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Stability of face recognition abilities after left or right anterior temporal lobectomy

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Abstract
Patients with anterior temporal lobe (ATL) resection due to mesial temporal lobe epilepsy (MTLE) have difficulties at identifying familiar faces and explicitly remembering newly learned faces but their ability to individuate unfamiliar faces remains largely unknown. Moreover, the extent to which their difficulties with familiar face identity recognition and learning is truly due to the ATL resection remains unknown. Here, we report a study of 24 MTLE patients and matched healthy controls tested with an extensive set of seven face and visual object recognition tasks (including three tasks evaluating unfamiliar face individuation) before and about 6 months after unilateral (nine left, 15 right) ATL resection. We found that ATL resection has little or no effect on the patients' preserved pre-surgical ability to perform unfamiliar face individuation, both at the group and individual levels. More surprisingly, ATL resection also has little effect on the patients' performance at recognizing and naming famous faces as well as at learning new faces. A substantial proportion of right MTLE patients (33%) even improved their response times on several tasks, which may indicate a functional release of visuo-spatial processing after resection in the right ATL. Altogether this study shows that face recognition abilities are mainly unaffected by ATL resection in MTLE, either because the critical regions for face recognition are spared or because performance at some tasks is already lower than normal preoperatively. Overall, these findings urge caution when interpreting the causal effect of brain lesions on face recognition ability in patients with ATL resection due to MTLE. They also illustrate

the complexity of predicting cognitive outcomes after epilepsy surgery because of the influence of many different intertwined factors.

KEYWORDS
anterior temporal lobe resection, cognitive neuropsychology, epilepsy surgery, face recognition

BACKGROUND

Patients with anterior temporal lobe (ATL) resection due to mesial temporal lobe epilepsy (MTLE), in particular of the right hemisphere, have been described as having deficits in face identity recognition (FIR; e.g., Barton, 2008; Drane et al., 2013; Glosser et al., 2003; Rice et al., 2018). However, whether their impairment concerns only familiar/famous faces or extends to the recognition of unfamiliar face identity remains unknown. This issue is important because identity recognition of familiar faces, which can be tested across a wide variety of tasks (e.g., naming, familiarity judgement, old/new recognition, sorting/matching with or without delay; e.g., Iowa Famous Faces Test in Drane et al., 2013; face naming and face-name matching in Luzzi et al., 2017) depends heavily on access to semantic information, including names. That is, familiar faces are recognized using multiple 'codes' (Bruce, 1982). In contrast, identity recognition of unfamiliar faces, i.e., the ability to tell that faces not encoded in memory are of the same identity or not,[1] must be based solely on visual cues (Bruce, 1982; Rossion, 2018). This raises the question of whether ATL resection in MTLE affects recognition of face identity based on visual cues only, a question that has both theoretical implications (i.e., does the ATL contribute significantly to unfamiliar face recognition as advocated by neuroimaging studies relying on multivariate pattern analysis; Anzellotti et al., 2014; Kriegeskorte et al., 2007) and clinical consequences (i.e., is the ATL resection – the most common surgical treatment for drug-resistant MTLE (Brotis et al., 2019) – likely to induce unfamiliar face recognition deficits, as found in some brain-lesion studies; Barton, 2008; Pancaroglu et al., 2016).

To our knowledge, only one study (Barton, 2008) reported an unfamiliar FIR impairment after ATL resection in MTLE: a man in his 40s assessed 11 years after right ATL resection was impaired not only at the old/new Warrington Recognition test with faces – which uses unfamiliar faces but requires encoding and maintenance in memory – but also at a test requiring the matching of simultaneously presented unfamiliar faces, the Benton Facial Recognition Test (BFRT; Benton & Van Allen, 1968). However, there was no information about his ability prior to ATL resection. In contrast, a pre- and post-operative case study (subject C.B. in Wisniewski et al., 2012) reported an improvement in the BFRT (short version) after ATL resection. Other than these case studies, a few group explorations of unfamiliar FIR in MTLE patients undergoing ATL resection have been carried out. Some studies reported postoperative results without providing information about preoperative performance, showing either an absence of difference between patients and controls (as assessed by the Facial Discrimination Task from the Florida Affect Battery: Carvajal et al., 2009) or lower performance in patients than controls (experimental unfamiliar face identity matching task: Braun et al., 1994; BFRT: Moran et al., 2005; Glasgow Face Matching task: Rice et al., 2018). Other studies have tested different pre- and postoperative groups of patients and showed no effect of ATL resection (on the BFRT; Glosser et al., 2003) or only stated that none of the patients included in each pre- or postoperative group was impaired on this cognitive function (according to BFRT scores; Drane et al., 2008, 2013). Only a few studies have used a longitudinal design, with the same patients assessed before and after ATL resection, reporting conflicting results (Chiaravalloti

[1]Here, 'recognition' is not defined as a judgement of previous occurrence (Mandler, 1980), but more generally as the capacity to provide specific (behavioural or neural) responses (to faces), these discriminant responses being reliable/reproducible across a wide variety of inputs (Rossion, 2022). In this context, it is perfectly legitimate, and more coherent, to refer to 'unfamiliar face identity recognition'.

& Glosser, 2004; Hermann et al., 1991, 1993; Seidenberg et al., 1998; Shaw et al., 2007). Specifically, some studies showed no significant change between pre- and postoperative performance on the BFRT (Chiaravalloti & Glosser, 2004; Seidenberg et al., 1998; Shaw et al., 2007), while other studies reported a significant pre- to postoperative decline on this same task (Hermann et al., 1991, 1993).

Overall, these previous studies present with three major limitations to resolve the issue at stake, i.e., whether ATL resection in MTLE concerns only familiar face recognition/learning or if it extends to identity recognition of unfamiliar faces. First, few studies have assessed unfamiliar FIR in the same groups of pre- and postoperative patients. However, longitudinal studies are mandatory to evaluate the specific effect of brain surgery, as cognitive impairment related to the chronic brain disease could be already present before surgery. Studies with only postoperative assessments may also miss the variable interindividual effect of surgery on cognitive functions, with some patients declining, some improving, and some remaining stable (Abdallah et al., 2021; Sherman et al., 2011). Second, the only variable taken into consideration when assessing these abilities has been accuracy rates at a given task (but see Rice et al., 2018). However, as studies of cases of visual object agnosia and prosopagnosia show, response times (RT) may also carry important information about normal versus impaired cognitive functioning, particularly for (unfamiliar) FIR (Delvenne et al., 2004; Rossion, 2022; Rossion & Michel, 2018). Third, there is a lack of comprehensive assessment of unfamiliar face recognition, with mostly only one task performed (mainly, the BFRT).

Here, we address these issues to shed light on the nature of the putative FIR impairment in MTLE patients undergoing ATL resection by reporting the results of 24 patients tested with a set of seven face and visual object recognition tasks before and about 6 months after unilateral ATL resection, taking into consideration both accuracy and RT. To provide an extensive evaluation of cognitive abilities related to FIR in patients before and after resection, we included three tasks assessing unfamiliar FIR but also tasks assessing face detection, famous face identity recognition and naming, and unfamiliar face identity learning.

MATERIALS AND METHODS

Participants

Twenty-four patients with refractory mesial temporal lobe epilepsy (MTLE) (12 females; mean age = 35 ± 11.7 years; two left-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971)) were recruited. Patients were tested on face and object recognition tasks before (T0) and about 6 months after (T1) ATL resection. They were part of a larger cohort of 42 pre-surgical MTLE patients tested preoperatively (Volfart et al., 2020). The inclusion criteria were as follows: (1) age above 18 years; (2) left or right MTLE as assessed by non-invasive examinations (structural MRI, EEG-video, PET, SPECT) and, for 17 out of 24 patients, stereotactic-EEG (SEEG); (3) underwent standard or tailored ATL resection in the context of epilepsy surgery (Figure 1); (4) tested with the same face and visual object recognition tasks before and at about 6 months after epilepsy surgery; (5) intellectual quotient as assessed by the WAIS-R or WAIS-IV above 65; (6) normal basic visual functions (as measured by the Visual Object and Space Perception battery). All MTLE participants gave written informed consent before their inclusion, and the study (ATENA-F, trial N°2013-A00515-40, ClinicalTrials.gov identifier NCT02888925) was approved by the local ethical committee (CPP Est III, 13.05.02).

Given the prevalence of FIR impairments in right as compared to left-lateralized epilepsy patients (Barton, 2008; Drane et al., 2013; Glosser et al., 2003; Rice et al., 2018), participants were divided into two groups according to the lateralization of their epilepsy and, as a consequence, of the side of surgery: a left MTLE group ($n = 9$) and a right MTLE group ($n = 15$; see Table 1 for patients' characteristics). The two patient groups did not differ statistically on gender, age at inclusion, handedness, educational level, mean time between surgery and T1, mean time between T0 and T1, postoperative Engel I outcome (i.e., is the patient free of disabling seizures after surgery) at last follow-up (i.e., at least 2 years after surgery),

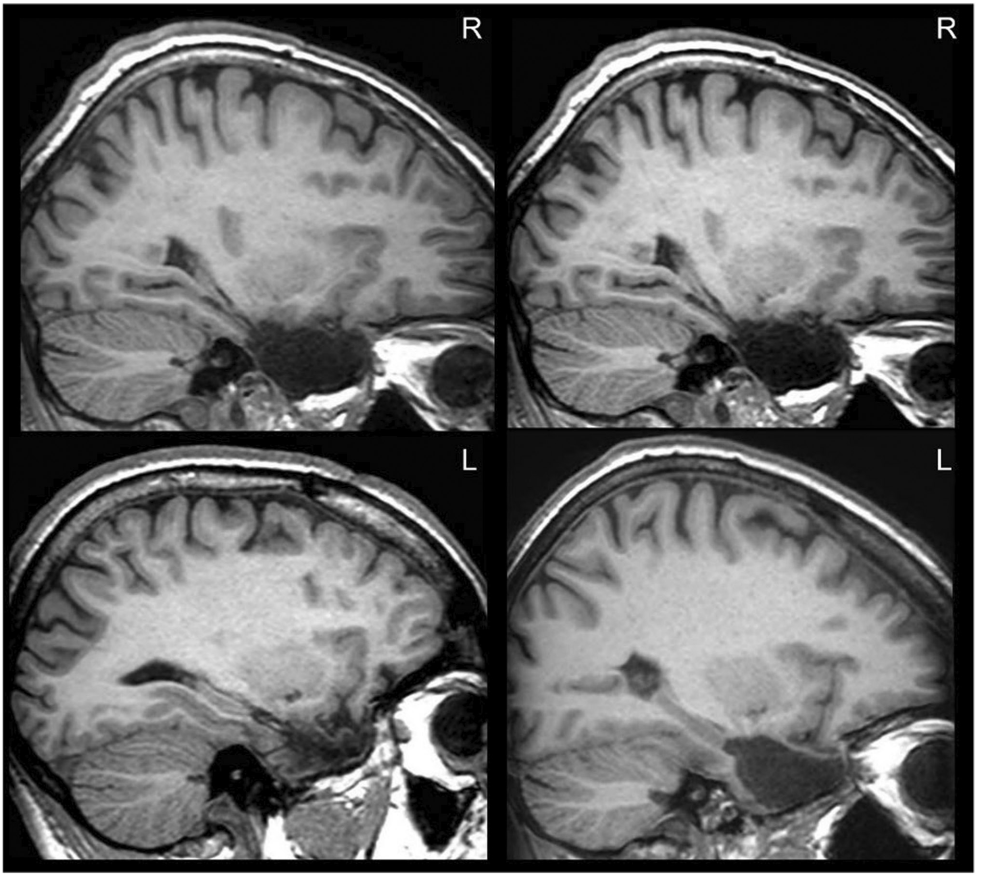

FIGURE 1 Examples of left and right anterior temporal lobe (ATL) resections performed in four mesial temporal lobe epilepsy (MTLE) patients included in this study (postoperative T1 MRI, sagittal slices). Note that the resection extended less posteriorly on the ventral ATL for left MTLE patients to surgically spare critical sites for language in this region (basal temporal language area; Abdallah et al., 2021; Bédos Ulvin et al., 2017; Snyder et al., 2023).

age at epilepsy onset, duration of epilepsy, number of antiepileptic drugs (AED) at the time of the pre- and postoperative assessments, structural status of the hippocampus (presence or absence of hippocampal sclerosis) and Total IQ (although right MTLE patients exhibited a mean IQ score 10-points lower than left MTLE patients). Note that AED tapering had not already started at T1 (the number of AED was highly similar between T0 and T1; left MTLE: $t(8) = -1.835$, $p = .10$; right MTLE: $t(14) = .807$, $p = .43$).

Normal controls (NC) were recruited to match each patient's characteristics on age range (±5 years), gender, handedness, level of education (<12, 12 to 14 or >14 academic years). Normal controls were divided into two groups: the left NC group matched to left MTLE patients (8 controls, 3 females; 1 left-handed; mean age = 32.50 ± 11.9) and the right NC group matched to right MTLE patients (15 controls, 8 females; 1 left-handed; mean age 35.00 ± 12.4). They were tested twice with the same face and object recognition tasks as MTLE patients, at T0 and at T1, with the time between T0 and T1 assessments being matched with the time between the pre- and postoperative assessments of their matched patient (19.12 and 15.27 months for left and right NC, respectively; see Table 1 for the T0–T1 mean time for patients). None of the control participants reported to have a history of neurological or psychiatric disease, drug or alcohol abuse. All NC participants gave a written consent before their inclusion.

TABLE 1 Demographic and clinical characteristics of MTLE patients.

Characteristics	Left MTLE (n = 9)	Right MTLE (n = 15)	Statistical comparisons
Gender			
Male	5	7	Fisher p = 1 FDR-c p = 1 V_{Cramer} = .086
Female	4	8	
Age at inclusion	33.78 ± 11.7	35.73 ± 12.1	U = 64, p = .834 FDR-c p = 1 g_{Hedges} = .157
Handedness (left/right)	1/8	1/14	Fisher p = 1 FDR-c p = 1 V_{Cramer} = .078
Educational level			
<12 academic years	3	5	Fisher p = .284 FDR-c p = .901 V_{Cramer} = .345
12–14 academic years	1	6	
>14 academic years	5	4	
Mean time between surgery and T1 (months)	5.62 ± 2.83	6.13 ± 2.32	U = 66, p = .926 FDR-c p = 1 g_{Hedges} = .195
Mean time between T0 and T1 (months)	18.33 ± 6.8	15.47 ± 6.7	t(22) = 1.009, p = .324 FDR-c p = .901 g_{Hedges} = .410
Postoperative Engel I class (Engel I/ not Engel I)	6/3	12/3	Fisher p = .635 FDR-c p = 1 V_{Cramer} = .149
Mean resection distance from tip of temporal pole along the ventral cortex (mm)	34.11 ± 6.7	42.10 ± 6.2	(22) = −2.954, p = .007 FDR-c p = .098 g_{Hedges} = −1.208
Age at epilepsy onset	12 ± 12.1	14.85 ± 9.8	U = 53, p = .386 FDR-c p = .901 g_{Hedges} = .257
Duration of epilepsy	21.78 ± 13.7	22.08 ± 14.3	t(22) = −.084, p = .933 FDR-c p = 1 g_{Hedges} = .020
Number of anti-epileptic drugs at T0	2.00 ± .5	2.47 ± .8	U = 50, p = .169 FDR-c p = .789 g_{Hedges} = .643
Number of anti-epileptic drugs at T1	2.44 ± .9	2.33 ± .8	U = 60.5, p = .639 FDR-c p = 1 g_{Hedges} = .127
Presence of hippocampal sclerosis (yes/ no)	4/5	8/7	Fisher p = 1 FDR-c p = 1 V_{Cramer} = .086
Total IQ	101.78 ± 17.0	88.47 ± 13.2	t(22) = 2.150, p = .043 FDR-c p = .301 g_{Hedges} = .874

Note: Values are shown as mean ± standard deviation or as the number of patients per category. Statistical comparisons were computed with Fisher or Fisher–Freeman–Halton exact tests for categorical variables, and with independent t-tests or Mann–Whitney U tests for continuous variables. p values are showed as raw and FDR-corrected. Effect sizes are reported as Cramer's V for categorical variables, and as Hedges' g for continuous variables.

Pre- and postoperative face recognition assessment

Patients and NC were tested with seven behavioural experiments at T0 and T1 as in Volfart et al. (2020). Face recognition tasks included, in testing order: (1) BFRT-computerized (BFRT-c); (2) old/new face recognition task; (3) old/new non-face recognition task; (4) face and car delayed matching task at upright and inverted orientations; (5) Mooney face test; (6) famous face identification test (CELEB); and (7) Cambridge Face Memory Test (CFMT). These tasks were created and administered with E-Prime, except for the CFMT test running in Java, and the CELEB test running with its own software (www.ipsp.ucl.ac.be/recherche/projets/Celeb/setup.exe). Testing lasted for about 2 h and was performed over the same day.

Mooney face test (see Busigny et al., 2010)

Participants are presented with upright or upside-down Mooney face stimuli (i.e., two-tone, thresholded black-and-white faces) and indicate whether the image depicts a face or not. One (left MTLE) patient and two (left) NC were not tested with this task because of technical issues.

Benton facial recognition test-computerized (see Rossion & Michel, 2018)

Participants have to find an unfamiliar target face among six unfamiliar probe faces presented simultaneously below the target. In the first part of the test (six items), one of the probe face is exactly the same picture as the target face. In the main part of the test (16 items), the target face has to be found three times under variations of viewpoints or lighting conditions. One right MTLE and one right NC were not tested with this task because of technical issues.

Face and car delayed matching task (see Busigny & Rossion, 2010)

Participants are presented with a full-front unfamiliar face or car, upright or inverted target and then with two ¾ profile probes. They have to find the probe that corresponds to the previously shown target.

Cambridge face memory test (see Duchaine & Nakayama, 2006)

Participants learn six unfamiliar target faces and have to retrieve these faces under three conditions: exact same pictures as encoded, novel pictures varying in viewpoints and lighting conditions, and novel pictures varying in viewpoints and lighting conditions with added Gaussian noise. Three right MTLE and one right NC were not tested with this task because of time constraints.

Old/new face recognition task (see Busigny et al., 2010)

First, participants have to learn 30 unfamiliar faces presented one after another for 4 s. Second, they are presented with a forced-choice recognition in which they have to indicate which of two faces was previously learnt. One right NC was not tested with the face task because of technical issues.

Old/new non-face recognition task

Same task as the old/new face recognition task but with bird images.

CELEB (see Busigny, Prairial, et al., 2014)

Participants are presented with famous faces devoid of external facial features and asked to name them in turn. If participants cannot name the face, they are asked to give as much biographic information as possible about the famous person. They are then presented with a multiple-choice with five names and asked to designate the correct name. At the end of the task and for all famous faces not correctly named or described and designated, participants are given the name of each face and asked if they are familiar with the person. If not, the identity is removed from the scores' calculation. Four (two left, two right) NC were not tested with this task because of time constraints.

Surgical procedure

All patients underwent a unilateral ATL resection, i.e., a resection of the antero-medial temporal structures including the temporal pole, the amygdala, the hippocampus, the parahippocampal gyrus, and the anterior ventro-temporal cortex, including the most anterior parts of the fusiform and inferior temporal gyri (Figure 1). The posterior limits of the resection along the ventral ATL (distance from the temporal pole) were assessed on the postoperative MRI for each patient: the mean distance was 42.1 ± 6.2 mm for the right MTLE group and 34.1 ± 6.7 mm for the left MTLE group. Seventeen patients benefited from a tailored ATL after SEEG, consisting of surgically sparing eloquent sites for language in the ventral ATL, as assessed with electrical stimulation during SEEG, explaining the shorter resection along the ventral ATL for the left MTLE group, although not significant (Table 1; Abdallah et al., 2021; Bédos Ulvin et al., 2017; Snyder et al., 2023). All resections were performed by the same neurosurgeon (SCC).

Statistical analyses

Statistical analyses were conducted using SPSS (all tests two-sided). Analyses comparing groups on demographic and clinical variables were carried out using Fisher exact tests for categorical variables with 2×2 contingency tables, Fisher–Freeman–Halton exact tests for categorical variables with 2×3 contingency tables, and two independent samples *t*-tests or non-parametric Mann–Whitney U tests for continuous variables, depending on whether the data were or were not normally distributed (as assessed by the Shapiro–Wilk test). Estimation of effect size is reported using Cramer's *V* for categorical variables and Hedges' *g* for continuous variables.

Analyses comparing the differences between performance at T0 (pre-surgery for MTLE patients, first test for NC) and T1 (post-surgery for MTLE, retest for NC) were carried out in two ways. Several authors (Dimitrov & Rumrill, 2003; van Breukelen, 2013; Wright, 2006) have emphasized the importance of ANCOVAs in analysing data from pre-post design such as ours, allowing to control for preexisting differences in non-randomized groups at T0 by adding these test measures as covariates. Thus, we first compared the results of MTLE and NC groups at T1, left and right groups separately, while controlling for scores at T0. However, considering that most of our data was in violation with the assumptions for a classical ANCOVA, we performed ANCOVAs on ranked scores (or RANCOVA) as recommended by Feys (2016) for non-parametric analyses in designs with repeated measures. We first ranked the scores at T0 and T1 separately for each test measure, ignoring the group variable. Then, we performed an ANCOVA with the ranked scores at T1 as dependent variable, the ranked scores at T0 as covariate, and the group as independent variable. Effect sizes were calculated based on the recommendation made by Morris (2008) on estimation of effect size in pretest-posttest group designs (d_{ppc2}, formula 8; effect size estimate using pooled pretest *SD*). Second, and as suggested by van Breukelen (2013), we also analysed difference scores between T0 and T1 (T1–T0; also called gain scores) in MTLE patients and their respective NC with independent *t*-tests, or with Mann–Whitney U tests when the distribution of difference scores was not normal. FDR correction was applied to control for multiple comparisons (Benjamini & Hochberg, 1995).

After analysing results at the group level, we also calculated the reliable change (RC) for each MTLE patient based on the change observed in the pool of 23 left and right NC according to Maassen's adjusted regression-based RC formula (Maassen et al., 2009, formula 10). We calculated the test–retest reliability as well as the standard error of prediction for each test measure (accuracy and RT). Within a 95% confidence interval, a patient was considered to exhibit a reliable pre-postoperative change if their score was above 1.96 or below −1.96 (as defined in the original paper from Jacobson & Truax, 1991). Considering non-normality of our data on most tests, and as suggested by Karlsen et al. (2022), we also calculated raw percentiles from our observed distributions in the pooled NC sample, thus providing measures that are not dependent on assumptions of normality and offering the possibility to compare an individual's performance with the observed distribution of scores in our sample of neurotypical participants.

RESULTS

The results at T0 and T1 for each patient group and their NC are summarized in Figures 2 and 3, and Tables S1 and S2.

Group level analyses

In pretest-posttest experimental designs, two methods are often used to analyse data (RANCOVA and independent samples *t*-tests). Given that these methods do not necessarily lead to the same results and answer different questions about the data (i.e., *t*-tests on difference scores estimate the effect of surgery on the difference between T0 and T1, while (R)ANCOVAs check for group differences at T1 while controlling for performance at T0; Wright, 2006; Köhler et al., 2021), we describe both. RANCOVA results can be found in Table S1 for left MTLE patients and Table S2 for right MTLE patients. When controlling for T0 scores, no significant difference at T1 were found after FDR correction for multiple comparisons, neither between left MTLE patients and their NC nor between right MTLE and their NC, suggesting that there was no reliable effect of the surgery at the group level. Results of the independent samples *t*-tests (comparison of T1–T0 difference scores) can be found in Table S3. As for RANCOVAs, no difference survived the FDR correction, neither for the comparison between left MTLE and their NC nor for the comparison between right MTLE and their NC. Altogether, both the FDR-corrected RANCOVAs and independent samples *t*-tests failed to show any significant and consistent effect of MTLE surgery at the group level.

However, Figures 2 and 3 suggest a clear reduction of RT in right MTLE, consistent across most of the tasks, but yet not significant. Averaging difference scores related to RT across all tasks showed a mean difference of −484 ms in right MTLE, and of −86 ms in right NC, with an important interindividual variability, especially in the right MTLE group (mean *SD* across tasks for the right MTLE: 1538 ms; for the right NC: 712 ms). For this reason, and because within-group differences might have been masked by group analyses, we computed analyses at the individual level.

Individual level analyses using RC scores

Percentages of improvement, stability and decline calculated using the RC score of each patient are shown for each task and each patient group in Table 2. These results were calculated based on the T0 to T1 change observed in the pool of all 23 control subjects. Therefore, if a significant reliable change is observed in an individual patient, test–retest effects (of the same magnitude as observed in the control population) can be confidently ruled out. We also report the natural distribution of difference scores

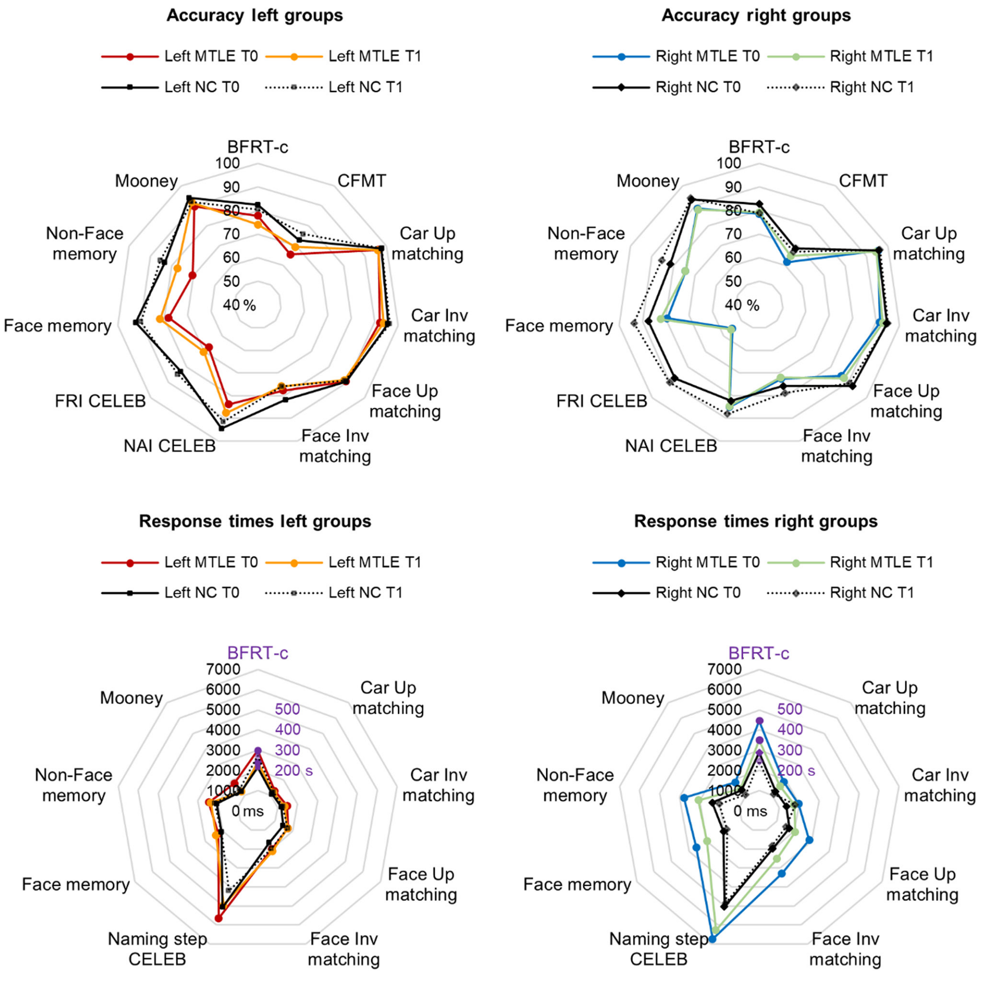

FIGURE 2 Accuracy and correct response times (RT) of mesial temporal lobe epilepsy (MTLE) patients and their matched normal controls (NC) in the face and object recognition tasks. Car Up/Inv and Face Up/Inv matching scores come from the face and car delayed matching task. FRI CELEB and NAI CELEB scores refer to the Face Recognition Index and Name Access Index of the CELEB test, respectively. Face and Non-Face memory scores refer to old/new recognition tasks. Accuracy is reported in percentages. BFRT-c and CFMT scores were converted in percentages for visual purposes. RT are reported in milliseconds. Since BFRT-c's RT were measured in seconds, we added a specific scale in seconds for it (in purple).

(T1–T0) in the pooled NC group in Table S4 for clinicians to assess whether the difference score of a specific individual falls below the 5th and 10th percentile, or above the 90th and 95th percentile.

From Table 2, we can see that within each test measure, most of the participants remained stable, although some individual MTLE patients – in particular right ATL-resected patients – significantly improved on some test measures while others declined. Within each test measure (accuracy and RT), we calculated whether there was a greater number of patients presenting a reliable change (improvements and declines being considered together) in left or right MTLE (Fisher's exact tests, two-sided). None of the test measure showed a significantly greater number of reliable changes in one group compared to the other (all FDR-c $p > .05$). Even when considering improvements and declines separately, no significant difference in proportions was found between groups (all FDR-c $p > .05$).

Among patients showing reliable changes, we tried to identify whether some of them exhibited consistent changes on similar measures (e.g., improving mainly on RT, or face-related measures). We considered patients showing a reliable change in the same direction (either improvement or decline) on two or

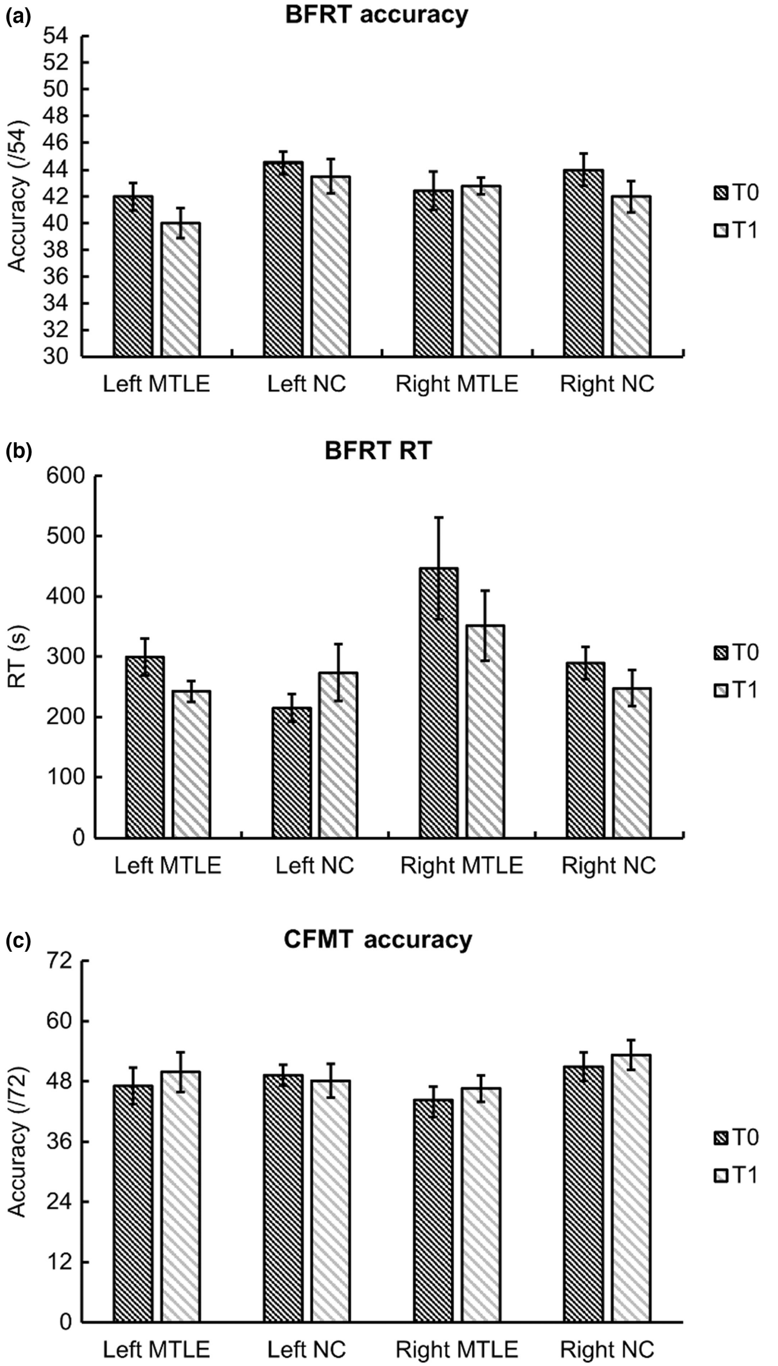

FIGURE 3 Accuracy and correct response times (RT) of left and right mesial temporal lobe epilepsy (MTLE) patients and their matched normal controls (NC) at two well-known unfamiliar face discrimination tasks, the BFRT and CFMT. Accuracy is reported on the original test scale (i.e., maximal score of 54 and 72 for the BFRT and CFMT, respectively). RT are reported in seconds and correspond to the average time taken to perform the task. Error bars represent standard error.

more measures evaluating similar constructs, and without any change in the other direction on the same constructs. These results highlight that a high proportion of right MTLE patients (5/15, 33.3%) but no left MTLE patients (0/9, 0%) improved on RT test measures, irrespective of face or non-face tasks.

TABLE 2 Percentage of left and right MTLE patients showing a reliable change in each test measure.

Cognitive tasks	Left MTLE %improvement	Left MTLE %no reliable change	Left MTLE %decline	Right MTLE %improvement	Right MTLE %no reliable change	Right MTLE %decline
Mooney face test						
Acc (%)	0 (0)	100 (8)	0 (0)	13.33 (2)	80 (12)	6.67 (1)
RT (ms)	0 (0)	100 (8)	0 (0)	0 (0)	100 (15)	0 (0)
BFRT						
Acc (/54)	0 (0)	100 (9)	0 (0)	14.285 (2)	71.43 (10)	14.285 (2)
RT (s)	11.11 (1)	88.89 (8)	0 (0)	21.43 (3)	78.57 (11)	0 (0)
Delayed matching task						
Cars						
Acc Up (%)	0 (0)	100 (9)	0 (0)	0 (0)	93.33 (14)	6.67 (1)
Acc Inv (%)	11.11 (1)	88.89 (8)	0 (0)	0 (0)	93.33 (14)	6.67 (1)
RT Up (ms)	0 (0)	100 (9)	0 (0)	20 (3)	73.33 (11)	6.67 (1)
RT Inv (ms)	11.11 (1)	88.89 (8)	0 (0)	33.33 (5)	66.67 (10)	0 (0)
Faces						
Acc Up (%)	11.11 (1)	88.89 (8)	0 (0)	13.33 (2)	86.67 (13)	0 (0)
Acc Inv (%)	11.11 (1)	77.78 (7)	11.11 (1)	13.33 (2)	80 (12)	6.67 (1)
RT Up (ms)	0 (0)	100 (9)	0 (0)	13.33 (2)	86.67 (13)	0 (0)
RT Inv (ms)	0 (0)	100 (9)	0 (0)	20 (3)	80 (12)	0 (0)
CELEB						
FRI (%)	11.11 (1)	88.89 (8)	0 (0)	20 (3)	73.33 (11)	6.67 (1)
NAI (%)	11.1 (1)	88.89 (8)	0 (0)	6.67 (1)	80 (12)	13.33 (2)
RT (ms)	11.11 (1)	77.78 (7)	11.11 (1)	20 (3)	60 (9)	20 (3)
CFMT						
Acc (/72)	11.11 (1)	88.89 (8)	0 (0)	16.67 (2)	66.67 (8)	16.67 (2)
Old/New tasks						
Faces						
Acc (%)	22.22 (2)	77.77 (7)	0 (0)	13.33 (2)	86.67 (13)	0 (0)
RT (ms)	0 (0)	100 (9)	0 (0)	40 (6)	60 (9)	0 (0)
Objects						
Acc (%)	22.22 (2)	66.67 (6)	11.11 (1)	6.67 (1)	86.67 (13)	6.67 (1)
RT (ms)	0 (0)	88.89 (8)	11.11 (1)	20 (3)	80 (12)	0 (0)

Note: Number of patients in each category is indicated in parentheses.

Abbreviations: Acc, Accuracy; FRI, Face Recognition Index; NAI, Name Access Index; RT, response times.

Among these five right MTLE patients, four exhibited a general improvement on RT test measures and one presented with an improvement on face-related RT test measures only (i.e., two face test measures showing a reliable change). On face accuracy measures (across all types of tasks, i.e., Mooney Face Test, BFRT, CFMT, Face Delayed Matching Task, Old/New Face, Face Recognition Index (FRI) of the CELEB), 11.1% (1/9) of left MTLE patients and 26.6% (4/15) of right MTLE patients improved, while 13.3% (2/15) of right MTLE patients declined. Among these patients with face-related reliable change, one left MTLE and two right MTLE patients improved on more than two measures of unfamiliar face discrimination (BFRT, CFMT, or Face Delayed Matching Task), and one right MTLE patient declined. Importantly, although this patient showed a reliable decline on unfamiliar face discrimination, her performance was within the normal range on the BFRT-c before and after ATL resection (pre-surgery: 52/54 in 239 s; post-surgery: 45/54 in 133 s) and the CFMT (pre-surgery: 70/72; post-surgery: 62/72).

We also counted the number of patients showing a reliable change in accuracy at learning unfamiliar faces, and recognizing and naming famous faces. Two left MTLE (22.2%) and two right MTLE (13.3%) patients showed a reliable improvement at learning unfamiliar faces, specifically for faces in three of them (i.e., no improvement observed at learning non-face objects, one left and two right MTLE). One left MTLE (11.1%) and one right MTLE (6.6%) showed a reliable improvement at naming famous faces (Name Access Index), while two right MTLE (13.3%) declined. Finally, one left MTLE (11.1%) and three right MTLE (20%) improved at explicitly recognizing faces (Face Recognition Index), while one right MTLE declined (6.6%).

Despite the small sample size, we tried to identify predictors of these reliable changes that were observed in several consistent test measures. We first considered the two categorical variables that were related to surgical outcomes: postoperative Engel I outcome at last follow-up (at least 2 years after surgery), and status of hippocampus. Among all patients classified as improving (improvements on RT and face accuracy considered together, $n = 9$; one left MTLE and eight right MTLE), eight (all right MTLE patients) were classified as Engel I postoperatively, and seven (all right MTLE patients) had a hippocampal sclerosis. Among the two patients who declined (both right MTLE), two still presented disabling epileptic seizures after ATL resection, and two had no hippocampal sclerosis. Fisher's exact tests showed no significant association between improving/declining status and the postoperative Engel I outcome (FDR-corrected $p = .080$) or the hippocampal status (FDR-corrected $p = .080$). Second, we tested continuous variables (T0 scores, age at inclusion, time between T0 and T1 assessments, time between surgery and T1 assessment, resection distance from tip of temporal pole along the ventral cortex, total IQ, age at onset of epilepsy, and duration of epilepsy) for correlations with T1 scores in all left and right MTLE patients respectively (see Tables S5 and S6). The only correlations that were still significant after FDR correction were positive correlations between scores at T0 and scores at T1 for the FRI (CELEB; $r = .94$), and the Mooney accuracy ($r = .92$) and RT ($r = .91$) in left MTLE patients, and for the BFRT-c's RT ($r = .83$), the FRI (CELEB; $r = .76$) and the Mooney accuracy ($r = .82$) and RT ($r = .81$) in right MTLE patients. In other words, patients with high performance in these measures at T0 were more likely to also have high performance at T1.

DISCUSSION

We assessed left and right MTLE patients before and after ATL resection with a range of face and non-face recognition/learning tasks. Our main findings are that (1) unfamiliar face discrimination performance remains stable after ATL resection, irrespective of the side of resection; (2) ATL resection has little to no effect on MTLE patient's performance at recognizing and naming famous faces, as well as learning and retrieving unfamiliar faces; (3) a third of right MTLE patients showed an overall improvement in RT, irrespective of task and stimuli.

Unfamiliar face discrimination abilities are mainly unaffected by ATL resection

Previous studies have showed either no effect of ATL resection on unfamiliar face individuation or only a small decline (Chiaravalloti & Glosser, 2004; Hermann et al., 1991, 1993; Seidenberg et al., 1998). However, these studies mostly relied on one single test, i.e., the BFRT. Here, we assessed unfamiliar face individuation with different tasks (BFRT, CFMT, Face Delayed Matching Task) and showed that, overall, behavioural performance of MTLE patients remained stable after ATL resection. This absence of difference cannot be due to a too small sample in the present study, as there was not even a hint of a decrease of performance at these tasks at the group level (Figures 2 & 3, Table 2).

Nonetheless, not all patients remained stable on unfamiliar face discrimination tasks. Specifically, one left and two right MTLE patients improved while one right MTLE declined. This latter patient still performed within the normal range on the BFRT-c and CFMT, i.e., the most widely used tests to evaluate unfamiliar face individuation, and did not complain about face identity recognition difficulties in daily life. This is in contrast with a report of an unfamiliar face individuation impairment in a patient explored 11 years after right ATL resection (subject 013 in Barton, 2008, with a BFRT score at 33/54, impaired at recognizing familiar faces, real life complaints). However, besides the lack of pre-operative measure in that study, the resection in this subject extended far more posteriorly, i.e., towards the posterior section of the ventral occipito-temporal cortex (VOTC), compared to the ATL resection undergone by our patient sample (Figure 1 for examples). Our findings also appear to differ with a few other case studies reporting unfamiliar face individuation disorders after a right ATL lesion not related to MTLE and lobectomy (head trauma, tumour resection, herpes simplex virus encephalitis; Busigny, Van Belle, et al., 2014; Pancaroglu et al., 2016). However, again, in these cases, the lesions were wider – or possibly wider (Busigny, Prairial, et al., 2014; Busigny, Van Belle, et al., 2014) – than those resulting from our ATL resection, especially towards posterior temporal regions. In contrast, brain damage restricted to the (right) ATL, due to, e.g., frontotemporal dementia or encephalitis, appears to lead to deficits restricted to the recognition of familiar faces (in the context of person agnosia) without difficulties at unfamiliar face recognition tasks (Busigny et al., 2009; Sergent & Poncet, 1990). Altogether, these studies suggest that an unfamiliar face individuation impairment could occur after ATL damage, but the lesion must be large, i.e., involving most of the ATL, as well as extending towards the posterior VOTC.

Here, we speculate that one specific ATL region could explain the discrepancies between these previous studies and our results. Recent intracerebral SEEG studies have highlighted a face-selective region in the posterior section of the anterior fusiform gyrus (AntFG; Jonas et al., 2016; Hagen et al., 2020), anteriorly to the well-known face-selective middle fusiform gyrus ("Fusiform Face Area", FFA; see Kanwisher et al., 1997). It is almost invisible in fMRI due to a large signal drop-out arising from magnetic susceptibility artefacts (Rossion et al., 2018; Volfart et al., 2022; Wandell, 2011). A recent large-scale mapping using intracerebral EEG recordings and frequency-tagging showed that the right AntFG is the most anterior VOTC region sensitive to unfamiliar face individuation (Jacques et al., 2020). This region is also the more anterior region – so far – for which electrical stimulation evoked a transient face identity recognition impairment (Jonas et al., 2015; Volfart et al., 2022; see Jonas & Rossion, 2021 for review). Importantly, in the most recent (and most documented) case report, direct electrical stimulation of this region evokes a transient impairment at matching pictures of both famous and unfamiliar faces for their identity, showing the causal role of this region in face individuation based primarily on visual inputs (Volfart et al., 2022). Thus, extensive lesions of the ATL might have affected the AntFG in studies mentioned above, while this region was surgically spared in our MTLE patient sample (for example, the critical site in the right AntFG of subject DN in Volfart et al., 2022 is located at 55 mm from the temporal pole, whereas the mean posterior limit of the ventral temporal resection in our right MTLE patients is located at 42.1 ± 6 mm from the pole; min: 28.3, max: 51; e.g., Figure 1).

Stable performance on learning, recognizing and naming faces

While difficulties in learning and naming non-face items (mostly words and common objects) frequently follow ATL resection (Helmstaedter, 2013; Ives-Deliperi & Butler, 2012; Sherman et al., 2011), less is known about the effect of ATL resection on learning unfamiliar faces and recognizing/naming famous faces.

Previous studies have shown that while MTLE patients are far from being comparable to cases of prosopagnosia, they have overall difficulties at recognizing and naming famous faces, either when tested preoperatively or postoperatively, with greater difficulties at naming famous faces in left MTLE patients and at judging face familiarity or providing semantic information about a face in right MTLE patients (Drane et al., 2008, 2013; Glosser et al., 2003; Hosokawa et al., 2021; Lambon Ralph et al., 2012; Rice et al., 2018; Volfart et al., 2020). Some of these studies have assessed both pre- and postoperative groups with a transversal design and have showed poorer performance in postoperative compared to preoperative patients (Drane et al., 2013; Glosser et al., 2003), although not systematically (Drane et al., 2008). However, the specific impact of ATL resection and the evolution of these functions after surgery in the same group of patients remain under-studied. One longitudinal study focusing on the comparison of cognitive outcomes after different surgical procedures (Drane et al., 2015) found a large proportion of patients (64.7%) declining at recognizing famous face identities after non-dominant open-resection (ATL resection or selective transcortical amygdalohippocampectomy). Unfortunately, the authors did not provide the reader with the proportion of patients declining specifically at naming famous faces. In contrast, we found no change at the group level, and only few patients exhibited a reliable change (see Table 2), with 8.3% and 8.3% of all patients improving or declining at naming famous faces, respectively, and 16.6% and 4.1% of all patients improving or declining at explicitly recognizing famous faces, respectively. Our results support the view that surgery had little or no effect on our patients' performance at recognizing/naming famous faces. Given that these patients were already impaired before ATL resection (Volfart et al., 2020) and their postoperative ability at recognizing famous faces (FRI) was significantly correlated with their preoperative performance (see Table S6), this stability is consistent with the view that neurocognitive outcome after surgery highly depends on preoperative performance, with postoperative cognitive declines more frequently observed in patients with good preoperative functioning and conversely (Baxendale et al., 2013; Helmstaedter, 2004; Helmstaedter & Elger, 1996; Hermann, Seidenberg, et al., 1995). This stability is therefore more likely related to an ATL dysfunction prior surgery, rather than to a possible degree of redundancy between semantic processes mediated by left and right ATL (Lambon Ralph et al., 2017) or to a functional reorganization as a shift of some functions to the contralateral healthy ATL (Binding et al., 2022; Foesleitner et al., 2020).

Several studies have assessed unfamiliar face learning and subsequent recognition in MTLE patients undergoing ATL resection. Patients after right ATL resection present with poorer performance, either when compared to left ATL resection or neurotypical controls (Warrington Face Memory Test: Després et al., 2011; Hosokawa et al., 2021; Moran et al., 2005; Morris et al., 1995; Camden Face Memory Test: Rice et al., 2018). Most longitudinal studies showed a decline after right but not left ATL resection (Warrington Face Memory Test: Dulay et al., 2009; Hermann, Connell, et al., 1995; Graduate Hospital Facial Memory Test: Chiaravalloti & Glosser, 2001, 2004). At the individual level, Dulay et al. (2009) reported that 20% of right patients declined after ATL resection. In our study, we did not find a significant change at the group level. At the individual level, four patients improved significantly at learning unfamiliar faces after ATL resection (two left and two right MTLE patients). The main difference with most previous studies is that we compared MTLE patients with normal controls preoperatively and showed that they already had difficulties at learning unfamiliar faces before ATL resection (Volfart et al., 2020). The only longitudinal study showing a stability of learning abilities after right ATL resection also showed that their patients were already impaired preoperatively, in agreement with our results (Chiaravalloti & Glosser, 2004). Altogether, these results suggest that ATL resection has little or no effect on learning new unfamiliar faces if MTLE patients are already impaired at this task preoperatively, even if the medial temporal structures known to be critical for long-term visual memory are resected (hippocampus, rhinal cortex). Again, this is consistent with the view that the neurocognitive outcome after surgery depends on preoperative performance, with postoperative cognitive declines more frequently observed in patients with good preoperative functioning (Baxendale et al., 2013; Helmstaedter, 2004; Helmstaedter & Elger, 1996; Hermann, Seidenberg, et al., 1995).

Improvement in response times in right MTLE patients

Even though we did not demonstrate a significant pre- to postoperative change in RT measures at the group level, probably because of high interindividual variability and low statistical power (small sample size), Figures 2 and 3 show a trend towards a general decrease of RT after right ATL resection.

At the individual level, 5 out of our 15 right MTLE patients (33.3%) presented with a reliable pre- to postoperative improvement in several RT measures across all tasks (detection, matching, learning, naming) and stimuli (face and non-face).

Preoperatively, right MTLE patients showed a general slowing of RT in virtually all tasks compared to their NC, suggesting a general slowdown in visuospatial processing (Volfart et al., 2020). At least two factors have been proposed to explain this slowdown: either a prominent role of the right hemisphere in sustaining visuospatial attention (with lower performance in patients with right-lateralized dysfunction; Becker & Karnath, 2007; Mesulam, 1981; Ringman et al., 2004; Thiebaut de Schotten et al., 2011) or a lower IQ in right than left MTLE (a strong association between processing speed and intellectual efficiency has been shown in many studies, see Sheppard & Vernon, 2008 for review).

The postsurgical improvement on RT measures observed in a third of right MTLE patients may be tentatively explained by the concept of nociferous cortex introduced in the 1950s (Helmstaedter et al., 2003; Hermann & Seidenberg, 1995; Penfield & Jasper, 1954; see also Bauman et al., 2019). This concept posits that the epileptogenic cortex adversely affects connected healthy regions and that these regions may be released after resection of the epileptogenic cortex. This may explain significant postoperative improvement in cognitive functions that are not supported by the resected epileptogenic cortex (e.g., improvement of executive functions after ATL resection; Hermann & Seidenberg, 1995). In our study, right-lateralized brain regions dominantly involved in visuospatial attention, mainly fronto-parietal, may have been affected by right MTLE and released after ATL resection, thus explaining the preoperative slowdown and the postoperative improvement specifically for the right MTLE patients. In line with this hypothesis, MTLE is associated with extra-temporal grey matter atrophy, especially in parietal and frontal lobes, illustrating the remote adverse effect of this pathology, potentially on brain regions supporting visuospatial attention (Coan et al., 2014). Moreover, consistently with this hypothesis, all five right MTLE patients who exhibited a reliable improvement on RT measures were classified as Engel I postoperatively (i.e., were free of disabling seizures), showing that the nociferous cortex was completely resected in these patients. However, even if this hypothesis is correct, this ATL nociferous cortex did not seem to affect face-selective regions located more posteriorly in the VOTC (AntFG, middle fusiform gyrus or FFA) as MTLE patients showed normal preoperative unfamiliar face individuation abilities and this function did not improve after surgery at the group level.

This general improvement in RT and the absence of RT increase specifically for face tasks further reinforce the idea that MTLE patients did not decline at face recognition. This observation contrasts with case studies of brain-damaged patients with prosopagnosia or visual object agnosia who, whether they perform within the normal range on accuracy scores at (unfamiliar) face identity recognition tasks or not, typically show a sharp slowdown at these tasks (e.g., patient LR with a score at 49/54 on the BFRT, but 55.18 s/trial; Bukach et al., 2006; see also Busigny & Rossion, 2010; Delvenne et al., 2004; Rossion et al., 2003; Schweinberger et al., 1995). Here, we clearly show that our patients do not fit into this category, since most of them exhibit stable performance at T0 and T1 with even a subgroup of right MTLE patients increasing their performance at T1. Moreover, this improvement in RT in a third of right MTLE patients was not specific to face test measures, and was observed also for non-face test measures (matching upright and inverted cars, learning non-face objects).

AUTHOR CONTRIBUTIONS

Angélique Volfart: Formal analysis; investigation; visualization; writing – original draft; writing – review and editing. **Bruno Rossion:** Conceptualization; methodology; resources; software; supervision; validation; writing – original draft; writing – review and editing. **Hélène Brissart:** Conceptualization; data curation; investigation; methodology; project administration; resources. **Thomas Busigny:** Conceptualization; methodology; resources; software. **Sophie Colnat-Coulbois:** Methodology; resources. **Louis Maillard:** Funding acquisition; methodology; project administration; resources. **Jacques Jonas:** Conceptualization; funding acquisition; methodology; supervision; validation; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY STATEMENT

Experimental data that support the findings of this study are openly available in OSF at https://osf.io/7muv8/?view_only=f01c78f94a694623b2b3d41ddad49c51.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1-S6

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