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Functional activity changes in memory and emotional systems of healthy subjects with déjà vu

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ABSTRACT

Déjà vu (DV) is a fascinating and mysterious human experience that has attracted interest from psychologists and neuroscientists for over a century. In recent years, several studies have been conducted to unravel the psychological and neurological correlates of this phenomenon. However, the neural mechanisms underlying the DV experience in benign manifestations are still poorly understood.

Thirty-three healthy volunteers completed an extensive neuropsychiatric and neuropsychological battery including personality evaluation. The presence of DV was assessed with the Inventory for Deja vu Experiences Assessment. Participants underwent episodic memory learning test, and 2 days later during event-related functional magnetic resonance imaging (fMRI), they are asked to rate old and new pictures as a novel, moderately/very familiar, or recollected.

We identified 18 subjects with DV (DV+) and 15 without DV (DV−) matched for demographical, neuropsychological, and personality characteristics. At a behavioral level, no significant difference was detected in the episodic memory tasks between DV+ and DV−. Functional magnetic resonance imaging analysis revealed that DV+, independently from task conditions, were characterized by increased activity of the bilateral insula coupled with reduced activation in the right parahippocampal, both hippocampi, superior/middle temporal gyri, thalami, caudate nuclei, and superior frontal gyri with respect to DV−. Our study demonstrates that individuals who experienced DV are not characterized by different performance underlying familiarity/recollection memory processes. However, fMRI results provide evidence that the physiological DV experience is associated with the employment of different neural responses of brain regions involved in memory and emotional processes.

1. Introduction

Déjà vu (DV) is a subjectively inappropriate impression of familiarity of present experience with an undefined past [1]. Although, it represents a common experience occurring in 0.8% of healthy individuals at least once in lifetime [2–5], DV is also frequently reported by patients with mesial temporal lobe epilepsy (MTLE), mainly with a familiar trend [5,6] as well as a common symptom in psychiatric disorders such as schizophrenia [7]. Although in recent years a considerable number of investigations have been carried out on the psychological mechanism of DV hypothesizing that this experience temporarily resulted from an erroneous activation of familiarity without recollection [8–10], the neural mechanisms underlying the DV experience are still poorly understood, especially in its benign manifestations.

In the clinical context, patients with epilepsy who experienced DV reported specific anamnestic features such as paranormal activity, remembering dreams, and travel frequency [11]. Electroencephalographic studies found that this kind of experience is associated with a specific pattern of neuronal activity of the mesial temporal regions and limbic systems such as the hippocampus, the amygdala, and the superior temporal gyrus [12–15]. Functional neuroimaging studies further confirmed this evidence reporting marked hypometabolism within the perirhinal/entorhinal cortex [16], whereas structural neuroimaging demonstrated

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that patients with epilepsy with DV are characterized by increased gray matter volume of the parahippocampal gyrus and the hippocampus together with the primary visual cortex [17].

However, this kind of evidence did not help to disentangle epileptic DV from "physiologic DV". In healthy subjects, few studies have investigated the neural basis of DV [4,17–19]. In the first neuroimaging study, Brázdil et al. [4] using a source-based morphometry approach described a set of anatomical regions including bilateral mesiotemporal regions, insular cortices, superior temporal sulci, basal ganglia, and thalami, which showed a reduction of gray matter volumes only in healthy controls experiencing DV [4]. This neural pattern strongly differs from those found by our group [17]. Using voxel-based morphometry (VBM), we only found reduced gray matter volume in the left insular cortex. Furthermore, a recent functional magnetic resonance imaging (fMRI) study found that the frequency of DV experience was correlated with the strength of the resting state functional connectivity between the parahippocampal gyrus and the dorsal lateral prefrontal cortex, two brain regions strongly involved with familiarity and recollection [19].

All these studies would seem to suggest that the experience of DV is embodied in the long-term memory and limbic systems. However, the neurophysiological mechanisms of DV remain still unclear. For this reason, we sought to study in healthy subjects with and without DV the neural functioning underlying DV in terms of the feeling of familiarity and recollection using brain functional correlates of the recognition process. According to previous literature, we hypothesized that processes underlying episodic memory are characterized by a different pattern of neural activity between subjects with and without DV [4,17,19]. We would expect that subjects with DV in recognition processing would display a different brain activity during recollection of familiar and unfamiliar objects with respect to individuals without DV.

2. Materials and methods

2.1. Participants

From January 2014 to June 2018, 102 right-handed healthy subjects were recruited from the University "Magna Græcia" of Catanzaro. Written informed consent was obtained from all participants, and the study was approved by the Ethical Committee of the University 'Magna Graecia' of Catanzaro, according to the Helsinki Declaration (http://www.wma.net/e/policy/b3.htm). Exclusion criteria were as follows: (1) evidence of neurological or psychiatric disorders (assessed with Structure Clinical Interview for Diagnostic and Statistical Manual of Mental Disorder-IV); (2) histories of substance abuse or other medical problems; (3) presence of vascular brain lesions, brain tumor, and/or marked cortical and/or subcortical atrophy on magnetic resonance imaging (MRI) scan; and (4) presence of cognitive impairment (Mini Mental State Examination (MMSE) score ≥ 24). After a careful evaluation of these exclusion criteria, 33 healthy subjects (18 with DV and 15 without DV) agreed to participate in the study and undergo brain fMRI evaluation. They underwent an accurate clinical and neuropsychological assessment to exclude asymptomatic neurological or psychiatric disorders. The Italian version of the Inventory for DV Experiences Assessment (I-IDEA), which is a 23-item self-administered questionnaire containing a general section of nine questions and a qualitative section of fourteen questions, was administrated [20]. The entire group underwent an extensive epileptologic interview and neuropsychological evaluation with the MINI DSM-IV diagnostic interview; Rey Auditory Verbal Learning Test (RAVLT), both Immediate and Delayed Recall; Modified Card Sorting Test (MCST); Rey–Osterreich Complex Figure Test (ROCFT), Copy, Immediate, and Delayed Recall; Trail Making Test (TMT); Stroop Color-Word Test; Controlled Oral Word Association Test (COWAT) Babcock Test Stroop Color-Word Test;; Beck Depression Inventory II (DBI II); and State-Trait Anxiety Inventory (STAI) Y 1–2. Moreover, all volunteers completed a computerized version of the Italian translation of the Revised NEO Personality Inventory (NEO-PI_R) questionnaire, a highly standardized measure of the five-factor model of personality [21]. Raw scores for each personality factor were converted in T-scores via a script written in SPSS (Statistical Package for Social Sciences, http://www.spss.it/) that used combined sex-norms reported in the NEO-PI-R manual.

2.2. Functional magnetic resonance imaging (fMRI) task

A set of 180 pictures of complex, black, and white scenes was selected representing both internal and external environments. They were randomly allocated to three sets of 60 scenes. Two of the three sets were shown at encoding, and all three were used at retrieval. A further 20 pictures, 10 representing internal and 10 representing external scenes, were used in practice trials before the experimental procedure. The experiment consisted of two phases, encoding and retrieval.

During encoding (Fig. 1A), subjects were asked to perform a forced-choice perceptual matching-to-sample task previously described by Montaldi [22,23]. In this test, they viewed three apparently identical scenes and had to state which of the two lower pictures was really identical to the upper one. To make it difficult, one of the two lower pictures was randomly shifted by only a few millimeters in one of its four sides, so that at first glance both lower pictures seemed a perfect copy of the upper one. The experimental procedure was performed using a home-made script, developed in a MATLAB (Mathworks®) environment, using the Psychophysics ToolBox extensions [24–26]. Each presentation was displayed on a 14"-screen personal computer for 4 s, with a 1-s cross displayed to separate each stimulus; subjects answered using a fORP four button box (Current Designs®, Philadelphia, PA, USA), pressing left or right button to indicate left or right lower scene as identical to the upper one. Instructions given to subjects before the task stressed the superficial nature of the scanning strategy that they had to adapt to succeed on the task within 4 s. The degree of similarity between the two choices was also emphasized. This task has been found to produce high levels of recognition and low levels of recall in healthy subjects [22,23]. Subjects viewed 120 presentations, corresponding to two of our stimuli datasets. Two days later, before retrieval phase, subjects were first trained how to give familiarity judgment about the scenes graded as weakly (F1) or strongly familiar (F2); secondly, subjects were also trained to distinguish recollection (R). We stressed them to focus on identifying how familiar a scene felt and that they should not try to recollect in an effortful manner, even though they were asked to state it when it happened. Afterwards, during the fMRI scanning (Fig. 1B), subjects were asked to make a familiarity (F1-F2), recollection (R), or novelty (N) judgment using the same button box they used during encoding. Each scene was separated by the others by a fixation cross lasting 1 s; moreover, 10 crosses, lasting on screen as long as trial scenes, were randomly intermixed to be used as baseline conditions. Subjects were trained not to answer anyway to these 10 crosses. Retrieval consisted of two fMRI sessions, each lasting 8 min and 40 s. During each session, 90 images and 10 baseline crosses were presented: subjects previously viewed only 60 out of 90 images during encoding. Participants viewed stimuli through a prismatic mirror attached to the head coil. For each subject, we collected "right" answers (F1-F2-R answers to "old" stimuli and N answers to "new" stimuli), null and/or miss answers, and "wrong" answers.

2.3. Data acquisition

Magnetic resonance imaging scanning was performed on a 3.0 T unit with an 8-channels head coil (Discovery MR-750, General Electric, Milwaukee, WI). Head movements during scanning were minimized using comfortable foam pads around participants' head. Functional magnetic resonance imaging data were acquired with echo planar images (EPIs) sensitive to the BOLD contrast (39 axial slices, 2.5-mm thickness each; repetition time: 2000 ms; echo time: 25 ms; voxel size: 2.5 × 2.5 × 3 mm). A total of 520 volumes (260 for each session) were acquired. A T1-weighted structural scan was obtained (368 sagittal slices, 1-mm

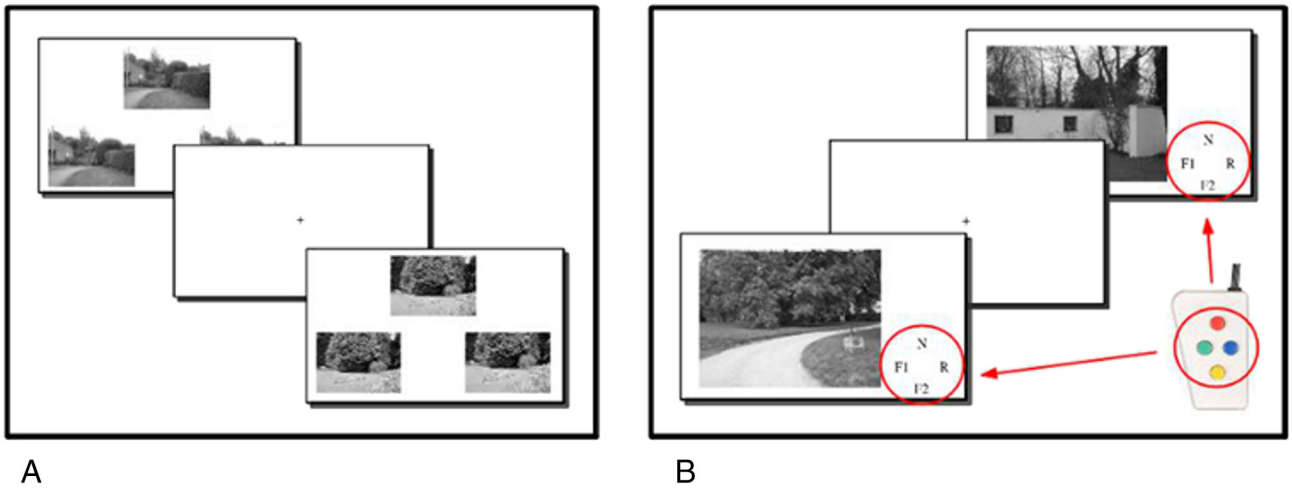

Fig. 1. A) During encoding, for each screen presentation, the top scene matches only one of the two lower scenes, the other is shifted vertically or horizontally by a small amount. Subjects had to identify the matching lower scene. B) During the fMRI scanning, individual scenes (or cross-hairs) were presented one at a time, and subjects pressed a key depending on whether they thought it was a new scene (N), whether it felt weakly (F1) or moderately (F2) familiar, or whether they effortlessly recollected something about its presentation (R).

thickness each; repetition time: 9.2 ms; echo time: 3.7 ms; voxel size: 1 × 1 × 1 mm) between the BOLD sessions.

2.4. Image processing

Functional magnetic resonance imaging data were preprocessed using Statistical Parametric Mapping (SPM8) (www.fil.ion.ucl.ac.uk/spm). The mean EPI was first computed for each participant and visually inspected to ensure that none showed excessive signal dropout. All EPIs were then realigned to the first scan by rigid body transformations to correct for head movements. Next, EPIs were normalized to the standard template in the MNI space (Montreal Neurological Institute (MNI)—International Consortium for Brain Mapping) using linear and nonlinear transformations, and smoothed with a Gaussian kernel of full width half maximum (FWHM) 8 mm. Realignment parameters were then inspected for each subject to make sure that movements of translation and rotation were <2 mm and 2°, respectively.

2.5. fMRI analysis of regional responses

To evaluate significant differences between subjects with (DV+) or without (DV−) DV experiences (as assessed by the I-IDEA questionnaire) in regional responses of brain areas implicated in familiarity and/or recollection processing, a two-stage process (first- and second-level), allowing inferences about general population from which the sample was drawn, was employed. For each subject, a general linear model (GLM) to evaluate regional brain effects of task parameters on BOLD (blood oxygenation level dependent) was employed [27]. The model included five experimental factors ("correct" N-F1-F2-R answers, i.e., F1-F2-R answers to "old" stimuli, seen during encoding, and N answers to "new" stimuli, and Rest Cross Epochs to be used as baseline condition) and six realignment parameters, which were included as covariates of no interest in order to account for residual motion-related variance. None of the participants had head movements >2 mm. Low frequency signal drift was removed using a high-pass filter (cutoff: 128 s), and an autoregressive modeling of temporal autocorrelations

Table 1
Demographic, clinical, and psychological data in healthy subjects with and without DV.

	DV+ (N = 18)	DV− (N = 15)	p-Value
Age	27.61 ± 5.33	31.33 ± 9.72	p = 0.15
Gender (M/F)	10/8	5/10	p = 0.20
Educational level (years)	15.14 ± 1.96	15.21 ± 2.01	p = 0.92
Rey Auditory Verbal Learning Test – Immediate Recall	49.92 ± 7.51	46.37 ± 8.35	p = 0.20
Rey Auditory Verbal Learning Test – Delayed Recall	9.88 ± 3.48	9.74 ± 2.56	p = 0.89
Modified Card Sorting Test	6.00 ± 0	6.00 ± 0	–
Rey–Osterreich Complex Figure Test – Copy	29.06 ± 2.12	28.83 ± 2.64	p = 0.78
Rey–Osterreich Complex Figure Test – Immediate Recall	14.07 ± 4.36	17.21 ± 5.25	p = 0.07
Rey–Osterreich Complex Figure Test – Delayed Recall	13.17 ± 5.09	15.62 ± 4.66	p = 0.16
Trail Making Test A	44.29 ± 7.67	39.14 ± 7.70	p = 0.06
Trail Making Test B	100.57 ± 33.35	103.36 ± 33.52	p = 0.81
Trail Making Test B-A	65.93 ± 22.94	71.21 ± 31.80	p = 0.58
COWAT	32.12 ± 8.07	29.39 ± 7.20	p = 0.30
Babcock Test	14.89 ± 1.63	14.74 ± 1.58	p = 0.79
Digit Span F	5.38 ± 1.25	5.59 ± 1.04	p = 0.61
Digit Span B	4.57 ± 1.09	4.21 ± 0.89	p = 0.31
Stroop Color-Word Test	23.86 ± 3.86	24.71 ± 4.72	p = 0.57
Beck Depression Inventory II	4.07 ± 4.53	3.00 ± 2.66	p = 0.42
STAI-I (state anxiety)	32.07 ± 8.22	35.14 ± 8.22	p = 0.29
STAI-II (trait anxiety)	32.57 ± 7.14	34.14 ± 7.42	p = 0.54
Neuroticism	54.54 ± 12.64	50.30 ± 9.97	p = 0.38
Extraversion	57.49 ± 8.06	54.22 ± 11.81	p = 0.44
Openness	51.17 ± 7.07	52.49 ± 8.92	p = 0.69
Agreeableness	45.20 ± 5.23	51.70 ± 10.86	p = 0.08
Conscientiousness	53.30 ± 11.72	57.47 ± 8.19	p = 0.33

Table 2
Differences between subjects with DV+ and DV− in the behavioral performances during fMRI task.

	DV+ (N = 18)	DV− (N = 15)	t-Value, p-Value
Number of answers	176.3 ± 4.4	176.3 ± 3.5	$T_{(31)} = 0.00$, $p = 1$
Number of correct answers	107.7 ± 11.6	106.2 ± 10.0	$T_{(31)} = -0.39$, $p = 0.70$
Number of correctly recognized "old" scenes: F1, F2, R answers	70.83 ± 17.56	74.14 ± 19.48	$T_{(31)} = 0.51$, $p = 0.61$
Number of correctly recognized "new" scenes: N answers	36.83 ± 9.81	32.64 ± 11.45	$T_{(31)} = -1.13$, $p = 0.27$
Number of missed answers	3.72 ± 4.41	3.78 ± 3.58	$T_{(31)} = 0.04$, $p = 0.96$

was applied. Consequently, contrast images assessing the effect of conditions 'N > Rest', 'F1 > Rest', 'F2 > Rest', 'R > Rest', and 'All conditions > Rest' were obtained for each participant. Group differences in brain responses to familiarity/recollection-based memory were then assessed via a full factorial model that involved two groups (DV+ and DV−) and four task conditions (i.e., the contrasts 'N > Rest', 'F1 > Rest', 'F2 > Rest', 'R > Rest') as main factors. Next, Fischer's SPM-related maps maps assessing the 'main effect of group', 'main effect of task responses', and the 'group by task response' interaction were generated. The analysis of second-level maps was restricted to a priori regions of interest that have been shown to play an important role in neural basis of DV in healthy controls and patients with epilepsy [4,17–19]. To this end, a single brain anatomical mask was created including thalamus, hippocampus, parahippocampal, basal ganglia, temporal cortex, sensorimotor cortex, prefrontal cortex, and insular cortex. We applied corrections for multiple comparisons as determined by Monte Carlo simulation at the cluster level using family-wise error correction implemented in the SPM REST plus software package [28]. This nonparametric method avoids inflation of false-positive rates occurring with cluster-level corrections [29,30]. It determines the number of contiguous voxels (k) needed to survive a cluster-wise corrected significance level. In this study, we performed Monte Carlo simulations running 10,000 iterations with an independent voxel threshold of $p < 0.001$ [28]. We applied a cluster-wise corrected threshold of $p < 0.05$. For each simulation, we estimated the inherent smoothness of the data within the mask using the smoothness estimation function of the toolbox entering each statistical F-map as input. The minimum required cluster size determined from the Monte Carlo simulations was 66, 98, and 110 voxels for the 'main effect of group', 'main effect of task responses', and the 'group by task response' interaction, respectively.

3. Results

3.1. Behavioral results

According to the I-IDEA questionnaire data, our sample was divided into two groups, subjects with DV (DV+, n = 18) and without DV (DV−, n = 15). None had a history suggestive of epilepsy. Groups did not differ in age, gender, and in a series of neuropsychological functions including working memory, verbal and spatial memory, verbal fluency, attention, and executive control. The two groups were also similar for anxiety, depression levels, and personality factors. The demographic and clinical characteristics of all participants are summarized in Table 1.

3.2. fMRI task-related behavioral performance

Behavioral data during the fMRI task are reported in Table 2. Overall, no differences were found between groups in the number of correct answers during the discrimination of previously seen or unseen scenes (DV+: 107.67 ± 11.62; DV−: 106.79 ± 10.01; $p = 0.82$). Moreover, no differences were found between groups regarding the number of total N, F1, F2, and R answers (Fig. 2).

3.3. fMRI task-related brain activity

During fMRI exams, none reported a feeling of DV. Concerning the main effect of group, independently from a task, we found significant differences between groups in the activation of several regions (Table 3). Of note, subjects with DV+ are characterized by neural changes in several brain regions, such as the right parahippocampal,

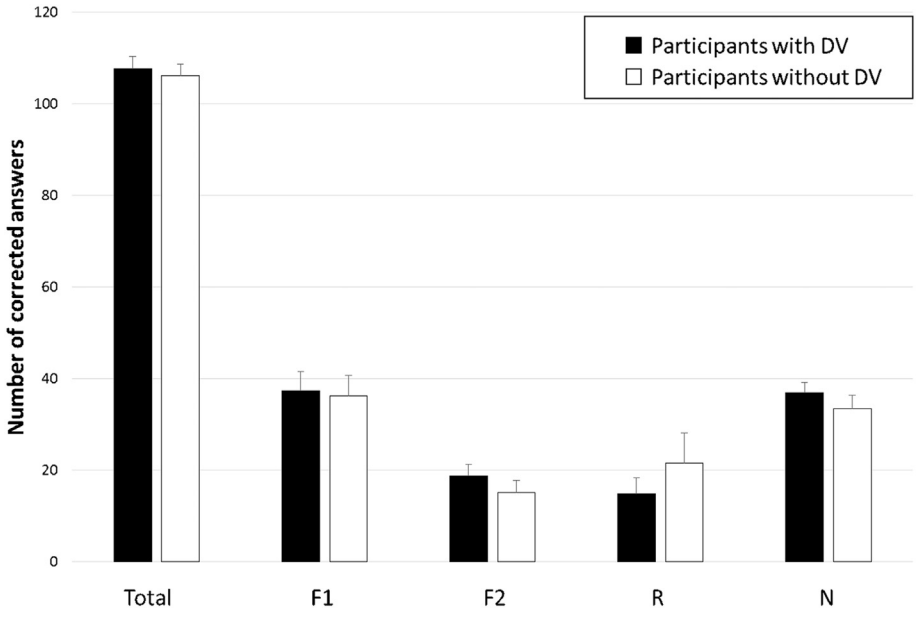

Fig. 2. Differences between subjects with DV+ and DV− in the behavioral performances during fMRI task.

Table 3
Main effect of group (DV+ vs DV−). Significant clusters were identified performing Monte Carlo simulations (10,000 iterations) with an independent voxel threshold of $p < 0.001$ and a cluster-wise corrected threshold of $p < 0.05$.

Main effect of group (DV+ vs DV−)					
Brain regions	Number of voxels	MNI coordinate local maxima			F local maxima
		x	y	z	
Right superior, middle, and inferior temporal gyri	1522	60	−48	10	64.28
Right parahippocampal/hippocampus/amygdala	120	18	−10	−18	23.26
Hippocampus/amygdala/parahippocampal					
Left and right thalamus	1774	−4	−8	8	50.51
Right fusiform gyrus	158	38	−76	−18	51.41
Left middle and inferior temporal gyri	101	−44	−64	2	25.51
Left and right anterior cingulum	528	8	44	8	25.26
Left insula gyrus	106	−34	10	6	20.78
Right caudate nucleus	125	10	2	8	19.75
Left caudate nucleus	173	−6	0	10	32.49
Left superior frontal gyrus	265	−16	24	42	46.59
Right superior frontal gyrus	99	16	38	42	18.05
Right superior parietal gyrus	86	20	−62	60	16.70
Right postcentral gyrus	129	34	−30	58	17.91

right middle temporal gyrus, and bilateral superior frontal gyrus when compared with subjects with DV−; moreover, they showed more activation in the left insula (Fig. 3). No significant differences were found in main effect of the task condition and group by task interaction.

4. Discussion

In this study, we investigated the neural correlates of the feeling of familiarity/recollection-based memory in healthy subjects with and without DV using a recognition fMRI task. We found that individuals with DV are characterized by different neural changes in brain areas involved in familiarity and recollection processes. Although we did not observe behavioral differences among groups during fMRI tasks, subjects with DV were characterized by a reduced activity within the right parahippocampal, bilateral hippocampi, temporal middle gyri, superior frontal gyri, thalami, and caudate nuclei when compared with healthy subjects without DV. Moreover, DV+ showed greater activity than DV− in the left insula. Of note, the differences in functional activations between the two groups were observed across all task conditions (recollection, familiar, and identification of new items), thus suggesting that physiological DV might be more linked to enduring cognitive predisposition rather than temporarily psychological experience.

A plethora of studies have investigated the role of temporal and hippocampal regions in the neural mechanisms that characterize recollection and familiarity processes showing strong association between structural alterations of these regions and DV phenomenon in both healthy controls and patients with epilepsy [4,17–19]. In a recent VBM study, we found an increased gray matter volume in the left hippocampus, parahippocampal gyrus, and left visual cortex in between benign MTLE with DV compared to MTLE without DV [17]. By contrast, healthy

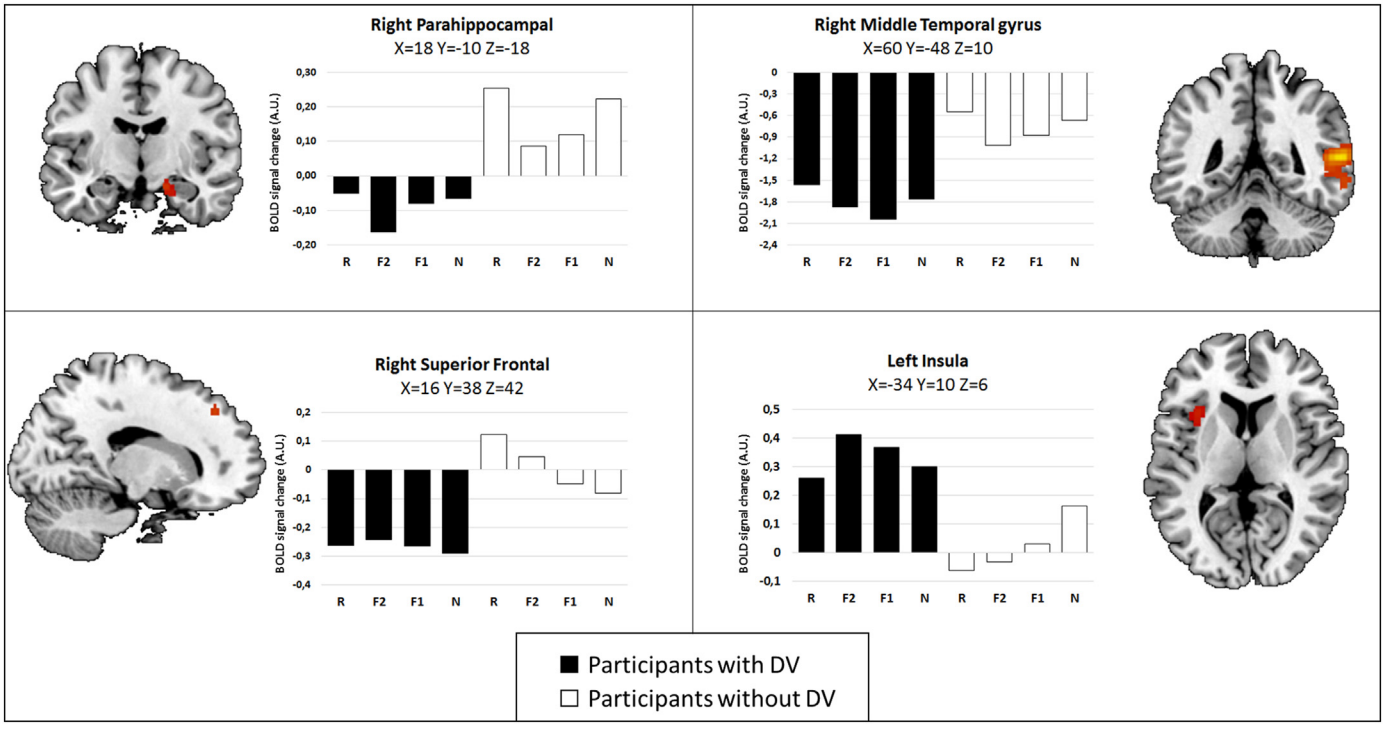

Fig. 3. Main effect of group: For each task conditions, healthy controls (HCs) with DV displayed reduced activity in the right parahippocampal, right middle temporal gyrus, and right superior frontal compared with HCs. Relative to DV−, HCs with DV showed increased activity in the left insula. Conditions: R = recollection answers > Rest Cross Epochs; F2 = strongly familiar answers > Rest Cross Epochs; F1 = weakly familiar answers > Rest Cross Epochs; N = new stimuli answers > Rest Cross Epochs. BOLD, blood oxygenation level-dependent signal; A.U., arbitrary unit.

controls having DV showed lower gray matter volume with respect to their respective counterparts without DV only in the left insular cortex [17]. Examining the variability in brain morphology in relation to the frequency of DV experiences, Brazdil et al. [4] observed a pronounced difference in gray matter volume within a widely distributed set of brain regions between healthy subjects with and without DV experiences [4]. In particular, individuals who had experienced DV showed a reduced gray matter volume in the amygdala, hippocampi and parahippocampal gyri, the basal ganglia, thalami, insula cortices, and superior temporal sulci compared with subjects without DV. Very recently, Qiu et al. [19] also observed that the anterior parahippocampal gyrus had significantly less gray matter volume in individuals with frequent DV compared to low frequency DV. These structural findings together with our functional results further confirm the strong involvement of the limbic system in the physiological DV experience.

Taken together, these results further confirm the strict relationship between DV experience and the neural mechanisms that characterized recollection and familiarity processes. Moreover, our findings provide new evidence on the involvement of limbic regions, such as the insula in the genesis of DV in healthy controls. Indeed, concerning the involvement of limbic system, insular cortex plays an important role as an emotional salience detector [31–34]. This region (mainly the anterior part) is a brain structure engaged during evaluation processes and conscious error perception. Thus, it is believed to operate as an inference between several cognitive, motor, and sensory activities also implicated in emotional experience, as well as, physical perception. Then, the insular hyperactivation observed in our study only in individuals DV+ could suggest a higher integration of interoceptive information and emotional experience [35,36]. Our result may explain the affective response experienced commonly reported during DV as already suggested by our previous structural study showing a reduced gray matter density in the insular cortex of healthy subjects with DV [17].

Another interesting finding of our study is the different activity of the prefrontal cortex and, particularly, of the superior frontal gyrus, between participants with and without DV. It is well-known that the right superior frontal gyrus is involved in the monitoring of the current scene and information retrieved from episodic memory [37,38]. In detail, there is substantial evidence that the anterior superior frontal gyrus is closely related to error detection and recognition between the current scene and episodic memory, while the posterior superior frontal gyrus is involved in making decision [39–45]. In fact, lesions of this brain region can result in deficits across a wide range of functions such as working memory, rule-learning, planning, attention, and motivation. In our study, we observed a decreased activity of the right superior frontal gyrus in subjects with DV, which could represent compensatory response to erroneous activation related to familiarity experience [46]. Moreover, our findings could be related to the negative association of the frequency of DV experiences with the strength of the functional connectivity between the anterior dorsal lateral prefrontal cortex and the anterior parahippocampal gyrus reported in a recent resting-state functional imaging study [19].

Despite DV continues to remain a complex phenomenon difficult to ascertain between clinical and physiological realms, in this study, we provide new evidence that this psychological feeling is not related to memory performance, although neural activity works differently. Indeed, during recollection phase, people with DV showed that neural systems underlying memory processes of familiar events are differently engaged with respect to individuals who did not feel DV. Exactly as already demonstrated for personality traits [47], DV experience may be considered as interindividual tendency to elaborate external information with a peculiar strategies and neural pathways. However, although our fMRI task could present limitations (i.e., small sample size), what it remains to be established is how triggering physiological DV in an experimental environment, considering that this phenomenon may result from different sources, such as a) changes in neural transmission from identical experience;, b) psychological illusion made by a brief split in a continuous perceptual experience, and c) implicit familiarity for some portion of a prior experience [9]. Future fMRI studies should also be conducted in patients with MTLE with and without DV in order to further characterize functional activity changes in pathophysiological mechanisms of DV experience, and then try to clarify whether there are some functional differences between healthy subjects and individuals with MTLE both suffering of DV.

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Declaration of competing interest

All authors report no conflict of interest.

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We confirm that we have read the journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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