Biological Psychology 133 (2018) 72–78

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Abnormal rsFC and GMV changes in parahippocampal and DLPFC for high Déjà vu experienced subjects

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ARTICLE INFO

Keywords:
Déjà vu
Familiarity
Recollection
DLPFC
Parahippocampal gyrus

ABSTRACT

How déjà vu works has long been a mystery, partially because of its characteristics of unpredictable occurrences and quick disappearances, which make it difficult to be explored. Previous studies have described the anatomical structures underlying déjà vu in healthy subjects; however, the functional mechanism of déjà vu remains unclear. Therefore, this study investigated the brain structural and functional components underlying déjà vu by combining voxel-based morphometry analysis (VBM) with resting-state functional connectivity (rsFC). The VBM analysis revealed that the anterior parahippocampal gyrus (PHG) had significantly less grey matter volume (GMV) in high déjà vu group than low group, confirming previous studies. Further functional connectivity analysis revealed that the frequency of déjà vu experiences was negatively correlated with the strength of the rsFC between anterior dorsal lateral prefrontal cortex (DLPFC) and anterior PHG but positively correlated with the strength of the rsFC between posterior DLPFC and posterior PHG. Moreover, the frequency of déjà vu experiences was negatively correlated with the strength of the rsFC between the anterior and posterior regions of the PHG. These findings indicated that familiarity without recollection (PHG) and superior context monitoring (DLPFC) are critical for real-life déjà vu experiences.

1. Introduction

The phenomenon of déjà vu, a subjective but inappropriate feeling of familiarity that a currently experienced event happened in the past, has attracted interests of psychologists and neuroscientists for over a century, yet still lacks of a widely accepted explanation. After the publication of the review article on déjà vu (Brown, 2003), there is growing interest in déjà vu experiences. Previous researches hypothesized that this experience temporarily resulted from an erroneous activation of familiarity without recollection (Brown, 2003, 2004; Cleary, 2008). Déjà vu experience is an error, though brain still perceives the error. Therefore the present study hypothesized that some higher-level cortices also participated in this psychological process.

A major theoretical standpoint in memory research is that memory retrieval includes two different processes: recollection and familiarity (Tulving, 1985). In brief, these two states map onto two distinct processes. Recollection is an effortful process of retrieving information, while familiarity is temporally and spatially bound to the current situation, and familiarity is necessary for the remembering of personally experienced events (Tulving, 1985). When a person remembers such an event, he will be aware of the event as familiar. Furthermore, recollection and familiarity have different physiological mechanisms (Diana, Reder, Arndt, & Park, 2006; Hales, Ocampo, Broadbent, & Clark, 2015). The posterior parahippocampal gyrus (PHG) supports recollection by encoding and retrieving contextual detail information, an effortful process (Aminoff, Kveraga, & Bar, 2013; Yonelinas & Ritchey, 2015), while the anterior PHG (such as the perirhinal cortex and entorhinal cortex), results in a sense of familiarity with a particular object by encoding and retrieving specific item information, a more automatic process (Diana, Yonelinas, & Ranganath, 2007; Elfman & Yonelinas, 2015).

In general, recollection and familiarity occur concurrently, while in some situations, there is a clash between recollection and familiarity. One theory of déjà vu suggests that people are not able to recollect

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https://doi.org/10.1016/j.biopsycho.2018.02.001
Received 6 November 2017; Received in revised form 5 January 2018; Accepted 1 February 2018
Available online 06 February 2018
0301-0511/

current scene; meanwhile, they feel that this scene is very familiar, and thus comes the déjà vu feeling (Brown, 2003). In some cases, a familiar element in the scene may over generalize this familiarity to the entire situation. In other cases, the familiar element may match something imagined in a dream (or daydream) (Brown, 2003) or observed in a movie (Wallisch, 2007). A variety of studies support this theory. In healthy subjects, studies have demonstrated that college students tended to report having this strange experience while they have more familiarity and less recollection (Brown & Marsa, 2008; Cleary et al., 2012; Cleary, Ryals, & Nomi, 2009; Sugimori & Kusumi, 2014). In pathologic studies, epileptics with impaired familiarity also felt déjà vu experience, which suggested a possible relationship between familiarity and déjà vu (Bowles et al., 2007; Martin et al., 2012). In neuroscience studies, researchers found the most marked brain structural difference between healthy subjects with and without déjà vu experiences was in the PHG, which is involved with familiarity and recollection (Brazdil et al., 2012; Labate et al., 2015). Above all, the occurrences of déjà vu experiences may involve the clash between recollection and familiarity. In addition, the frequency of déjà vu experiences may also be related to the individual difference of PHG.

However, the essential characteristic that distinguishes déjà vu experiences from the false memory is a subjective awareness of inappropriateness. Numerous types of evidence have indicated that the prefrontal cortex played a critical role in evaluative monitoring processes that guide memory decisions and helped to avoid memory errors (Chevrier, Noseworthy, & Schachar, 2007; Dobbins, Rice, Wagner, & Schacter, 2003; Fandakova, Lindenberger, & Shing, 2014; Navarro-Cebrian, Knight, & Kayser, 2016; Schacter & Slotnick, 2004). Recently, Urquhart and his team (2016) found that the frontal areas involved in decision making were also activated during déjà vu experience. Therefore, the prefrontal cortex might play an important role in the process of déjà vu.

According to previous reviews (Brown, 2003, 2004), the frequency of déjà vu experiences is a stable trait, and experimental tasks may cannot guarantee that déjà vu itself can be induced because participants are motivated to confirm what they perceived as the experimental interest (Jersakova, Moulin, & O'Connor, 2016). Therefore, this study used voxel-based morphometry (VBM) and resting-state functional connectivity (rsFC) methods to verify the hypothesis that déjà vu experience is a clash between recollection and familiarity. In the current study, the participants underwent MRI scans and psychological tests which included the Inventory for Déjà vu Experiences Assessment (Sno, Schalken, De Onghe, & Koeter, 1994). Firstly, we investigated different group in brain morphology between groups with high and low déjà vu frequency. Based on previous findings (Bartolomei et al., 2012; Guedj, Aubert, McGonigal, Mundler, & Bartolomei, 2010; Martin et al., 2012), we hypothesized that the high déjà vu group had significantly less grey matter volume (GMV) than the low déjà vu group in the anterior PHG. Additionally, we hypothesized that having more déjà vu experiences would be negatively correlated with the rsFC between the prefrontal cortex and the anterior PHG (familiarity) but positively correlated with the rsFC between the prefrontal cortex and the posterior PHG (recollection) (Achim & Lepage, 2005; Chevrier et al., 2007; Dobbins et al., 2003; Fandakova et al., 2014; Navarro-Cebrian et al., 2016; Schacter & Slotnick, 2004). This study aimed to explore morphologic and functional connectivity patterns in healthy individuals with déjà vu and to help to deepen our understanding of the cognitive process underlying déjà vu.

2. Materials and methods

2.1. Subjects

This study was part of our ongoing project to build a Gene-Brain-Behavior database. A total of 119 healthy volunteers participated in this study, but 21 participants were excluded due to large head motion (*FD* > 0.2 mm). Thus, the final sample was composed of 98 subjects (20 males; mean age = 20.00, SD = 1.56). Although female subjects are more than male, the frequency of déjà vu experiences showed no significant gender differences ($U(96) = 699.50$, $p = .40$). According to previous literature (Brazdil et al., 2012; Warren-Gash & Zeman, 2014), subjects were divided into two groups according to their answer to the critical question A1: 'Have you ever had the feeling of having experienced a sensation or situation before you are actually experiencing it for the first time in exactly the same way?' Respondents answering '3′ which means 'Yes, often (a few times a month)' or '4′ which means 'Yes, more frequently (a least weekly)' were categorized as high déjà vu group (n = 67) and respondents answering '1′ which means 'Yes, very infrequently (less than once per year)' or '2′ which means 'Yes, sometimes (a few times per year)' as low déjà vu group (n = 31). All subjects were from Southwest University, and recruited through the internet or advertisements. After providing written informed consent, participants completed the Inventory for Déjà vu Experiences Assessment and MRI scans. All study procedures were performed in accordance with relevant guidelines approved by the responsible committee for experiments involving human subjects of the Southwest University Brain Imaging Center Institutional Review Board. Importantly, before executing the experiment, the experimental protocols of behavior and brain were approved by the Southwest University Brain Imaging Center Committee. All subjects were right-handed, and they had no psychiatric disorders, mental disorders, or substance abuse (including drugs and alcohol).

2.2. Measures

The Inventory for Déjà vu Experiences Assessment (IDEA) (Sno et al., 1994) was used in this study. The IDEA consists of 23-item self-assessment questions, which including general section of nine questions and qualitative section of fourteen questions. Past research has shown that the IDEA has good reliability and validity (Sno et al., 1994). The Cronbach's α was 0.62 in this study.

2.3. Imaging data acquisition

All functional images were obtained from a 3-T Siemens Magnetom Trio scanner (Siemens Medical, Erlangen, Germany) at the Brain Imaging Research Central in Southwest University, Chongqing, China. The whole-brain resting-state functional images were acquired using T2-weighted gradient echo planar imaging (EPI) sequence: slices = 32, repetition time (TR)/echo time (TE) = 2000/30 ms, flip angle = 90°, field of view (FOV) = 220 mm × 220 mm, thickness = 3 mm, slice gap = 1 mm, matrix = 64 × 64, resulting in a voxel with $3.4 \times 3.4 \times 4\,mm^3$. During the functional images acquisition, participants were asked to close eyes lightly and keep still as much as possible. The scan lasted for 484 s and acquired 242 vols in total for each subject. Additionally, high-resolution T1-weighted anatomical images were acquired for each participant (TR = 1900 ms; TE = 2.52 ms; inversion time = 900 ms; flip angle = 9°; resolution matrix = 256 × 256; slices = 176; thickness = 1.0 mm; voxel size = $1 \times 1 \times 1\,mm^3$).

2.4. Structural MRI pre-processing procedures and analysis

The sMRI ($1 \times 1 \times 1\,mm^3$) data was processed with VBM-DARTEL using SPM8 (Welcome Department of Cognitive Neurology, London, UK; www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB 2012a (MathWorks Inc., Natick, MA, USA). Each sMRI was first displayed in SPM8 to check quality. Firstly, the reorientation of the images was manually set to the anterior commissure. Then, the images were segmented into gray matter, white matter, and cerebrospinal fluid by using the new segmentation tool in SPM8. Furthermore, we executed registration (MNI pace), normalization (FWHM = 10 mm), and modulation (Jacobian determinants derived from spatial normalization) using