces rather than from names, whereas the opposite pattern of results was obtained by patient StG. Gefen et al. (2013) examined the anatomical correlates of naming vs recognition of faces in patients with primary progressive aphasia and showed that, despite the widespread distribution of atrophy in this disease, face naming impairments correlated with atrophy of the left anterior temporal lobe while face recognition impairments correlated with bitemporal atrophy. Luzzi et al. (2017) investigated famous face and voice recognition in Alzheimer's disease (AD) and in SD patients and checked if the corresponding recognition disorders could be related to the prevalent side of temporal lobe atrophy They showed that face and voice recognition disorders prevailed in SD patients with right temporal lobe atrophy. Finally, Borghesani et al. (2019) analyzed data from a large sample of patients with neurodegenerative disorders (including more than 40 patients with a Semantic variant of Primary Progressive Aphasia), They correlated, using voxel-based morphometry, whole-brain grey matter volumes with scores on three experimental tasks targeting respectively: (a) familiarity judgment, (b) semantic/biographical information retrieval, and (c) naming. Their results showed that performance in naming and semantic association significantly correlated with grey matter volume in the left ATL, whereas familiarity judgment correlated with integrity of the right ATL. Taken together, results obtained in patients with TLE and in SD patients with a prevalent atrophy of the right and left temporal lobe clearly indicate that naming people is predominantly disrupted in patients with left ATL damage. They do not clarify, however, if person recognition disorders through face and voice are only due to a prevalent disruption of the corresponding familiarity feelings (as could be suggested by results obtained by Viskontas et al., 2002 and Rice et al., 2018 in TLE patients and by Borghesani et al., 2019 in patients with neurodegenerative lesion) or are also due to a more properly semantic defect (as could be suggested by results obtained by Drane et al., 2008 and 2013 in individuals with TLE and by Gainotti et al. 2010 in SD patients).

Methodological problems which could explain these contrasting results: These conflicting results were probably in part due to methodological inconsistencies, because lack of face familiarity was considered in some studies as a component of recognition disorders and in other investigations as an autonomous factor. Furthermore, semantic identification was based in some investigations (e.g. Drane et al., 2008 and 2013; Snowden et al., 2004; Rice et al., 2018) on verbal description of occupation and in other studies (e.g. Seidenberg et al., 2002; Griffith et al., 2006; Borghesani et al., 2019) on results obtained matching faces of famous people according to their profession. Finally, assessment of semantic (biographical) information was often made only on (face or voice) stimuli rated as familiar (e.g. Seidenberg et al., 2002; Drane et al., 2008 and 2013; Rice et al., 2018), but in other cases (e.g. Griffith et al., 2006; Gainotti et al., 2010; Borghesani et al., 2019) it was not limited to familiar stimuli. The aim of the present investigation therefore consisted in trying to clarify some of these problems, by administering to large groups of patients affected by neoplastic or degenerative disease affecting the right or left ATL, the 'Famous People Recognition Battery' (FPRB), in which subjects are required to recognize the same 40 famous people through their faces, voices and names (Quaranta et al., 2016; Piccininni et al.,2018). The decision to put together patients with neoplastic and degenerative lesions was due to the difficulty of gathering in a reasonable time frame a number of patients affected by neoplastic or degenerative disease allowing to obtain significant results on such a complex research program. Three steps of the recognition process are, indeed, taken into account for each recognition modality (face, voice and name) in the FPRB. The first step consists in showing all stimuli presented in a given modality (e.g. all faces) asking for each of them a judgment of familiarity. The second step consists in asking general and specific semantic information about the professional category of each famous person whose face, voice or name had been judged as familiar and the third step consists in asking to provide the corresponding name. The FPRB therefore allows to obtain familiarity, semantic and naming scores through faces, voices and names of the same 40 famous people.

On the basis of the specific aspects of person recognition that can be orderly investigated through the FPRB, we have formulated as it follows the distinct aims of our research:

(1) to assess the components of famous people recognition (familiarity, semantic and naming) through face, voice and name, that are disrupted depending on the side of ATL damage;

(2) to evaluate if defective recognition of famous people through non-verbal (face and voice) modalities is due to familiarity defects;

(3) to evaluate if the differences possibly observed between individuals with right or left ATL damage at the group level could be confirmed on subjects with selective deficits in a single recognition modality

Patients with a selective defect for face or voice (in comparison to name) could, indeed, be considered as particularly representative of the clinical conditions of prosopagnosia and phonagnosia that have attracted the attention of researchers on the right lateralization of face voice recognition processes. A consistency between results obtained on unselected groups of patients with left and right ATL lesions and in patients with a selective defect for face or voice (in comparison to name) could, therefore, strengthen the validity of results obtained in unselected samples of patients with left and right ATL lesions.

2. MATERIALS AND METHODS

2.1. Participants

The investigation was carried out on 43 patients, 11 affected by semantic dementia, and 32 affected by temporal tumors. Subjects included in the present study were recruited by the Neuropsychology Unity of the Policlinico Gemelli in Rome, the Neurology Institute of the Università Politecnico delle Marche – Ancona, and the Center for Mind/Brain Sciences, Rovereto. Due to organizational problems, all these patients carried out the 'face' and the 'voice' sections of the FPRB, whereas only 30 of them could be given the 'name' section.

A clinical history, neuropsychological profile, structural neuroimaging (MRI or CT scan) and 18 FDG positron emission tomography (PET) were gathered for each subject. Patients affected by Semantic Dementia fulfilled Gorno-Tempini et al. (2011) and Rascovsky & Grossman (2013) criteria. All of them exhibited temporal lobe atrophy on structural (MRI) and in the PET imaging, with a clearly prevalent asymmetrical pathology revealed by atrophy and decreased FDG uptake. The other patients, 21 men and 11 women, [mean age 41.75 (SD=12.71, range=21–68), mean education 13.96 years (SD=3.01, range=8–18)] were affected by a glioma, which was a high-grade (HGG) in 24 patients, and a low-grade (LGG), namely an oligodendroglioma, in eight. LGG were equally distributed in the left and right hemisphere. MRI showed an involvement of the right or left temporal lobe; all underwent awake or asleep surgery and were evaluated between three and six months after surgery. The onset symptom was a generalized seizure in 18 cases, a partial seizure in six, while in three was persistent headache, in two anomia, one had gait disorders, one cacosmia, one movement disorders. Patients with left temporal or right temporal glioma did not differ in age [t

(30)=0.85, p=0.4] or years of education [t (27)=0.40, p=0.68], or tumor size [U=242, p=0.76].

Exclusion criteria were: any prior neurological disease affecting CNS (e.g., brain injury or stroke); current or past history of alcohol or drug abuse; current depression or major psychiatric diseases; chronic medical conditions potentially affecting CNS (e.g., hypothyroidism, renal or hepatic failure), concomitant medical conditions that could cause or influence cognitive impairment (such as, but not limited to: liver or renal failure; vitamin B12 deficiency; hypothyroidism; etc.). All patients were native Italian. All participants and their caregivers gave their consent and the study was carried out in accordance with the Helsinki declaration.

2.2. Neuropsychological evaluation

All patients initially underwent an extensive evaluation of long and short term memory, language, attentional-executive and visuo-praxic functions (see Gainotti et al., 2020 for details, and Supplementary table 1 for details on the sample)

Patients affected by neurodegenerative disorder and oncologic pathology were subjected to the Famous People Recognition Battery (FPRB) (Quaranta et al., Piccininni et al., 2018) to assess recognition and identification of famous persons by three different modalities, visual (face), auditory (voice) and verbal (name) way, together with a people naming task (Piccininni et al 2020). Each participant underwent three separate sessions over a gap of at least two months, and in each session one modality was tested, in a randomized order.

2.2.1. ***The Famous People Recognition Battery*** is composed by three tests of recognition of the same 40 famous people by their face, voice or name, mixed to 20 faces, voices and names belonging to unknown persons.

In the *Face Recognition test (FA-REC)* each subject was requested to recognize the famous 40 faces distinguishing them from the faces of 20 unknown people. The patient had to look at each face and to provide a familiarity judgment. The familiarity score was obtained by summing the number of faces correctly identified as famous or non-famous (score range: 0-60); a false alarm score (number of non-famous faces identified as famous; score range: 0-20) was also obtained. If the answer concerning the familiarity judgment was positive and the face belonged to a famous person, semantic information was probed by means of three identification questions. The first two questions had a multiple choice format and explored the general and specific categories to which famous persons belonged. The third question was open and the subject was asked to provide univocally identifying information about the person. One point was assigned to each correct answer (semantic score for each face: 0-3; total semantic score: 0-120). Finally, subjects were requested to say the proper name of the person to whom the famous face belonged. One point was assigned to each correct proper name (naming score range: 0-40). In addition to the familiarity score and false alarms score, we also considered the number of famous face correctly judged as familiar (hits: score range 0-40).

In the *Voice Recognition test (VO-REC)* participants listened to 60 audio fragments, lasting 15 s each, of 40 famous voices (belonging to the same famous persons who entered the FA-REC) along with the fragments of 20 non famous voices. Then familiarity scores (range 0-60), semantic scores (range 0-120), naming scores (range 0-40), false alarms (range 0-20) and hits scores (range 0-40) were obtained. In the *Name Recognition test (NA-REC)*, stimuli were written names of the same 40 Italian celebrities whose faces and voices had been included in the previous tests, mixed with the written names of 20 unknown people. In the same way described before, participants had to judge these names as familiar or not, and were asked for identification of persons recognized as familiar. The scores obtained are familiarity score (range 0-60), false alarms (range 0-20), hits (range 0-40) and semantic score (range 0-120).

2.3. Identification of patients showing a selective defect for face, voice or name

A complementary assessment of hemispheric asymmetries in person identification through different modalities was obtained by taking into account the laterality of lesion in subjects who showed a selective deficit for face, voice and name recognition. To identify these patients, all the familiarity, semantic and naming raw scores obtained by patients on the Famous People Recognition Battery were converted into deciles. Then the discrepancy in deciles scores among the different modalities (e.g. comparing the familiarity score from face with that from name and voice) was assessed for every patient, choosing as criterion a difference in score of at least two deciles between two modalities. Finally, the frequency of patients who showed a selective defect for face, voice or name entered on a contingency table, together with the side of their lesion.

3. STATISTICS

The statistical analyses were carried out with the SPSS statistical package. Since most of the variables were not normally distributed, non-parametric statistics were performed. Comparisons between the mean values of continuous variables were conducted using Mann-Whitney tests.The significance of lesion laterality in patients with selective defects for face, voice or name was assessed by means of chi-squares on the contingency tables.

The effect of side of lesion (SIDE), modality of administration (CONDITION), and their interaction (SIDE X CONDITION) on scores obtained in familiarity, false alarms, hits, semantics and naming was assessed by means of factorial analyses of variance (ANOVA) after Aligned Rank Transformation (Wobbrock et al., 2011) with post-hoc pairwise comparisons (Elkin et al., 2021).

Control for multiple comparisons was performed by applying the False Discovery Rate method (Benjamini & Hochberg, 1995).

4. RESULTS

4.1. Sample description

The descriptive characteristics of the whole sample of 43 subjects are: mean age 49.02 ± 17.160 (range 21-79), mean education 13.12 ± 3.831 (range 5-18), and female subjects = 16 and male subjects = 27. Of these patients, 24 presented a prevalent or complete right-sided lesion and 19 a prevalent or complete left–sided lesion. No differences were observed between right and left-sided patients in terms of age (51.83 ± 17.522 for right-sided patients vs 45. 47 ± 16.463 for left-sided patients |t| =1.223; p=0.228) and education (13.58±3.463 for right-sided patients vs 12.53 ± 4.273 for left-sided patients; |t|=0.875; p=0.388).

Demographic and clinical data of the whole group of patients are reported in Table 1

N.	Age	Education	Sex	Etiology	Side lesion
1	78	17	M	SD	R
2	65	17	M	SD	R
3	65	9	F	SD	R
4	76	8	M	SD	R
5	79	17	M	SD	R
6	79	5	F	SD	L
7	68	5	F	SD	R
8	68	8	F	SD	S
9	65	13	M	SD	R
10	50	13	M	SD	R
11	77	5	F	SD	L
12	38	13	F	Tumor	L
13	43	13	M	Tumor	R
14	57	17	F	Tumor	R
15	68	8	M	Tumor	R
16	41	17	M	Tumor	L
17	37	13	F	Tumor	R
18	58	17	M	Tumor	R
19	38	13	F	Tumor	R
20	38	13	F	Tumor	R
21	58	13	F	Tumor	L
22	43	13	M	Tumor	L
23	39	17	M	Tumor	L
24	21	13	M	Tumor	L
25	42	13	F	Tumor	L
26	28	17	F	Tumor	L
27	27	16	M	Tumor	L
28	32	13	M	Tumor	R

29	56	13	M	Tumor	R
30	50	8	M	Tumor	L
31	24	16	F	Tumor	R
32	41	17	M	Tumor	L
33	24	15	F	Tumor	R
34	50	17	M	Tumor	R
35	64	17	M	Tumor	L
36	40	13	M	Tumor	L
37	25	17	M	Tumor	R
38	40	8	M	Tumor	L
39	32	17	M	Tumor	L
40	36	8	M	Tumor	L
41	30	13	M	Tumor	R
42	59	11	F	Tumor	R
43	59	18	M	Tumor	R

Table1. Demographic and clinical characteristics of left (L) and right (R) patients. Education is reported in years. F=female, M=male. SD= semantic dementia.

4.2. Comparison between the mean scores obtained by left and right sided patients on the various components of FA-REC, VO-REC and NA-REC.

4.2.1. General comparison

A comparison between the mean scores obtained by patients with right and left ATL damage on familiarity, semantic and naming tasks on face, voice and name stimuli is reported in Tables 2 and (as supplementary material) in Graphs 1, 2 and 3.

	Side of lesion			
	R	**L**		
Familiarity score			**P**	**FDR**
Face	52.48 (±7.954)	56.31 (±3.773)	**0.017**	0.068
Voice	38.43 (±8.701	42.94 (±9.594)	**0.050**	0.133
Name	57.00 (±2.670)	53.69 (±7.920)	0.238	0.317
Semantic Score				
Face	86.61 (±30.365)	81.05 (±22.285)	0.178	0.285
Voice	43.65 (±30.534)	55.31 (±20.624)	0.255	0.291
Name	87.76 (±27.788)	80.69 (±29.859)	0.402	0.402
Naming				
Face	24.5 (±11.494)	6.7 (±6.194)	**0.000**	**0.000**
Voice	10.54 (±8.342)	5.78 (±0.164)	**0.093**	0.186

Table 2. Mean naming scores with standard deviations in brackets, R= right ATL lesions; L=left ATL lesions.
FDR: p-value corrected according to the False Discovery Rate method.

In the comparison between the mean scores of patients with right and left ATL lesions, the worse performance of the right brain-damaged patients reached significance on familiarity scores by face, and voice, whereas non-significant was the worse performance of the left brain-damaged patients on familiarity scores by name.

On the other hand, no laterality effects were observed, irrespective of the modality, when the semantic scores were taken into account. No differences were observed on the semantic score for face, voice, and name.

Clear laterality effects, in a direction opposite to those observed in the assessment of familiarity, were obtained when we took into account naming scores for faces and voices, because in this case better performances for both modalities were observed in right-sided patients.

4.2.2. A separate analysis of trends observed in patients with neoplastic and degenerative lesions

Since only mild significant differences have been observed between patients with right and left ATL lesions in our whole pathological sample, no additional information could be obtained by a separate analysis of results obtained in patients with neoplastic and degenerative lesions. However, we compared the mean values of scores obtained in these two subgroups of patients, to check if in each of them could be observed a similar trend of patients with right ATL lesions to obtain worst results on face and voice and of those with left ATL lesions to obtain worst results on name stimuli. Results of this comparison are reported in Table 3.

	Degenerative lesions		Neoplastic lesions	
	R	**L**	**R**	**L**
Familiarity score				
Face	47.00 (±11.45)	51.00 (±5.21)	55.22 (±3.45)	57.32 (±4.86)
Voice	35.86 (±8.701	41.33 (±9.594)	39.56(±8.41)	43.25(±10.70)
Name	56.10 (±2.670)	49.60 (±13.460)	57.78(±6.17)	54.00(±6.20)
Semantic score				
Face	87.61 (±24.365)	81.35 (±22.285)	77.49(±25.57)	84.58(±15.483)
Voice	27.65 (±17.814)	35.31 (±20.624)	40.15(±18.41)	49.76(±7.48)
Name	78.59 (±23.987)	74.63 (±19.985)	90.14(±23.95)	77.86 (±24.8)
Naming				
Face	14.5 (±11.494)	3.81(±6.34)	26.7 (±9.41)	14.65(±8.76)
Voice	7.54 (±8.342)	1.38 (±2.54)	12.7 (±6.16)	10.70(±8.27)

Table 3. Separate analysis of scores obtained by patients with neoplastic and degenerative lesions

Data reported in Table 3 show that very similar trends have been shown on familiarity and naming tasks by patients with right and left ATL lesions of degenerative and neoplastic nature. On familiarity scores, the worst results on face and voice stimuli have been, indeed, obtained by patients with right-sided lesions, whereas on naming tasks the lowest scores have been obtained by patients with left-sided lesions in both aetiological groups. The only difference between these groups resides in a greater overall impairment of semantic dementia patients across the familiarity, semantic and naming levels of famous people recognition and across the right or left side of the lesion.

4.2.3 Analytical comparison of Familiarity components (Hits and False Alarms)

The number of hits and false alarms (FA) observed in patients with right and left ATL lesions in each recognition modality is reported in Table 4.

	Side of lesion			
	R	**L**	**p**	**FDR**
Hits				
Face	34.55 (±8.377)	37.15 (±3.004)	0.444	0.533
Voice	22.91 (±10.462)	26.12 (±7.445)	0.336	0.504
Name	38.05 (±2.512)	34.01 (±7.788)	**0.027**	0.081
False Alarms				
Face	2.03 (±2.261)	0.84 (±1.344)	**0.076**	0.152
Voice	4.46 (±5.266)	1.10 (±1.185)	**0.015**	**0.090**
Name	1.05 (±2.135)	0.30 (±0.480)	0.815	0.815

Table 4. Hits and false alarms mean score; R= right ATL lesion; L=left ATL lesion. FDR: p-value corrected according to the False Discovery Rate method.

A very mirror pattern of results was obtained by patients with right and left ATL lesions when the number of hits and FA observed on familiarity judgements was separately computed for each recognition modality. The number of hits was, in fact, lower in patients with right ATL lesions for faces and voices and lower in patients with left-sided lesions for famous names, but only in this last case the difference was statistically significant. On the contrary, the number of FA was significantly higher in patients with right ATL lesions on faces and voices and non-significantly lower for famous names in patients with left-sided lesions.

Furthermore, since FA could be a consequence of reduced inhibitory control, we assessed the correlations between FA scores and scores obtained on neuropsychological tests assessing executive functions. We did not observe any significant correlation (Supplementary Table 2).

4.2.3. Factorial ANOVA aiming to evaluate the effects of laterality, non-verbal recognition modalities and the interactions between these two main factors.

Since results reported in the previous sections seemed to suggest that both at the familiarity and at the semantic level an interaction could exist between laterality effects and scores obtained on the non-verbal (face and voice) recognition modalities, we tried to check this possibility by means of factorial ANOVAs concerning familiarity scores, the number of hits and FAs, semantic scores and naming scores on face and voice stimuli in right and left ATL lesions. The indipendent variables entered in the general model were side lesion and the face and voice modalities. The effects of SIDE ($F_{5,78}$= 22.62; p<0.001), CONDITION ($F_{5,78}$=19.83; p<0.001) and SIDE X CONDITION ($F_{5,78}$=5.099; p<0.001) were all highly significant.

The p values of the analysis of variance can be summarized as it follows:

Familiarity scores: in the univariate model for familiarity, SIDE ($F_{1,80}$=8.920; p=0.008) and CONDITION ($F_{1,82}$=99.100; p=0.000) were significant, but the interaction between them was not significant ($F_{1,81}$=0.844; p=0.350). At the post hoc, however, familiarity was significantly worse from voice than from face in patients with both right and left ATL damage (p=0.000), while no differences in face (p=0.055) and voice (p=0.230) recognition emerged between left and right patients.

False Alarms: the univariate model for false alarms showed an effect of SIDE ($F_{1,82}$=10.040, p=0.002) and CONDITION ($F_{1,82}$=4.132, p=0.045), while the interaction between them was not significant ($F_{1,82}$=2.700, p=0.104). At the post-hoc, the number of FA from voice was significantly higher in right-sided patients (p=0.025).

Hits: in this case, the univariate model was significant for CONDITION ($F_{1,82}$=59.35, p=0.000) only, and post-hoc confirmed that the number of hits was significantly lower from voice than from face both in patients with right and in those with left ATL damage (p=0.000 for both groups); no differences emerged between left and right ATL patients.

Semantic scores: the univariate model showed an effect of CONDITION ($F_{1,82}$=40.97, p=0.000), and post-hoc analyses confirmed that semantic scores were significantly lower from voice than from face in patients with both right and left ATL damage (p=0.000 for right patients and p=0.006 for left patients).

Naming scores: in the univariate model, an effect of SIDE ($F_{1,82}$=43.92, p=0.000), CONDITION ($F_{1,82}$=31.86, p=0.000) and SIDE X CONDITION ($F_{1,82}$=17.25, p=0.000) was present. At the post-hoc, naming scores were significantly lower from voice than from face in patients with right (p=0.000), but not in those with left ATL lesions (p=0.901).

4.3. Number of patients with right and left ATL lesions showing a selective defect for famous faces, voices or names.

The number of patients with right and left ATL lesions who showed a selective defect in the comparisons face vs name, voice vs name and face vs voice is reported in Table 5.

	Dissociations	Right ATL patients			Left ATL patients			χ^2	p	FDR
Familiarity score	n.patients	n.patients			n. patients					
			face>voice	voice>face		face>voice	voice>face			
comparison face-voice	30	16	8	1	14	2	5	0.621	0.431	0.517
			face > name	name > face		face > name	name > face			
comparison face-name	16	9	1	8	7	5	2	6.112	**0.035**	**0.070**
			voice > name	name > voice		voice > name	name > voice			
comparison voice-name	18	10	1	9	8	6	2	7.901	**0.013**	**0.039**
Semantic score										
			face>voice	voice>face		face>voice	voice>face			
comparison face-voice	25	13	10	3	12	2	10	9.077	**0.003**	**0.018**
			face > name	name > face		face > name	name > face			
comparison face-name	10	3	0	3	7	3	4	1.837	0.475	0.475
			voice > name	name > voice		voice > name	name > voice			
comparison voice-name	15	12	1	11	3	2	1	5.104	0.081	0.122

Table 5. Contingency table in which dissociations between different modalities in familiarity and semantic scores, according to the criteria detailed in paragraph 2.3.of the methodological section, are reported for left and right ATL patients. Face > voice means better performance for faces than for voices FDR: p-value corrected according to the False Discovery Rate method

When the influence of lesion side on familiarity for famous faces, voices and names was assessed in these patients, we found a significant familiarity impairment for people recognition through face and voice (in comparison with name) in patients with right ATL lesions. The number of patients who showed a selective defect for faces (in comparison to names) was, in fact, significantly higher in subjects with right (8 out of a total of 9) than in those with left ATL lesions (2 out of a total of 7) (χ^2=6.112; p=0.035). Analogously 9 right brain-damaged patients out of 10 showed a selective defect for voice (in comparison with name), while only 2 out of 8 left brain-damaged patients showed a similar selective impairment for voices (χ^2=7.901, p=0.013)

On the contrary, no clear influence of laterality of lesion on semantic scores obtained through face and voice in comparison with name was observed in the same patients, even if a trend toward a greater semantic impairment from voice than from name failed just to reach significance in patients with right ATL lesions. As a matter of fact, all 3 patients with right ATL lesions (but also 4 out of 7 with left ATL lesions) showed a selective semantic defect for faces (in comparison to names (χ^2=1.837 p=0.475). A similar selective semantic defect for voices was obtained by 11 out of 12 right and only by 1 out of 3 left brain-damaged patients (χ^2=5.104; =0.081). An unexpected influence of laterality on semantic scores obtained through face (in comparison with voice) was, however, observed in these patients, because 10 out of 13 patients with right ATL lesions, but only 2 out of 12 with left ATL lesions, obtained higher semantic scores on face than on voice (χ^2= 9.077 p=0.003).

1. DISCUSSION

The purpose of the present investigation consisted in trying to evaluate the links between right and left ATL lesions and impairment of different modalities (face, voice and name) and levels (familiarity judgement, retrieval of semantic information and naming) of famous people recognition. Results obtained in familiarity judgements (which correspond to the lowest levels of person recognition), semantic retrieval and in naming (which correspond to the highest levels of person identification) will be orderly considered in our discussion.

Laterality effects obtained in familiarity judgements for face, voice and name.

When the comparison between patients with right and left ATL lesions took into account familiarity judgment for faces, voices, and names, we found, as expected, that familiarity judgments were significantly more impaired in patients with right ATL lesions with famous faces and. famous voices. Unexpectedly, the greater impairment of patients with left ATL lesions was non-significant on famous names, but this could be due to the lower number of patients taken into account for this comparison (30 patients instead of the 43 involved in the right vs left comparison concerning the familiarity of famous faces and voice) or, alternatively, to some subjects reaching ceiling effect. We must acknowledge that at group-level the differences between subjects with damage in the right and left ATL did not survive after correction for multiple comparisons. However, the results followed the same trend in the comparison (with a contingency table) between patients showing a selective deficit in a single modality. Selective familiarity defects for faces and voices were, in fact, significantly more frequent in patients with right ATL lesions, but this time also the selective familiarity defect for famous names was significantly more frequent in patients with left ATL damage. Also consistent with models assuming that familiarity may be mainly mediated, by right ATL structures for faces and voices and by left-sided cortices for famous names are the results obtained taking separately into account the number of hits and of false alarms (FA) in each recognition modality. In this case, patients with right ATL lesions showed a significantly higher number of false alarms both with faces and with voices (and a similar trend was observed for hits), whereas patients with left ATL lesions obtained the opposite result (namely a significantly higher number of hits and a trend in the same direction with FA) with famous names. Furthermore, in this separate analysis of the number of hits and FA, the worst results (namely the lowest number of hits and the highest number of FA) were observed with famous voices in patients with both right and left ATL lesions, showing that familiarity recognition is harder from voice than from both name and face.

Taken together, both laterality effects obtained by patients with unilateral ATL lesions on familiarity judgements for faces, voices and names and the very poor results obtained with famous voices, irrespectively of lesion laterality, are consistent with those of studies that investigated the same effects in normal subjects or in patients with unilateral brain lesions. Glass et al. (1985), Young et al. (1985), Stone and Valentine (2005) and Bourne and Hole (2006), have shown that the right hemisphere is crucially involved in face familiarity decisions in healthy subjects, whereas Belin and Zatorre (2003), Pickering and Schweinberger (2003) and von Kriegstein and Giraud, 2004) have reported a right lateralization of structures involved in the recognition of familiar vs. unknown voices. Consistent with the hypothesis of a right hemisphere dominance for face and voice processing are also results of investigations conducted in patients with unilateral brain lesions. Reviews of face recognition disorders resulting from temporo-occipital vascular lesions (e.g. De Renzi et al., 1994; Gainotti, 2007 b; Gainotti and Marra, 2011) or from atrophy of the ATL cortices (e.g. Snowden et al., 2004; Gainotti, 2007a; Borghesani, 2019) have shown that a selective defect of face familiarity is found in patients with right temporal lesions. Similar results have been obtained by Gainotti (2011) in a review of single case studies of patients with right ATL lesions in which voice recognition disorders had been investigated. On the other hand, Snowden et al.(2004) and Gainotti (2007a) have shown that patients with left ATL atrophy reported more familiarity feelings for faces than for names.

Greater difficulty was shown by our patients in the processing of voice (in comparison with face) stimuli.

Consistent with data from the literature are also the worst results obtained, irrespectively of lesion laterality, by our patients while assessing the familiarity of famous voices in comparison to that of famous faces and names. Data obtained in normal subjects have shown that both familiarity judgment and retrieval of semantic information are more difficult from voices than from the faces of celebrities (Hanley et al., 1998; Hanley and Turner, 2000; Damjanovic & Hanley, 2007; Hanley & Damjanovic, 2009; Barsics & Bredart , 2011 and 2012) and that it is more difficult to evaluate familiarity from their faces than from their names (Haslam et al., 2004; Snowden et al., 2004; Bizzozzero et al., 2007; Piccininni et al., 2018). Several reasons have been advanced to explain the relative weakness of voice in comparison to face recognition. Thus, Young et al. (2020) have noticed that areas involved in voice perception show a lower degree of functional specificity than regions involved in face perception. On the other hand, Schirmer (2018), analyzing emotion perception from face and voice, has underlined the different temporal dimensions of face and voice processing. Faces can, indeed, be discerned from a single snapshot, whereas voices constitute dynamic stimuli for which receivers must integrate information over time. Thus, to tell whether a voice is familiar or not requires more complex processing than to evaluate the familiarity of a face. Furthermore, from a purely behavioral point of view, the visual modality is probably the principal channel through which famous people reach the audience, whilst the exposure to voice is more limited. This hypothesis is partially confirmed by a previous work that our group performed on heathy participants (Piccininni et al. 2017) in which we found that consistency in familiarity judgment and semantic retrieval between faces and voices was influenced by level of exposure. Some results, obtained on the factorial ANOVA for faces and voices in patients with right and left ATL damage, suggested, however, that voice processing is not only more complex and perceptually demanding than face processing, but could also be more strongly lateralized to the right hemisphere.

On this analysis we observed, in fact, that, even if all scores concerning familiarity were worse from voice than from face, when the number of FAs was taken into account this difference reached significance only in patients with right ATL lesions. Data suggesting a stronger right lateralization of voice, in comparison to face have been recently obtained by Papagno et al. (2021) in patients with unilateral temporal lobe tumours and normal subjects tested after anodal tDCS over the left or right ATL.

Less clear laterality effects observed passing from familiarity judgements to the retrieval of semantic information and naming.

Less clear laterality effects were observed when we passed from the lowest to the highest levels of person recognition, namely from familiarity judgements to the retrieval of semantic information and naming. Naming scores for both faces and voices were in fact (as expected) strongly lower in patients with left than with right ATL lesions, but no difference was found between the two hemispheric groups when semantic scores from faces, voices and names were taken into account No significant difference was, indeed, found in the comparison between the mean semantic scores of patients with left or right ATL damage on face and name stimuli and only a trend toward lower scores in patients with right-sided lesions was observed with voice stimuli.

Partly similar results were obtained when we passed from the comparison between the mean semantic scores obtained by all patients with left and right ATL lesions, to the study of patients who showed a selective defect for a single recognition modality. In this case, there was no difference between the number of patients with right or left ATL lesions who showed a selective defect for faces (in comparison to names) but a higher number of patients with right-sided lesions obtained selective semantic defects by voice (in comparison to name) and this difference approached significance. The difference between results obtained by patients with right ATL lesions on face and voice stimuli was underlined in this last analysis by the significantly higher number of patients showing a selective semantic defect for voices in comparison to face. These results obtained in patients showing a modality-specific semantic defect mirror those obtained in patients with right and left ATL damage on the factorial ANOVA for false alarms on faces and voices, because in both cases voices were more impaired and tended to be more right-lateralized than faces. A tentative interpretation of these unexpected results could consist in assuming that the perceptual complexity of a task may increase its right lateralization and that the more complex task of voice recognition may be more right-lateralized than the less perceptually demanding face recognition task.

Leaving aside these partly unexpected results, our data substantially agreed with those reported by Viskontas et al. (2002) and Rice et al. (2018) in TLE patients and by Borghesani et al. (2019) in patients with neurodegenerative disorders. These authors had shown, in fact that greater deficits in recognition of famous faces and voice after right ATL lesions and of famous names after left ATL damage can be found only at the lower (familiarity) levels, but not at the higher (semantic) levels of people recognition. Apparently, however, these positions were inconsistent with results of previous investigations (e.g. Snowden et al., 2004; Gainotti, 2012; Luzzi et al., 2017; Woollams and Patterson, 2018), which had shown that the semantic network of concrete objects is stored in a verbal format in the left hemisphere and in a non-verbal (pictorial) format in the right hemisphere. Using the verbal and the pictorial version of the Pyramis and Palm Trees (PPT) test (Howard and Patterson, 1992), these investigations had, indeed, shown that patients with right ATL lesions are mainly impaired on the pictorial- and patients with left ATL damage on the verbal- version of the PPT test. On the basis of these results, it could be expected that drawing semantic information about famous people from faces (or voices) should be more impaired after right ATL lesions, whereas drawing the same information from names should be more impaired by left ATL lesions. Since no laterality effects had been found at the semantic level in our study and in those reported by Viskontas et al. (2002) and by Rice et al. (2018), we wondered whether this lack of laterality effects at the semantic level for faces and voices could be due to a methodological bias, namely to the fact that, both in our study and in those of Viskontas et al. (2002) and Rice et al. (2018), the assessment of semantic identification had been based on verbal questions. It was, therefore, possible that the lack of laterality effects could be due to a balance between the non-verbal nature of the (face and voice) stimuli and the verbal nature of the identification response. Woollams and Patterson (2018) have, indeed, shown that their patients with right and left ATL atrophy were equally impaired on a Spoken Word to-Picture Matching task with an intermediate loading on verbal and visual processing, whereas those with right ATL damage had significantly lower scores on the pictorial version of the PPT test, which involved making semantic associations with purely visual stimuli. This hypothesis was, however, at odds with results obtained by Borghesani et al. (2019) investigating in patients with neurodegenerative diseases, the brain regions associated with different aspects of famous face recognition disorders by means of the UCSF Famous Faces Battery. This battery, which also comprises tasks of face familiarity and face naming, evaluates, in fact, the retrieval of semantic information with a 'Famous Face Semantic Association' task, in which subjects must select, among three famous faces, the two which share a semantic connection (i.e. the same profession). Now, even if no verbal response is requested in this task to prove the retrieval of the correct personal information, semantic score correlated in this study with grey matter volume in the left ATL, whereas face familiarity judgment correlated with integrity of the right ATL.

The discordance between laterality effects obtained by Snowden et al. (2004), Gainotti (2012), Luzzi et al. (2017) and Woollams and Patterson (2018) on the pictorial version of the PPT test and those obtained by Borghesani et al. (2019) on the 'Famous Face Semantic Association' task, could suggest that the format of the semantic network of the 'concrete objects' categories may be partly different from that of the 'famous people' category. The former could be based on both verbal and non-verbal associations, concerning the perceptual and contextual similarities between the target stimuli, and could be subtended respectively by the left and right ATLs. The latter, on the contrary, could substantially require that the pictorial information, provided by the face stimulus, be recoded (perhaps through the name of the person) into the corresponding verbal information to retrieve the critical (same profession) semantic association. This semantic network should therefore be mainly represented in the left ATL. This explication could not only explain our results and those obtained by Viskontas et al. (2002) and Rice et al. (2018), but also help to understand why in the Borghesani et al. (2019) study both naming scores and scores obtained on the 'Famous Face Semantic Association' task correlated with grey matter volume in the left ATL, whereas face familiarity judgment correlated with the volume of the right ATL.

Finally, we must acknowledge that the lack of laterality effect on semantic scores may also be due to low statistical power. In fact, both groups (right- and left-sided ATL damage) showed large SDs on semantic scores. However, as the inspection of both tables and graphs can easily show, central measures were quite close (the maximal difference, observed for voices, was 11.66, less than 10% of total score), making the claim for a pure lack of statistical power quite unlikely.

Is there a quantitative difference between the right lateralization of faces and voices?

Apart from these theoretical problems, there are in our study some differences between results obtained (both at the familiarity and at the semantic level) on the non-verbal tasks of person recognition through face and voice, which suggest that some graded dissimilarities may even exist between the right lateralization of these non-verbal modalities. These differences consisted of a greater difficulty in the recognition of voices in comparison to faces, which was present both at the familiarity and at the semantic level and was more significant after right than left ATL lesions. Results, obtained on the factorial ANOVA for faces and voices in patients with right and left ATL damage showed, indeed, that the number of false alarms was significantly higher (and the naming score significantly lower) from voice than from face in patients with right, but not in those with left ATL lesions. Furthermore, when a comparison was made between the number of patients with right and left ATL lesion who showed a selective difficulty in the recognition of voices (in comparison to faces) the number of patients showing a selective semantic defect for voices was significantly higher in patients with right ATL damage. These results could suggest: (a) that the greater right laterality effects mainly concerned the more perceptually demanding task of voice (in comparison to face) recognition and (b) that the impact on laterality of the perceptual difficulty of the voice recognition task extended from the lower (familiarity), to the higher (semantic) levels of famous person recognition. These suggestions raise, however, the problem of explaining why the perceptual complexity of voice recognition should increase its right hemispheric lateralization and how this effect might extend from the lower (familiarity), to the higher (semantic) levels of famous person recognition. A tentative answer to these problems might perhaps be given by two assumptions concerning respectively: - the determinants of the right hemisphere superiority in perceptual recognition tasks and – the quantitative rather than qualitative differences between the (verbal) representations of semantic knowledge in the left ATL and their (sensory- motor) representations in the right ATL. These suggestions raise, however, the problem of explaining why the perceptual complexity of voice recognition should increase its right hemispheric lateralization and how this effect might extend from the lower (familiarity), to the higher (semantic) levels of famous person recognition. De Renzi (1982) was the first author who proved, with a series of neuropsychological investigations, the greater involvement of the right hemisphere in perceptual recognition tasks and gave a convincing explication of its determinants. In a first time this author and his school showed that the right hemisphere plays a greater role both in high-level visual perceptual tasks, such as the "Ghent overlapping figures" test (De Renzi & Spinnler, 1966; De Renzi, Scotti & Spinnler, 1969), or the “Color Matching” task (De Renzi & Spinnler, 1967) and in hight level auditory tasks, such as the “Meaningless Sounds Discrimination” task. (Faglioni, Spinnler & Vignolo, 1969). In a second time De Renzi (1982) interpreted results of these investigations in terms of neural plasticity, assuming that the cortical areas involved in language processing in the left hemisphere could be (at least in part) dedicated to perceptual functions in homologous areas of the right hemisphere. Similar positions were expressed by Gazzaniga (2000) who claimed that “While language emerged in the left hemisphere at the cost of pre-existing perceptual systems, the critical features of the bilaterally present perceptual system were spared in the opposite half-brain” (see Gainotti, 2021 for a more thorough discussion of this question). On the other hand, the hypothesis of a quantitative, rather than qualitative difference between the (verbal) representations of semantic knowledge in the left ATL and its (sensory- motor) representation in the right ATL was proposed by Gainotti (2014), making a criticism to Paivio's (1971 and 1986) 'dual code ' theory, which assumed that visual and verbal information should be processed along distinct channels in the human mind, creating separate representations for information processed in the right and left hemisphere.

According to Gainotti, (2014) a quantitative difference between the left verbal and the right perceptual components of the conceptual representations could be explained by the sensory-motor model of conceptual knowledge (e.g., Saffran & Schwartz, 1994; Gainotti, 2000; Martin, Ungerleider & Haxby, 2000; Gainotti, Ciaraffa, Silveri & Marra, 2009), which assumes that each conceptual representation results from the convergence, in a 'high order convergence zone' (Damasio, 1989, 1990) of different perceptual, motor and verbal sources of knowledge. Since this model also posits that each of these sources of knowledge may have a different weight at the level of the right and left hemisphere, it could be logical to assume that the right lateralization of a more demanding perceptual task may exceed that of a similar less demanding task. This model could, therefore, explain the greater right lateralization of the more perceptually demanding voice (in comparison to face) modality of person recognition. A more specific explanation of the extension of the right hemisphere superiority for voice (in comparison to face) from the lower (familiarity), to the higher (semantic) levels of famous person recognition could consist in acknowledging that a continuum exists between the levels of person recognition that we have tried to dissociate. According to this position, familiarity cannot be considered in terms of an all-or-nothing, but in terms of a graded effect.(e.g. Vokey & Read, 1992; Clutterbuck & Johnston, 2002) and both familiarity feelings and semantic retrieval are better understood as processes that operate on graded evidence than as processes with discrete categorical states (e.g. Bowles & Kohler (2014). Evidence supporting this position comes from the observation that a dissociation between spared familiarity and impaired semantic retrieval has been found in healthy subjects and that these 'familiar only' responses prevail with voices rather than with face stimuli. Hanley, Smith, and Hadfield (1998) were the first authors who described this asymmetry, asking undergraduate students to identify a set of celebrities from either their voices or their faces. They found not only that the participants were better at recognizing celebrities from their faces than from their voices, but also that among the stimuli judged as familiar, the recall of the corresponding occupation was correctly made by 92% of the participants in the face condition, but only by 63% in the voice condition. In other words, subjects gave significantly more semantic errors in the voice condition than in the face condition even for stimuli judged as familiar.

5. CONCLUDING REMARKS

The aim of our investigation consisted in trying to clarify a number of controversial problems concerning the lateralization of different components and levels of people recognition, by administering a complex battery of famous people recognition to a large sample of patients with neoplastic or degenerative lesions of the right or left ATLs. Unfortunately, our results have complicated rather than clarified these problems, because they have shown that, in addition to the variables taken into account in previous investigations, other variables must be considered and that the dichotomy left=verbal and right=non-verbal is too simple to account for the complexity of the semantic representations. Our results have, indeed, suggested that, besides the verbal vs non-verbal nature of the input and output modalities, it is also necessary to consider the nature of the intermediate processes that develop between the former and the latter. Thus, it is likely that the procedures used to retrieve the person-specific semantic information may necessarily require the use of an intermediate verbal formulation, regardless of the verbal or non-verbal format of stimulus and response modalities. Our results have also shown that a greater right lateralization of voice, in comparison to face, can be found both at the familiarity and at the semantic level and this finding suggests that a graded lateralization may exist within the non-verbal modalities and that the perceptual complexity of the task may be a determinant of this graded lateralization.

Study Limitations. We are obviously aware of the discrepancy that exists between the weight of these general statements and some weakness of our data. First of all, the heterogeneous etiology of ATL damage taken into account in our research may have influenced the results to some extent. Furthermore, our investigation took into account several behavioral measures, that, in some cases, displayed high level of variance (e.g., semantic score) that probably affected the statistical power of the study. Nevertheless, we think that the suggestions arisen by our data could be stimulating enough to encourage new investigations aiming to check more thoroughly the solidity of these hypotheses.

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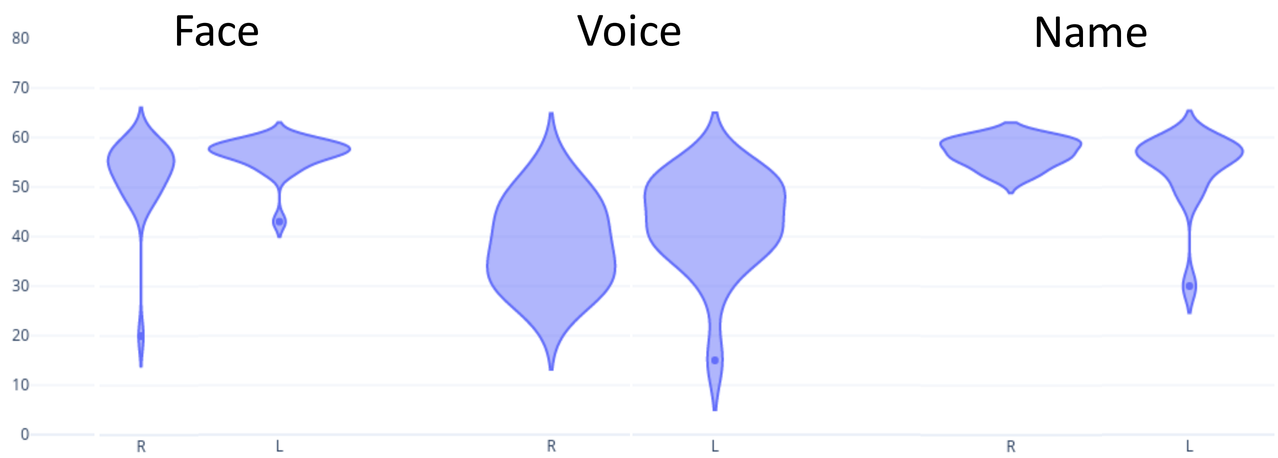
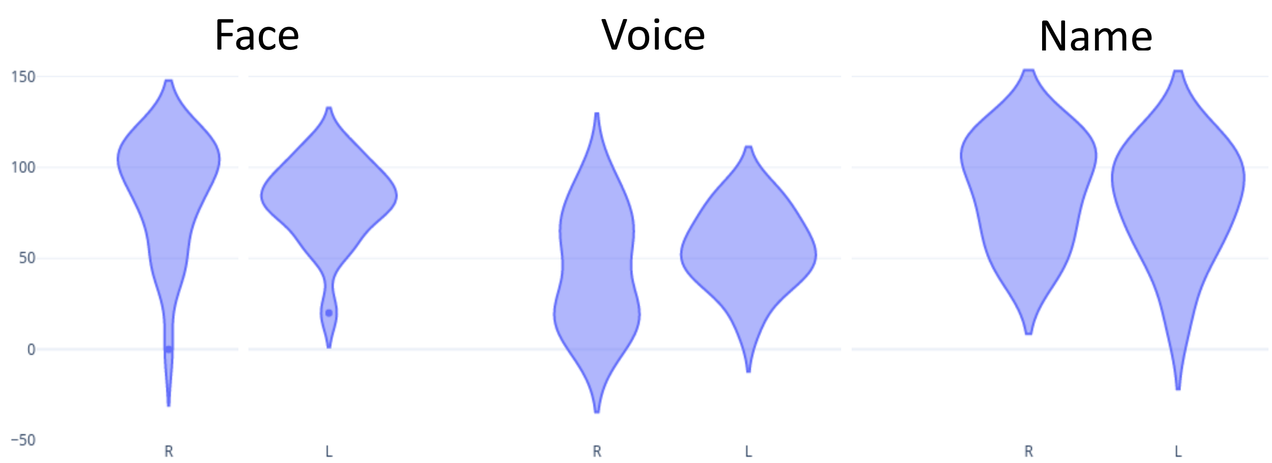
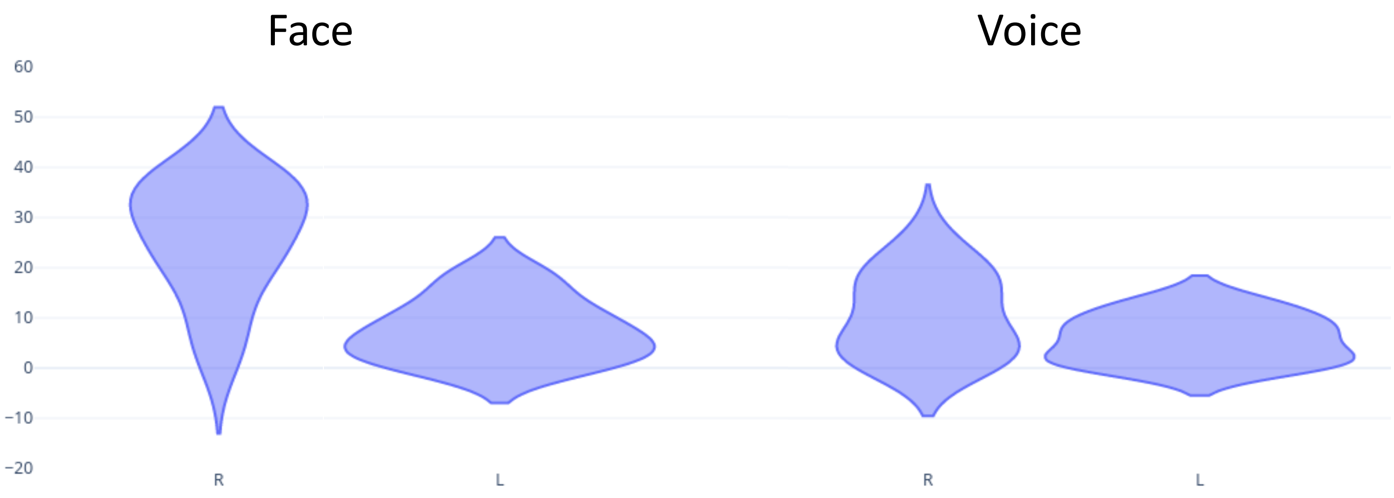
Supplementay Material



Graph 1.: violin diagrams displayng the familiarity scores on the three modalities of subjects with right (R) or left (L) lesion of the ATL.



Graph 2.: violin diagrams displaying the semantic scores on the three modalities of subjects with right (R) or left (L) lesion of the ATL.



Graph 3.: violin diagrams displaying the naming scores on face and voice of subjects with right (R) or left (L) lesion of the ATL.

	Age	Education	Gender	Dur.	Side	MMSE	Stroop Interference Time	Stroop interference errors	Digit span forward	Spatial span forward	Rey Osterrieth Figure copy	Rey Osterrieth Figure recall	RAVLT Immediate recall	RAVLT Delayed Recall	Category fluency	Phonological Fluency	Reading	Matching	Naming	ADL	IADL
SEMANTIC DEMENTIA																					
							Caffarra et al. 2002		Monaco et al. 2013		Caffara et. al 2002		Carlesimo et. al 1996		Quaranta D et al 2016	Carlesimo et al. 1996		Snowden et al. 2004	Snowden et al. 2004	Katz et al., 1963	Lawton and Brody, 1969
						≥23.8	≤36.92	≤4.24	>4.26	>3.46	>28.87	>9.46	≥28.53	≥4.69	≥9.28	≥17.35		=40	≥39		
1	78	17	M	1	R	29	36.5	6	6	6	27	13.5	36	7	12	33	40	36	35	6	8
2	65	17	M	2	R	23	31	10.5	4	2	.	.	16	2	8	15	40	36	36	5	5
3	65	9	F	1	R	29	32	0	7	5	30	5	29	4	14	39	40	37	33	6	7
4	76	8	M	2	R	27	50.5	0	5	5	29	12	27	6	14	19	40	38	33	6	7
5	79	17	M	3	R	28	50	0	5	5	35	10	.	.	17	17	40	37	19	6	5
6	79	5	F	4	L	28	50	0	5	5	35	10	.	.	17	17	40	37	19	6	.
7	68	5	F	3	R	25	34	0	5	5	35	31	15	2	15	19	40	37	13	4	0
8	68	8	F	4	L	27	50	1	5	5	32	27	.	.	6	7	40	27	1	6	5
9	65	13	M	3	R	26	34	0	6	6	36	27	39	5	21	22	40	39	23	6	5
10	50	13	M	2	R	26	34	0	6	6	36	27	39	5	16	22	40	39	23	6	5
11	77	5	F	3	L	28	54	1	4	5	34	33	20	0	12	16	40	40	16	6	8
BRAINTUMORS							Caffarra et al. 2002		Monaco et al.		Caffara et. Al 2002		Carlesimo et. al 1996		Novelli et al. , 1986	Carlesimo et al. 1996		Catricalà et al, 2013	Catricalà et al, 2013	Katz et al., 1963	Lawton and Brody, 1969
							≤36.92	≤4.24	>4.26	>3.46	>28.87	>9.46	≥28.53	≥4.69	≥23.59	≥17.35		≥47.09	≥41.48		
12	38	13	F	<1	L		17.5	0	5	5	32	17	42	11	51	44		48	46	6	8
13	43	13	M	<1	R		16.5	2.5	5	5	34	15.5	42	8	51	19		48	46	6	8
14	57	17	F	<1	R		32.5	2.5	4	4	34	10	20	4	29	28		48	47	6	8
15	68	8	M	<1	R		8.5	0	7	4	31	10	35	4	67	45		48	46	6	8
16	41	17	M	<1	L		52	2	5	4	31	5	7	0	34	23		48	46	6	7
17	37	13	F	<1	R		26.5	2	4	4	33	12	37	7	18	21		48	41	6	6
18	58	17	M	<1	R		7.5	0	5	5	35	25	51	13	44	38		48	46	6	8
19	38	13	F	<1	R		14	0	5	5	36	14.5	35	8	35	27		48	48	6	8
20	38	13	F	<1	R		23	0	5	5	35	17	36	8	30	32		48	44	6	8
21	58	13	F	<1	L		25.5	1.5	5	6	28	2	4	0	69	43		48	48	6	8
22	43	13	M	<1	L		12	1.5	5	5	29	11.5	19	2	20	40		48	34	6	6
23	39	17	M	<1	L		30.5	2	5	5	30.5	11	9	0	37	26		48	39	6	6
24	21	13	M	<1	L		26	0	4	4	36	5.5	2	0	32	6		48	45	6	6
25	42	13	F	<1	L		64	7.5	6	5	31.5	3	16	2	34	20		48	45	6	6
26	28	17	F	<1	L		19	0	6	4	32	20.5	21	7	36	28		48	48	6	5
27	27	16	M	<1	L				6	5	32	6	0	0	25	19		48	38	6	8
28	32	13	M	<1	R		19	0	6	5	32.5	12	32	8	48	42		48	47	6	6
29	56	13	M	<1	R		0	0	5	5	34	13	38	5	51	37		48	48	6	8
30	50	8	M	<1	L		15	0	6	5	33.5	13	24	2	48	30		48	47	6	8
31	24	16	F	<1	R		22.5	0	5	5	33	9	29	6	35	38		48	48	6	7
32	41	17	M	<1	L		19.5	0	3	4	32.5	6	12	1	49	25		48	47	6	8
33	24	15	F	<1	R		22	0	5	5	29.5	16	23	4	36	35		48	48	6	7
34	50	17	M	<1	R		24	0	5	6	34	18	35	5	36	24		48	46	6	8
35	64	17	M	<1	L		7	0.5	3	4	32	10.5	28	0	40	48		48	46	6	8
36	40	13	M	<1	L		19	0	9	5	31	11	10	0	40	33		48	46	6	6
37	25	17	M	<1	R		30	0	5	4	30	0	45	10	25	17		48	48	6	8
38	40	8	M	<1	L		43	2	8	4	33.5	11.5	5	0	46	30		48	48	6	8
39	32	17	M	<1	L		16.5	0	5	6	31	12	36	2	34	22		48	48	6	6
40	36	8	M	<1	L		27.5	2	6	4	32	7.5	0	0	50	35		48	48	6	6
41	30	13	M	<1	R		16	0	8	5	30	10.5	33	15	36	25		48	45	6	8
42	59	11	F	<1	R		3	0	4	4	31	9.5	45	9	33	23		48	46	6	8
43	59	18	M	<1	R		15	0	6	5	29	10	4	6	71	56		48	46	6	8

Supplementary Table 1:.: Neuropsychological profiles of subjects with neurodegenerative and neoplastic lesions of ATL. MMSE: Mini Mental State Examination; RAVLT: Rey's Auditory Verbal Learning test; ADL: Activities of Daily Living; IADL: Instrumental activities of Daily Living. Performances. Scores highlighted in grey are below the cut-off.

References to tests reported in Supplementary Table 2

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False alarms		MMSE	Stroop Interference	Stroop errors	Rey Osterrieth Figure copy	Rey Osterrieth Figure recall	RAVLT immediate recall	RAVLT delayed recall	Category fluency	Phonological Fluency	Naming
Face	p	0.710	0.701	0.844	0.602	0.572	0.709	0.850	0.729	0.704	0.866
Voice	p	0.742	0.859	0.541	0.437	0.937	0.453	0.123	0.681	0.463	0.811
Name	p	0.377	0.423	0.953	0.165	0.563	0.918	0.995	0.328	0.999	0.759

Supplementary Table 2.:correlation analysis between FA scores and scores obtained on neuropsychological tests assessing (specifically or in part)executive functions.