Neuropsychologia 104 (2017) 76–91

Contents lists available at ScienceDirect

Neuropsychologia

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

Familiarity and recollection vs representational models of medial temporal lobe structures: A single-case study

Emilie Lacot[a,b,*], Stéphane Vautier[c], Stefan Kőhler[d], Jérémie Pariente[e], Chris B. Martin[f], Michèle Puel[e], Jean-Albert Lotterie[g], Emmanuel J. Barbeau[h]

[a] Université de Picardie Jules Verne, UPJV, Centre de Recherche en Psychologie: Cognition, Psychisme et Organisations, EA 7273 Amiens, France
[b] Centre d'Activité de Génétique Clinique et d'Oncogénétique – Centre de Référence des Maladies Rares, CHU Amiens-Picardie, France
[c] Université de Toulouse, UT2J, Laboratoire OCTOGONE-LORDAT, EA 4156 Toulouse, France
[d] Brain and Mind Institute, Department of Psychology, Western University, London, Ontario, Canada
[e] Service de Neurologie, CHU Toulouse-Purpan, INSERM - UMR 1214, Toulouse, France
[f] Memory & Perception Lab, Department of Psychology, University of Toronto, Ontario, Canada
[g] Département de médecine nucléaire, CHU Toulouse-Rangeuil, INSERM - UMR 1214, Toulouse, France
[h] Université de Toulouse, UPS, Centre de Recherche Cerveau et Cognition, CNRS - UMR 5549, Toulouse, France

ARTICLE INFO

Keywords:
Recall
Recognition
Familiarity
Recollection
Memory
Representational account
MTL
Human

ABSTRACT

Although it is known that medial temporal lobe (MTL) structures support declarative memory, the fact these structures have different architectonics and circuitry suggests they may also play different functional roles. Selective lesions of MTL structures offer an opportunity to understand these roles. We report, in this study, on JMG, a patient who presents highly unusual lesions that completely affected all MTL structures except for the right hippocampus and parts of neighbouring medial parahippocampal cortex. We first demonstrate that JMG shows preserved recall for visual material on 5 experimental tasks. This finding suggests that his right hippocampus is functional, even though it appears largely disconnected from most of its MTL afferents. In contrast, JMG performed very poorly, as compared to control subjects, on 7 tasks of visual recognition memory for single items. Although he sometimes performed above chance, neither familiarity nor recollection appeared fully preserved. These results indicate that extrahippocampal structures, damaged bilaterally in JMG, perform critical operations for item recognition; and that the hippocampus cannot take over that role, including recollection, when these structures are largely damaged. Finally, in a set of 3 recognition memory tasks with scenes as stimuli, JMG performed at the level of control participants and obtained normal indices of familiarity and recollection. Overall, our findings suggest that the right hippocampus and remnants of parahippocampal cortex can support recognition memory for scenes in the absence of preserved item-recognition memory. The patterns of dissociations, which we report in the present study, provide support for a representational account of the functional organization of MTL structures.

1. Introduction

Medial temporal lobe (MTL) structures include the hippocampus, the amygdala as well as neighbouring extrahippocampal structures that include the entorhinal, perirhinal and parahippocampal cortices, and the medial temporal pole. Although it is known that these structures support declarative memory (Cohen and Squire, 1980; Stefanacci et al., 2000) and that they function largely in an integrated manner, they also have fascinated scientists due to their diversity of architectonics and circuitry, suggesting that individual structures may make unique functional contributions. With this regard, selective lesions of MTL structures have been highly informative in the long-standing quest to understand how these different brain structures support memory. However, most case reports have focused on isolated bilateral lesions of the hippocampus with preservation of anterior extrahippocampal structures (Aggleton et al., 2005; Bastin et al., 2004; Holdstock et al., 2005; Mayes et al., 2002; Turriziani, 2004), a bias due to the large variety of neurological conditions that can affect the hippocampus. Such lesions usually induce amnesia and impair recollection, *i.e.,* the ability to retrieve information with their context of acquisition. Whether such lesions also impact recognition of previously encountered items, and if so, under what circumstances, remains a matter of intense

* Correspondence to: Université de Picardie Jules Verne, CRP-CPO, Bâtiment E. Chemin du Thil, 80025 Amiens Cedex 1, France.
E-mail address: emilie@lacot.net (E. Lacot).

http://dx.doi.org/10.1016/j.neuropsychologia.2017.07.032
Received 12 May 2017; Received in revised form 26 July 2017; Accepted 27 July 2017
Available online 29 July 2017
0028-3932/

debate (Manns et al., 2003; Manns and Squire, 1999; Montaldi and Mayes, 2010; Reed and Squire, 1997; Yonelinas et al., 2010). Accordingly, progress remains to be made in our understanding of the functional organization of MTL structures.

In this study, we report on a highly atypical pattern of lesions in JMG, a patient who suffered from a meningo-encephilitis. In contrast to previous patients, extrahippocampal structures were largely destroyed, along with the left hippocampus. The only preserved MTL structure appears to be the right hippocampus, with visible remnants of surrounding parahippocampal cortex in place as well. This patient thus presents a very rare lesion pattern which, to the best of our knowledge, has never been studied in depth up to now (with the exception of an approaching case reported in Delbecq-Derouesné et al., 1990). As this patient has an unusual lesion pattern, we expected that it would help shed light on the functional organization of the MTL.

The hippocampus and related structures of the extended hippocampal system are thought to be critical for recall (defined as the ability to retrieve information from memory in the absence of pertinent stimulus cues) (Hannula et al., 2013; Tompary et al., 2016). However, medial temporal structures are usually viewed as being hierarchically organized, with the pattern of anatomical connections between these structures placing the hippocampus at the top of this hierarchy (Mishkin et al., 1997; Suzuki and Amaral, 1994). Following this view, lesions of extrahippocampal structures that preserve the hippocampus should impair recall, because the afferences to the hippocampus would then be damaged. However, the hierarchical view of MTL organization has recently been questioned (Aggleton, 2013; Vann, 2010). Therefore, our first aim was to investigate the status of recall in JMG.

Given that the right hippocampus is preserved in JMG, what prediction can be made regarding the status of recognition memory? Preserved recollection, and hence partially preserved recognition memory performance, could in principle be predicted based on models arguing that the hippocampus supports recollection whereas perirhinal cortex and neighbouring parahippocampal gyrus supports familiarity (Aggleton and Brown, 1999; Bowles et al., 2007; Brown and Aggleton, 2001). Only two patients presenting with isolated damage to anterior subhippocampal structures (perirhinal or entorhinal cortex), preserving the hippocampus, have reported supporting this view (Bowles et al., 2007; Brandt et al., 2016). How JMG fits with these previous cases, although his lesions are much larger, could be particularly significant. A second aim of the current study was, therefore, to shed further light on this issue by investigating whether recognition memory was preserved and relied on familiarity, recollection or on both processes. We were specifically interested in determining whether any above-chance performance in recognition memory tasks would be related to partially recollection.

An alternate account of the functional organization of MTL structures that has been proposed in recent years, emphasizes the type of representation that different structures support (Cowell et al., 2010; Ranganath, 2010; Shimamura, 2010). In particular, it has been argued that the perirhinal cortex may be part of a larger system involved in object processing, *i.e.,* the visual ventral stream. The hippocampus, by contrast, has been proposed to play a comparable role in scene processing, perhaps based on additional connectivity with the dorsal visual stream (Murray et al., 2007). Following such representational account of MTL organization, one might more specifically predict that our patient would be impaired on recognition memory tasks for single-items such as objects or abstract patterns, but would perform better on recognition memory tasks for scenes (for a recent review, see Lee et al., 2012). This idea is further supported by the fact that the medial part of the right parahippocampal cortex appeared preserved in JMG, and that this area is also known to play a critical role in scene processing (Epstein and Ward, 2010; Habib and Sirigu, 1987; Maguire et al., 1998; O'Craven and Kanwisher, 2000). Accordingly, an additional aim of the present study was to investigate JMG's recognition abilities for scenes in more detail, and to obtain corresponding measures of familiarity and recollection.

Here, we report an extensive investigation of JMG's memory abilities that includes 15 experiments, which we grouped into three sections. All were based on visual material, as a previous study highlighted systematically impaired performances for verbal material in JMG (Barbeau et al., 2011), and given the role of the right hemisphere in visual processing. In the first section, we conducted 5 experiments to investigate visual recall. In the second section, we focused on familiarity and recollection for single items (7 experiments), while in the third section we focused on familiarity and recollection for scenes (3 experiments). Hence, our goal was to evaluate whether and how JMG's pattern of performance, across these different sections, would fit with current conceptions of the role of the MTL in memory.

2. Patient and methods

2.1. Case description

JMG was born in 1954. He is right-handed (Edinburgh handedness evaluation: 90%). He attended regular school until the age of 16 at which time he switched to professional training as a hairdresser. He then obtained his first-level diploma (CAP). He contracted meningo-encephalitis in July 1974 at the age of 20 during his military service. He was treated in a military hospital in the Pacific and not much information is available from this period. He had hyperthermia and convulsions, was confused and remained comatose during five weeks. Weight loss was severe. His condition was serious and, for several weeks, the medical staff feared for his life. He was treated with unspecified antibiotics. He was sent back to a military hospital in Paris in September and back home in November 1974. He was then described as having severe memory difficulties. He did not undergo any kind of rehabilitation program.

Following this period, JMG was able to resume a normal life by himself. He managed to resume professional training as a hairdresser, and qualified successfully for his second-level diploma (BEP) after his second attempt in 1976. He then worked for nine years in three different barbershops, providing a perfectly satisfactory service. He opened his own barbershop in 1985, which he managed alone, including staff. He lived alone, caring for himself until 1993. He was socially active. He liked dancing and this is how he met his wife whom he married in 1993. JMG is well aware of his difficulties (*i.e.*, no anosognosia) and probably very good at concealing them. His behaviour appears normal for most people, including customers. His main complaint is related to person knowledge, a deficit that he managed to overcome during his professional life; he used to resort to various strategies to identify usual customers, although he was not able to recognize them in a standard way.

An intriguing feature of JMG, considering the extent and location of his lesions, is that a few years after his disease he spontaneously became very fond of leisure that were related to spatial cognition. For example, he started biking frequently. He estimates, using his bike monitoring system, that he bikes about 12–16000 km each year. He always bikes alone, using different roads back and forth. JMG also started learning French geography, and he has since then acquired a lot of knowledge about French cities, departments and regions. Overall, it seems that spatial memory was largely preserved.

2.2. Lesion documentation

In 2007, MRI imaging was carried out after a medical examination diagnosed that JMG suffered from a psychological fatigue. MRI revealed normal frontal, parietal and occipital lobes but very extensive and severe lesions of the temporal lobes bilaterally extending to the insula (Fig. 1). The total lesion volume was estimated to be 109 cc. The most notable finding was that all MTL structures (temporal pole, amygdala, perirhinal, entorhinal and parahippocampal cortices,

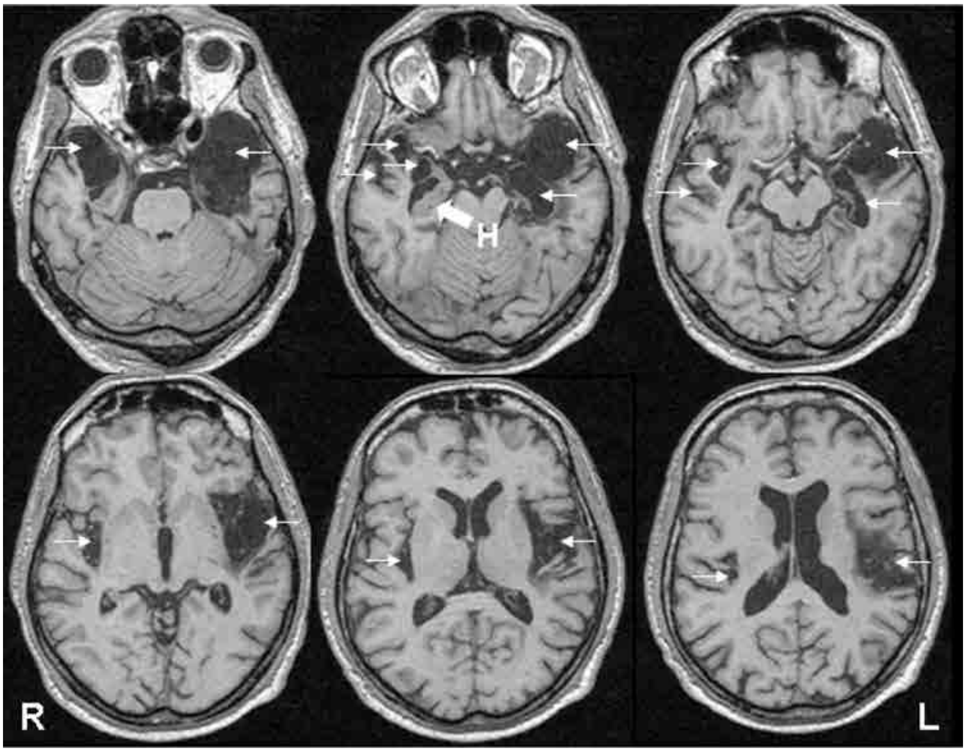

Fig. 1. axial T1-weighted MRI slices aligned to the bi-commissural plane. The small arrows indicate the different lesions. H indicates the remaining right hippocampus. L: left, R: right.

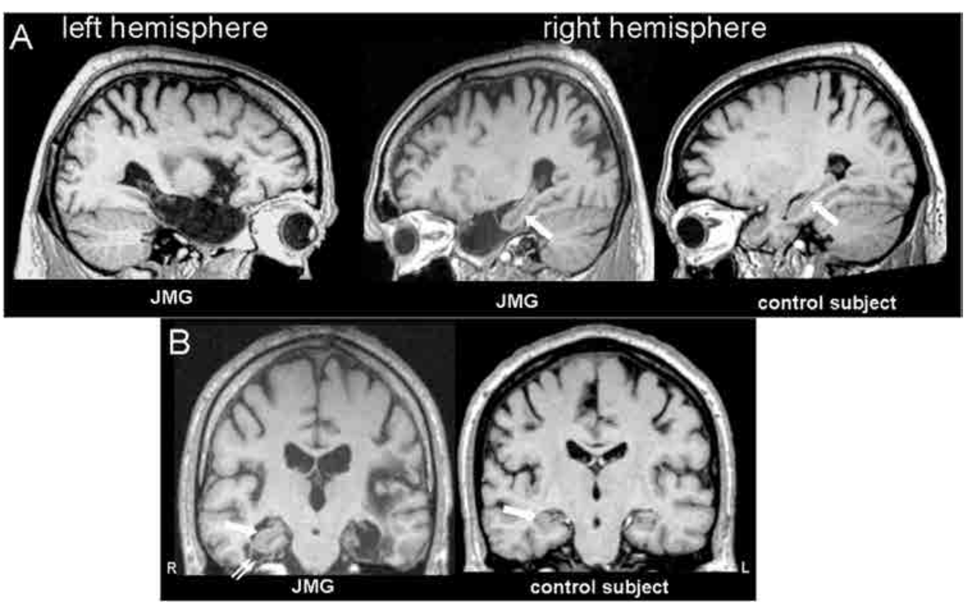

Fig. 2. MRI of JMG and of a representative control participant. The MRI of both subjects was normalized using the SPM template to show the slices at the same level. A) Sagittal slices. B) Coronal slices. The reduced length of JMG's hippocampus can be observed on the sagittal slice (large arrow). The thickness of his hippocampus compared to the control subject can be observed on both sagittal and coronal slices (large arrows). Note the extrahippocampal lesion on the right (double arrow) indicating that the lateral parahippocampal cortex is damaged.

hippocampus) were either completely destroyed or extensively damaged, except for the right hippocampus, which appeared to be the only preserved structure (Fig. 1 and Fig. 2). Manual segmentation indicated that its overall volume was 85%, significantly below the mean of a group of 16 control subjects matched in age ($p = 0.02$). Loss of tissue probably affected its anterior part as the distance between the rostral pole and the hippocampal head was greater than for any control participant ($p = 0.01$). As one would expect, the length of the hippocampus was also shorter (34.1 *vs.* 41.7 mm, $p = 0.003$). The only other structure that appeared partially preserved was the right parahippocampal cortex. While the structure was severely damaged laterally, the medial part appeared to be relatively intact (Fig. 2). Patches of residual tissue could also be observed where the right amygdala should have been and along the right subiculum.

Despite this loss of volume, the right hippocampus appeared unusually thick compared to control subjects, a phenomenon clearly visible on JMG's MRI (Fig. 2). We linearly regressed the volume of the hippocampus against its length in the group of control subjects. We thus obtained a model of volume prediction. Using this model, volume variability in the control group was small (± 7%). However, JMG's right hippocampus volume showed a 57% increase compared to what was predicted by its length (z-score = 7.8, $p < 0.001$). JMG's overall intracerebral volume (including the lesion volume estimations) was slightly lower than control subjects (z-score = −0.75) and thus did not appear to explain the increased hippocampal thickness.

2.3. General assessment

JMG's verbal IQ was at 84, his performance IQ at 100, and his total IQ at 90 (mean = 100, SD = 15, WAIS-III, Wechsler, 2000). His general delayed memory index was 71 (−1.9 SD below control subjects) without any difference between verbal and visual memory (delayed MQ = 72 each, −1.9 SD) (mean = 100, SD = 15, WMS-III, Wechsler, 2001).

JMG's memory for verbal material was tested using free and cued recall, as well as recognition tasks, but was found to be systematically impaired, in accordance with his large left MTL lesions (Barbeau et al., 2011).

2.4. Experiments

JMG participated in a set of 15 experiments, including five tests of recall of visual material and 10 tests of visual recognition memory. Recall experiments involved the use of paper and pencil; copies from memory were rated in terms of visual detail and reaction times were obtained as well. Visual recognition memory tasks were computerized and stimuli were presented using E-prime v.1.2 (Schneider et al., 2002). As there are a large number of different experiments reported in this study, the methods for each experiment are presented before each result rather than in the Methods section for the sake of clarity.

2.5. Control subjects and statistical analyses

It would have been very difficult to find control subjects agreeing to follow all 15 experiments of the current study. Consequently different groups of control subjects (minimum 10 control subjects per experiment) were used. We acknowledge the possibility that the use of different groups of control subjects might have had an effect on the results. However, the number of experiments and the fact that results were congruent should limit this effect. The characteristics of each group, as well as which experiment they underwent are described in Table 1. JMG was between 57 and 58 at the time of assessment and had 11 years of education. All subjects were matched with JMG regarding age and years of education (all $p > 0.05$ using SINGLIMS_ES, Crawford and Garthwaite, 2002; Crawford and Howell, 1998).

Recognition memory performance was calculated using *d*-prime (corrected according to Snodgrass and Corwin, 1988), a measure of the ability to discriminate targets and distractors. Different indices were used to calculate familiarity and recollection (described for each experiment below). To compare JMG's scores with those of control subjects, we used a modified *t*-test enabling a comparison between an individual's score and a small control sample (Crawford and Howell, 1998). The test was implemented using the program SINGLIMS_ES (Crawford and Garthwaite, 2002; Crawford and Howell, 1998). Given that the existing theory supports the idea that JMG should present scores lower than control subjects, a unilateral hypothesis was used and the level of significance was set at $p < 0.05$. Furthermore, we plotted for each analysis the individual performance of each control subjects along with that of JMG. This easily allows readers to assess whether JMG's performance is within or outside the distribution of control subjects' performance.

Table 1
Overview of control subjects' characteristics for each experiment. JMG was between 57 and 58 at the time of assessment and had 11 years of education. Five control groups were used. Group B was composed of the participants from group A and 8 other participants. Group C was composed of 7 participants from group A and 3 other participants.

	Group A	Group B	Group C	Group D	Group E
N	10	18	10	10	10
Gender (F/M)	6/4	10/8	5/5	5/5	7/3
Age (mean, SD)	57.8 (4.1)	56.9 (4.5)	57.2 (3.6)	54.2 (3.8)	63.5 (7.6)
Educ. Level (mean, SD)	10.9 (3.0)	11.8 (2.9)	10.5 (2.3)	14.2 (4.7)	12.3 (2.5)
Experiments					
Recall	1–4	5			
Single item recognition	9–10	11	6	7–8	12
Scene recognition	13–15				

3. Results

3.1. Visual recall

We used five different tests to assess visual recall, varying the nature of encoding (incidental *versus* intentional), type of material, and delay. The same ten control subjects (Table 1) were tested for experiments 1–4. Results are displayed in Fig. 3 and Fig. 4.

3.1.1. Experiment 1: VPT test

3.1.1.1. Materials and procedures. The VPT (Della Sala et al., 1999) is a paper test assessing visual memory. Different checkerboards were presented to the participants in an ascending level of difficulty (grids progress from a 2 × 2 matrix with two black cells to a 5 × 6 matrix with 15 black cells). Learning of each grid lasted 10 s. The delay lasted one minute and was filled with the Corsi block-tapping task. Subjects were then instructed to recall the correct position of the black cells by darkening squares in an empty grid. We used version A of this test and learning was intentional.

3.1.1.2. Results. JMG's level of performance was higher than that of control subjects (JMG: 9.2 points; mean: 8.2 points, SD: 2.7; $t(9) = 0.35$, $p = 0.37$) (Fig. 3A).

3.1.2. Experiment 2: Rey-Osterreich simple figure (Rey, 1959)

3.1.2.1. Materials and procedures. This figure is a very simple drawing –without complicated details– usually used for children. JMG was explicitly instructed to learn the figure, without copying it, during two minutes. Recall took place after 25 min.

3.1.2.2. Results. JMG's score was within the normal limits in terms of accuracy; it was below control subjects' average but higher than that of two of them (JMG: 15.0 points; mean: 18.7 points, SD: 2.98; $t(9) = -1.18$, $p = 0.13$) (Fig. 3A).

3.1.3. Experiment 3: Taylor's figure (Taylor, 1969)

3.1.3.1. Materials and procedures. As compared to the previous task, the Taylor's figure is composed of more specific and complex details. Learning was incidental and based on the copy of the figure. For the recall phase, JMG was instructed to reproduce the figure immediately from memory. After a delay of 15 min, JMG was asked to draw the figure again.

3.1.3.2. Results. JMG's scores were within normal limits in terms of accuracy: his immediate recall score was above one participant and his delayed recall score was above three of them (JMG: 18.0 points; mean: 25.4 points, SD: 8.28; $t(9) = -0.85$, $p = 0.21$). There appeared to be no loss of detail between immediate and delayed recall as JMG obtained the exact same score in both phases (Fig. 3A).

3.1.4. Experiment 4: Toulouse's figure

3.1.4.1. Materials and procedures. We developed a new complex geometric figure for the purpose of this experiment (Fig. 3B). In this case, we used intentional learning without immediate recall. JMG was instructed to memorize the figure during three minutes with the aim to reproduce it with as much detail as possible. After a delay of 20 min, he was asked to draw the figure from memory.

3.1.4.2. Results and discussion. Despite the increased delay between

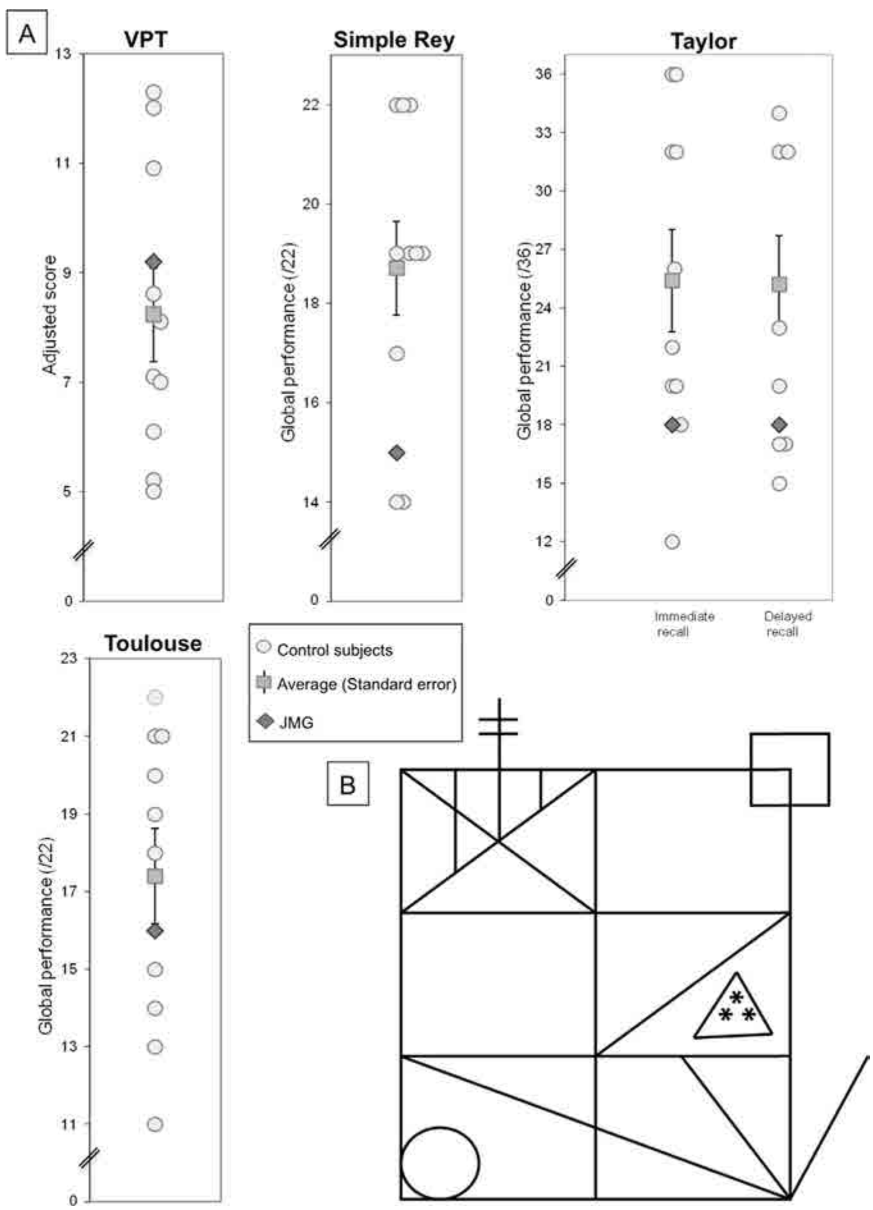

Fig. 3. Results of JMG and ten age/level matched controls for the four visual recall tasks. The Toulouse figure is presented in B.

study and recall, JMG's score was within normal limits in terms of accuracy, and above four control subjects (JMG: 16.0 points; mean: 17.4 points, SD: 3.86; t (9) = −0.35, p = 0.37) (Fig. 3A).

3.1.5. Experiment 5: R^2 test - assessing recall and recognition for the same material – recall part

This novel test was developed with the aim to evaluate recall and recognition using the same encoding phase. Fig. 4 displays the design and the results of this experiment. We focus on the results of the recall phase. The results of the recognition phase are presented below.

3.1.5.1. Materials and procedures. Participants were instructed to memorize 13 black and white abstract pictures presented on a computer screen one by one during the encoding phase. After a distraction phase of five minutes, participants were asked to draw from memory all abstract picture they could remember. Their drawings were scored by two independent raters on a scale of zero to three. The correlation between both raters showed high inter-rater concordance (r = 0.98). Two scores were derived from this procedure: 1) the total number of figures reproduced that obtained a score of at least 1 (meaning they were recognized by the raters as drawings of one of the stimuli), 2) a normalized score corresponding to the quality of the production: total score / (total number of figures reproduced * 3).

3.1.5.2. Control subjects. 18 controls were tested (Table 1).

3.1.5.3. Results. JMG was able to draw two pictures rated at least 1, in the same range as control subjects (mean = 3.22, SD = 2.13, t (17) = −0.56, p = 0.29). His normalized score was above four controls' scores (JMG: 0.33 points; mean: 0.46 points, SD: 0.20; t (17) = −0.63, p = 0.27) (Fig. 4).

3.1.5.4. Summary of the visual recall tasks. The points estimate for the effect size (z_{cc}, see Crawford et al., 2010) for the comparisons of JMG to controls varied from −1.24 (Experiment 2) to 0.37 (Experiment 1). Overall, there was no significant difference between JMG and controls performances across the five recall tasks (JMG: 55.5%; mean: 63.9%, SD: 13.9; t (9) = −0.58, p = 0.29 – z_{cc} = −0.60), and his performance was above the level of some control subjects in all experiments.

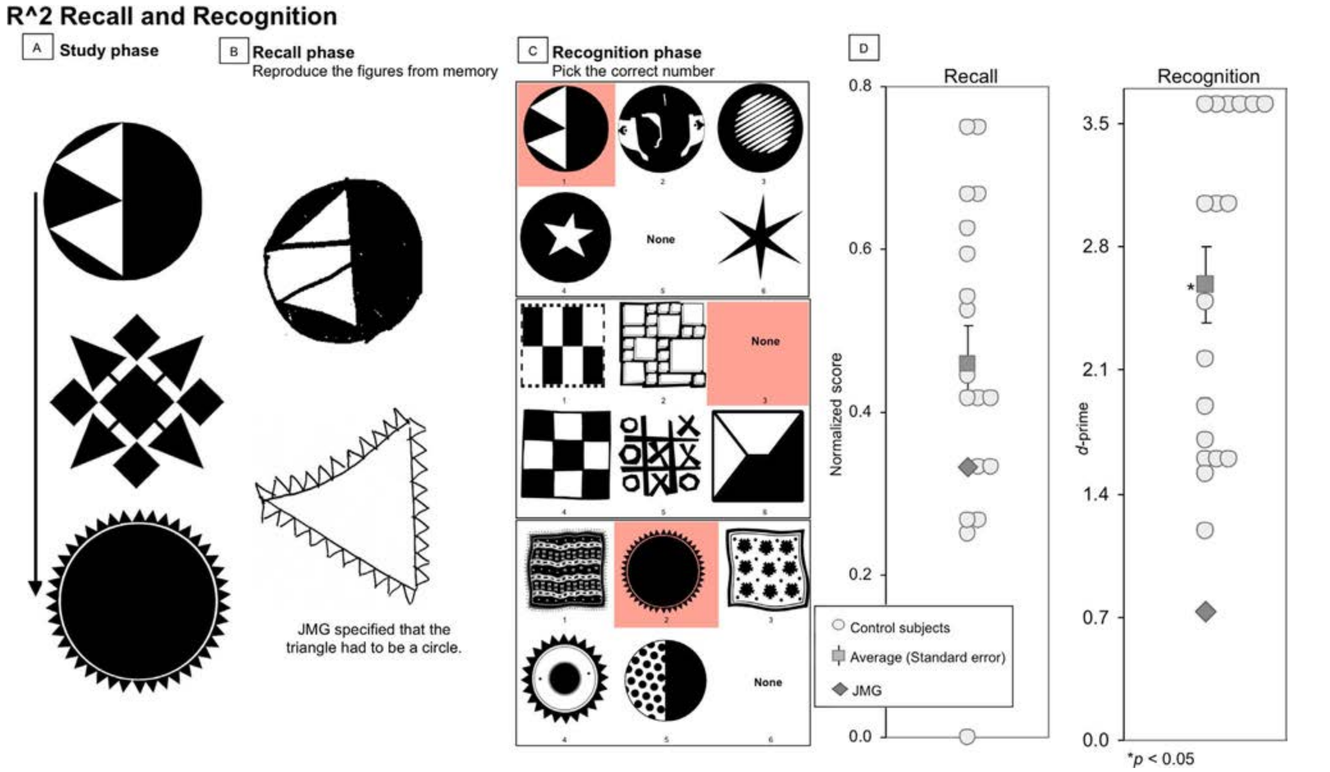

Fig. 4. Experiment 5 - R^2. Recall and recognition of the same material. A) Example of the stimuli. B) Example of JMG drawings during the recall phase. C) Example of the recognition phase. D) Distribution of the performance of control subjects and JMG's results.

3.2. Single item recognition

Recall is defined as the ability to retrieve information from memory. Recollection is defined as the process by which qualitative information about an event are retrieved, such as in which context it occurred. Since recall was preserved in JMG and given the proximity between recall and recollection (Quamme et al., 2004), we were specifically interested in determining whether any above-chance performance in recognition memory tasks would be related to partially preserved recollection. However, recent studies suggested that recollection may be content-dependent (Cowell et al., 2010; Ross et al., 2017), *i.e.,* dependent on whether recognition of items or scenes were probed. We therefore expected that recollection could be impaired for one type of stimulus (*i.e.,* objects) and preserved for the other (*i.e.,* scenes).

We addressed this possibility in the following series of experiments in which we used single-item tasks (*i.e.,* using stimuli such as objects and abstract pictures), and combined them with methods that allowed probing familiarity and recollection processes. Note that some of these tasks, based on the RKG or process-dissociation procedure, rely on assumptions that have been questioned (Curran and Hintzman, 1995; Wixted et al., 2010) and that dual-process models proposing that familiarity and recollection are independent processes have similarly been debated (Pazzaglia et al., 2013; Wixted, 2007). In order to take these issues into account, we used several different methods to assess familiarity and recollection as has been suggested (Yonelinas et al., 2001; Bowles et al., 2007) including recent ones not relying on the RKG or PDP procedures. Our aim was to collect results using different methods and assess whether they were coherent.

3.2.1. Experiment 6: RKG with abstract items

We used here a very simple recognition memory task with a classic Remember/Know/Guess procedure for which each verbatim was noted. Fig. 5 displays the experimental design, examples of the stimuli, and results.

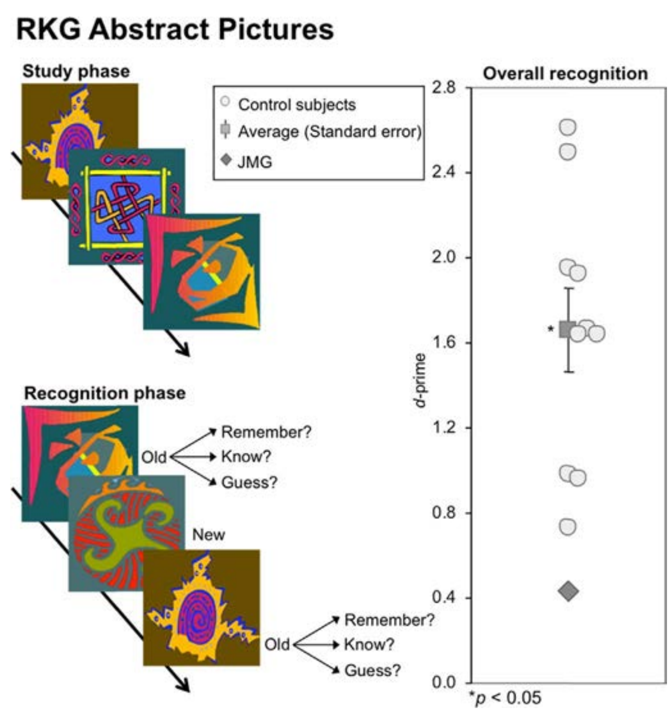

Fig. 5. Experiment 6 – RKG with abstract patterns. Summary of the recognition and study phases, example of the stimuli used and performance of participants and JMG.

3.2.1.1. Materials and procedures. During the encoding phase participants were instructed to judge 40 colourful abstract figures as pleasant or unpleasant. These stimuli were colourful cliparts gathered from the internet and have been used in previous studies by our group (Barbeau et al., 2008). They were not told that they had to specifically learn them (incidental encoding). After a five minutes interfering phase,

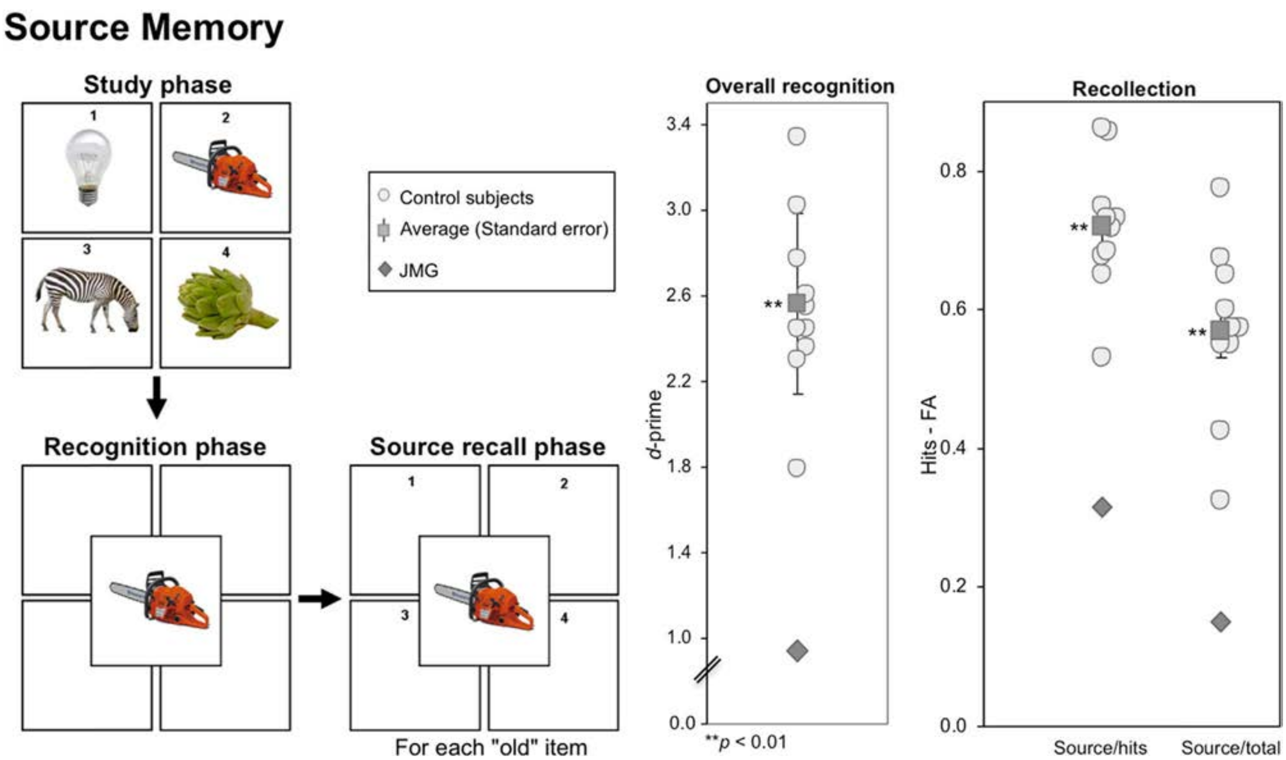

Fig. 6. Experiment 7 – Spatial source Memory. Summary of the recognition and study phases, example of the stimuli used and performance of participants and JMG.

the 40 targets intermixed with 40 distractors were presented to the participants who had to decide whether they were old or new. If the participants' decisions were 'old', they had to justify and described their responses with a recollection/know/guess judgment (RKG; Gardiner, 1988). As will be seen below, JMG's performance was so poor so that R and K estimates were not analysed.

3.2.1.2. Control subjects. Ten control subjects were tested (Table 1).

3.2.1.3. Results. JMG's recognition performance was lower than that of all participants (*d*-prime, JMG: 0.43; mean: 1.66, SD: 0.63, t (9) = −1.86, $p < 0.05$) and close to chance (58%, chance = 50%). As estimates of familiarity and recollection tend to become unreliable when performance is close to chance, familiarity and recollection were not estimated in this experiment.

3.2.2. Experiment 7: Spatial source memory

Since JMG failed the previous task, we next examined whether he might benefit from provision of spatial context. Fig. 6 displays the experimental design, examples of the stimuli and results.

3.2.2.1. Materials and procedures. This experiment was adapted from Wolk et al. (2008). Items were presented four by four (two living items *vs*. two non-living items) in four different quadrants on the screen. Participants were explicitly instructed to learn the non-living items that were presented, as well as the quadrant in which they appeared. To facilitate encoding, the items and quadrant number had to be named. 20 different trials were presented, for a total of 40 non-living items. The recognition phase took place three minutes later, and consisted in presenting one by one the 40 non-living targets intermixed with 40 distractors. Participants were asked whether the items were old or new. If an "old" judgment was made, participants had to designate in which of the four quadrants the item was previously presented. Visual spatial source memory abilities were estimated as a ratio of correct quadrant judgments over the number of hits (correct recognition judgment) and over the total number of items.

3.2.2.2. Control participants. Ten control subjects were tested (Table 1).

3.2.2.3. Results. JMG's recognition and recollection performances were significantly lower than every control participants (all $p < 0.01$). Thus, JMG does not appear to benefit from this type of spatial contextual information.

3.2.3. Experiment 8: Process Dissociation Procedure with repetition

We conducted another experiment in which stimuli were repeated, aiming to determine whether repetition could help JMG to overcome his impairments. Fig. 7 displays the experimental design, examples of the stimuli and results.

3.2.3.1. Materials and procedures. The task was adapted from Wolk et al. (2008). In this experiment, 64 single items were learnt (all objects from different categories, 32 presented once, 32 presented four times). Each item was presented on a different coloured background (green or red) and participants had to name the background colour, the object, and tell whether the object was pleasant or not. They were told that they had to learn the object/background association for a future test (incidental learning). The recognition session took place after a three minutes delay. The 64 targets as well as 32 distractors were presented one by one with a green or red rectangle indicating which was the target background. Participants were instructed to make old/new judgments, old judgments corresponding to the correct association between item and background. 32 targets were presented with their correct background and 32 with an incorrect background. Recollection and familiarity estimates were derived from the same process dissociation procedure logic described in Wolk et al. (2008).

3.2.3.2. Control participants. Ten participants were tested (Table 1).

3.2.3.3. Results. JMG's recognition and familiarity performances for the items presented once were above two control subjects (t (9) = −0,83, p = 0.21 and t (9) = −0,77, p = 0.23, respectively). JMG's recollection score for these items was higher than that of six controls,

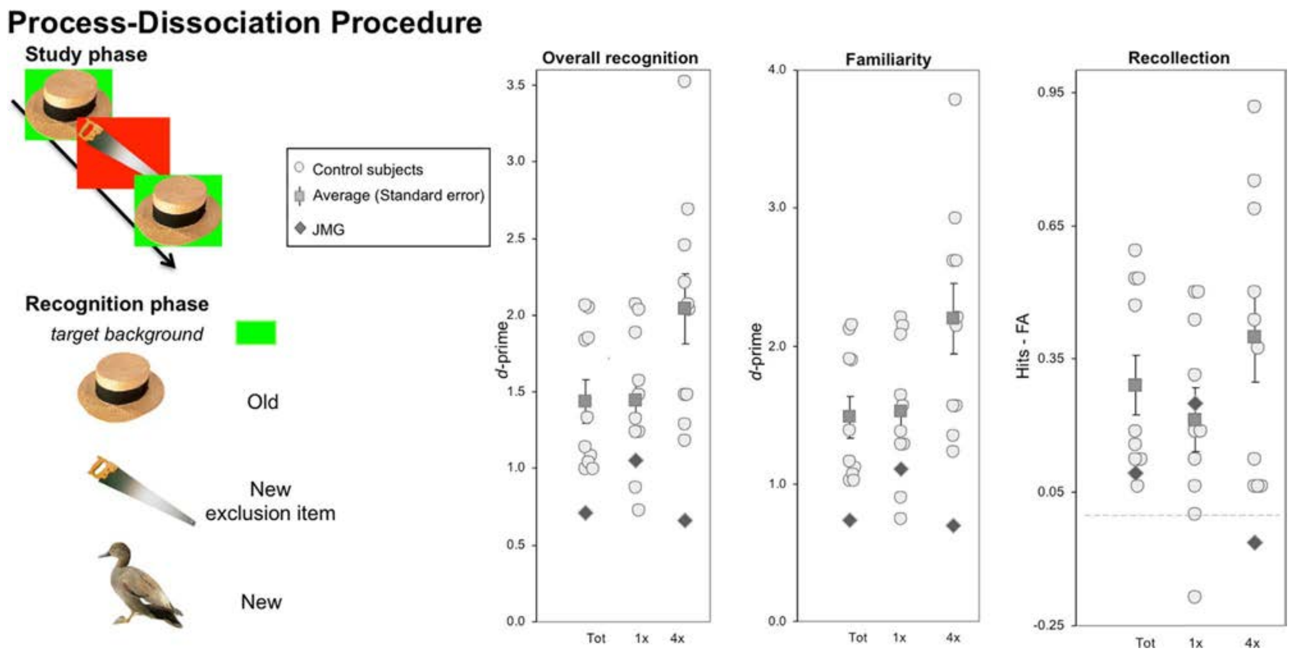

Fig. 7. Experiment 8 – Process dissociation procedure experiment with items that appear once (1x) or four (4x) times. Summary of the recognition and study phases, example of the stimuli used and performance of participants and JMG.

and even above controls' average (JMG: 0.25; mean: 0.21, SD = 0.23, t (9) = 0.17, p = 0.44). However, JMG's performance was not improved with repetition as his performances actually *decreased* (d-prime: 1.05 for items presented once; 0.66 for items presented four times). In contrast, every control subject showed an improvement (mean d-prime: 1.45 *vs.* 2.04 for repeated items). Likewise, JMG's familiarity and recollection scores decreased for repeated items and were below those of all control subjects (t (9) = −1.77, p = 0.06 and t (9) = −1.37, p = 0.10, respectively). This result suggests that repetition does not provide benefits to JMG in the same manner as it does for control participants. No dissociation between familiarity and recollection was observed in the two conditions as both were either normal (items presented once) or impaired (repeated items). An interpretation as to why JMG may have performed at the level of control subjects only after a single presentation on this task is presented in the Discussion.

3.2.4. *Experiment 9: Spontaneous recollection of animals in scenes*

In Experiment 9, our goal was to assess how JMG would perform in a task allowing assessing recollection with greater ecological validity. We tried in this novel experiment to assess recollection without having to give specific instructions about Familiarity or Remember judgments that can be difficult to understand by patients with memory difficulties (Baddeley et al., 2001; Barbeau et al., 2005) and without JMG having to resort to possibly complicated reasoning. Single animals (n = 40) were presented on different landscapes, participants were explicitly instructed to learn the items (Fig. 8). After a distraction phase of five minutes, only the animals were presented among animal distractors (n = 40). Participants made old/new judgments and in the case of an old judgment were asked to justify their responses orally. We expected that participants would in some occasion spontaneously refer to the landscapes in which the animals were presented to justify their response. A response was judged as an instance of recollection if reference to the appropriate landscapes were made, such as in "I remember that this animal was on the beach". The measure of correct recollection responses for targets was corrected for false alarms (hits - FA).

3.2.4.1. Control participants. Ten control subjects were tested (Table 1).

3.2.4.2. Results. JMG's recognition performance was lower than that of all of the controls (d-prime, JMG: 0.89; mean: 1.73, SD: 0.62, t (9) = −1.29, p = 0.11). Unlike control participants, JMG never spontaneously referred to the landscapes in the justification of his recognition responses. His recollection score was equal to zero and significantly lower than that of all control subjects (JMG: 0.0; mean: 0.28, SD: 0.11; t (9) = −2.43, $p < 0.05$).

3.2.5. *Experiment 10: Spontaneous recollection of vehicles in scenes*

This experiment was similar to the previous one and used the same group of control subjects, except that vehicles, rather than animals, were presented to participants. The purpose of this was to investigate whether changing the category of the stimuli to a non-living category would change the results (Fig. 8).

3.2.5.1. Results. JMG's performed lower than every control subjects (d-prime, JMG: 1.44; mean: 3.08, SD: 0.95, t (9) = −1.65, p = 0.07). It is noteworthy that JMG performed well above chance (76.3%, chance: 50%), although below control subjects. This could suggest that contextual information may have helped him. However, his recollection performance was poor, JMG almost never spontaneously referring to the landscapes contrary to the control subjects (JMG: 0.05; mean: 0.26, SD: 0.17; t (9) = −1.18, p = 0.14).

3.2.6. *Experiment 11: R^2 test: assessing recall and recognition for the same material – recognition part*

The R^2 test allows assessing recall and recognition for the same material. Results for the recall phase was presented in Experiment 5, where we showed that he performed normally. Here, we assessed whether JMG would recognize these same items. The recognition phase took place immediately after the recall phase. JMG and the same control subjects were instructed to recognize the previously learnt pictures. To avoid a ceiling effect, 26 slides were presented. Each slide was composed of (i) five pictures and (ii) one response "none" (meaning that none of the other picture was recognized as a target). A forced-choice format was used (*i.e.,* subjects were requested to make a choice among the 6 possibilities). Among the 26 slides, 13 slides contained one of the targets among the five pictures (subjects were thus expected to choose the target and avoid choosing "none"), and 13 contained only pictures of distractors (the response "none" was expected in this case).

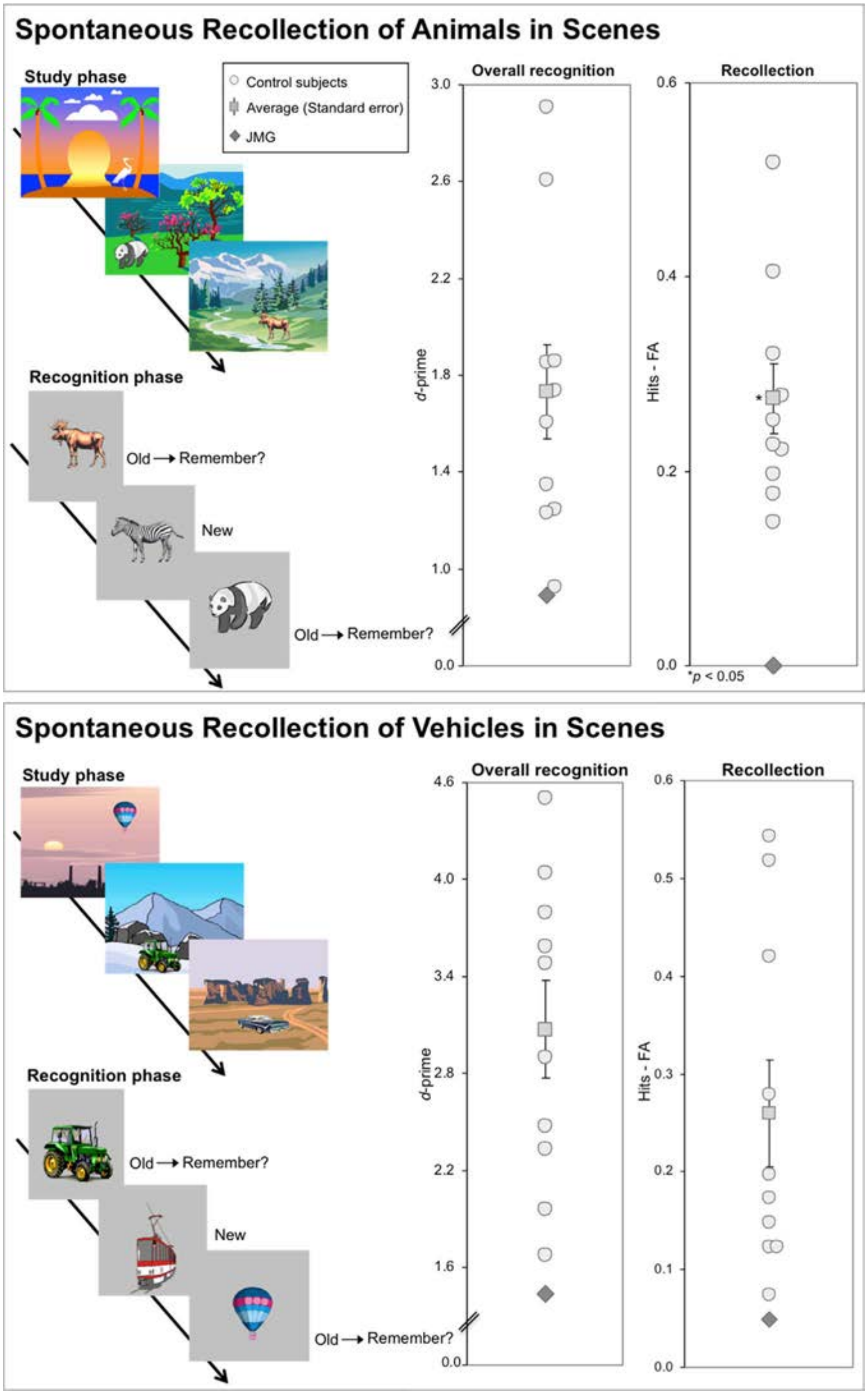

Fig. 8. Experiments 9 and 10 – Spontaneous recollection of animals and vehicles in scenes. Summary of the recognition and study phases, example of the stimuli used and performance of participants and JMG. Note that the recollection's answers were counted only when a justified response was made with a specific detail of the background.

Fig. 4 displays the design and the results of this experiment.

3.2.6.1. Results. JMG's *d*-prime was significantly lower than controls' mean (JMG: 0.74; control subjects' mean: 2.58, SD: 0.92; t (17) = −1.95, $p < 0.05$) and below that of all controls subjects. However, JMG was able to recognize the two pictures that he had recalled during the recall part.

3.2.7. Experiment 12: The Speed and Accuracy Boosting Procedure

We mainly focused in the previous experiments on the assessment of recollection. Here we focused specifically on the assessment of familiarity using the SAB (Speed and Accuracy Boosting Procedure), a paradigm that was recently developed to assess familiarity (Besson et al., 2012, 2015). Familiarity is supposed to be a fast process (Brown and Aggleton, 2001). Hence, responses made under strong speed constraints should be based mainly on familiarity as has been suggested in previous studies (Bowles et al., 2007; Sauvage et al., 2010). The SAB applies such speed constraints in that participants have to make a response before a response deadline. A previous experiment in which the SAB was combined with a detailed Remember/Know procedure indicated that 75% of the responses were based on familiarity (Besson et al., 2012). Furthermore, responses based on recollection started later than responses based on familiarity, in accordance with the idea that familiarity is faster than recollection. Here, the response deadline was set at 700 ms based on previous results (Besson et al., 2015, 2012). Practically, participants have to make a go response before this deadline when a target is presented or the response is considered as an omission (Fig. 9). If a distractor is presented, participants have to

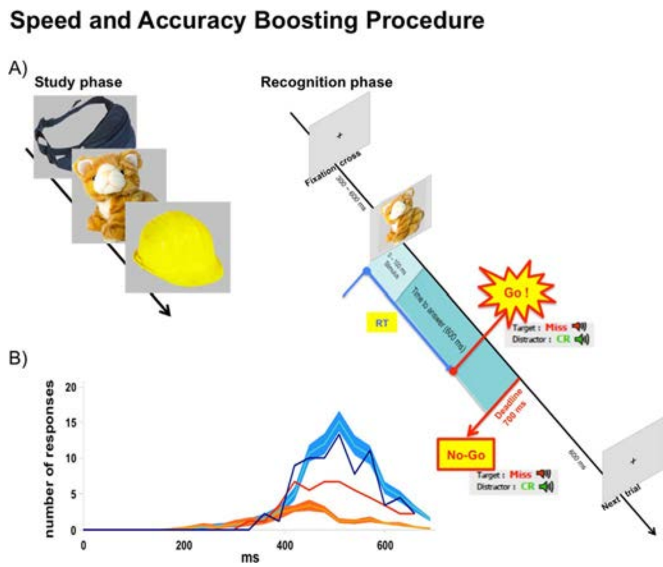

Fig. 9. Experiment 12 – SAB. A) Experimental design. B) Reaction time distributions across time of control subjects (mean and 95% confidence interval) and JMG (thin lines). Blue: hits, red: false alarms. Although JMG made about the same number of hits as control subjects across time, he also made more false alarms. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

withhold their response or the response is considered as a false-alarm. Because the SAB is highly demanding, positive or negative audio feedbacks are played after each response to keep motivation high. The full details about this task have been described in Besson et al. (2015). Subjects underwent 3 blocks. Each block began with a study phase, in which stimuli (30 photographs of objects, examples of stimuli in Fig. 9) were presented one by one. Participants were explicitly instructed to remember all single-trial stimuli. After an interfering phase of three minutes, during which participants viewed a cartoon with the sound on, they had to recognize the stimuli that were presented earlier, intermixed with 30 distractors.

3.2.7.1. Participants. 10 controls were tested (Table 1).

3.2.7.2. Results. JMG's *d*-prime was lower than all control subjects (JMG: 0.68, control subjects' mean: 1.83, SD = 0.56, t (9) = −1.96, $p < 0.05$). Analysis of the distribution of the reaction times across time (Fig. 9) indicates that JMG made responses at about the same speed as control subjects but that he also made more false alarms during the whole period preceding the response deadline. These results support the idea that JMG's familiarity assessment is largely impaired when assessed with single objects.

3.2.8. Summary of the visual recognition memory tasks. The effect size indexes (z_{cc}) varied from −3.86 (Experiment 7) to −1.37 (Experiment 9) for this set of single item recognition experiments. Overall, JMG performances were below control subjects' performances (Fig. 12).

3.3. Scene recognition memory

Following our investigation of single-items recognition in the preceding section, we next assessed whether recognition of scenes could be preserved. The parahippocampal cortex has indeed been implicated in scene processing in numerous studies (*e.g.,* Epstein and Kanwisher, 1998). Given the preservation of the medial portion of the parahippocampal cortex and right hippocampus in JMG, we investigated whether his performance could be in the normal range for scenes.

3.3.1. Experiment 13: Indoor Scenes Exclusion Task (Martin et al., 2012)

3.3.1.1. Materials and procedures. We used the task developed by Martin et al. (2012) in which the procedure is extensively described. 72 indoor scenes (examples in Fig. 10) were incidentally learnt. Subjects had to evaluate the relative wealth reflected in the scene content in each image on a three points scale. During the recognition phase, JMG and controls were instructed to judge if the presented item was previously encountered. There were 72 lures. Each lure was repeated once after lags of 4, 18, or 48 intervening items. Participants were explicitly informed that lures were repeated and that they still had to be considered "new". Data analyses rested on the same method as Martin et al. (2012). We examined recognition performance with a *d*-prime, taking into account targets and non-repeated lures. We also calculated the exclusion error, which was defined by the proportion of false alarms among the repeated lures (hence, the lower this ratio is, the better is recollection). This ratio was considered as a measure of the ability to recollect contextual detail about whether the item was encountered during the encoding or during the test session. Fig. 10 displays the experimental design and results.

3.3.1.2. Control participants. 10 participants were tested (Table 1).

3.3.1.3. Results. JMG's recognition performance was above five participants (*d*-prime, JMG: 0.85; control subjects' mean: 0.94, SD: 0.32, t (9) = −0.27, p = 0.40) (Fig. 10). In the same vein, JMG's exclusion ratio was within normal limits (JMG: 0.28; mean: 0.20, SD: 0.11, t (9) = 0.69, p = 0.25). Thus, JMG presents preserved recognition memory as well as preserved recollection for scenes.

3.3.2. Experiment 14: outdoor scenes exclusion task (adapted from Martin et al., 2012)

3.3.2.1. Materials and procedures. Given that JMG appears to have difficulties processing single objects and that the indoor scenes used in the previous experiment were filled with such single items, the same experiment was run using full-screen outdoor scenes without any object (example of stimuli in Fig. 10). Our hypothesis was that JMG would perform as well, and possibly better than in the previous experiment.

3.3.2.2. Results. JMG's recognition performance was above seven participants (*d*-prime, JMG: 1.31; control subjects' mean: 1.31, SD: 0.72, t (9) = 0.0, p = 0.50). As in the previous experiment, there was no significant difference between JMG's and controls' exclusion ratio (JMG: 0.17; control subjects' mean: 0.19, SD: 0.15, t (9) = −0.13, p = 0.45). JMG thus performed at least as well as in the previous experiment, confirming his preserved recognition memory ability for scenes.

3.3.3. Experiment 15: RKG Outdoor Scenes

Here, we tested whether JMG would also show preserved familiarity and recollection using an alternative paradigm. We thus used a classic Remember / Know paradigm.

3.3.3.1. Materials and procedures. Participants were explicitly instructed to learn a list of 55 full screen outdoor scenes. After a five minutes interference phase, the target scenes intermixed with 55 distractors were presented. Participants were asked to make an old/new judgment and in the case of an old judgment to report whether they remembered or knew about prior stimulus exposure. A remember response (*R*) had to be justified with specific details about the encoding phase whereas a known response (*K*) was to be provided for recognition in the absence of successful recollection of any pertinent contextual detail. Recollection was estimated with the number of *R* responses corrected for false alarms: $R = (R_{\text{old}} - R_{\text{new}})/(1 - R_{\text{new}})$. Familiarity was estimated with a *d*-prime measure, employing a correction for independence of the two processes (Yonelinas and Jacoby, 1995).

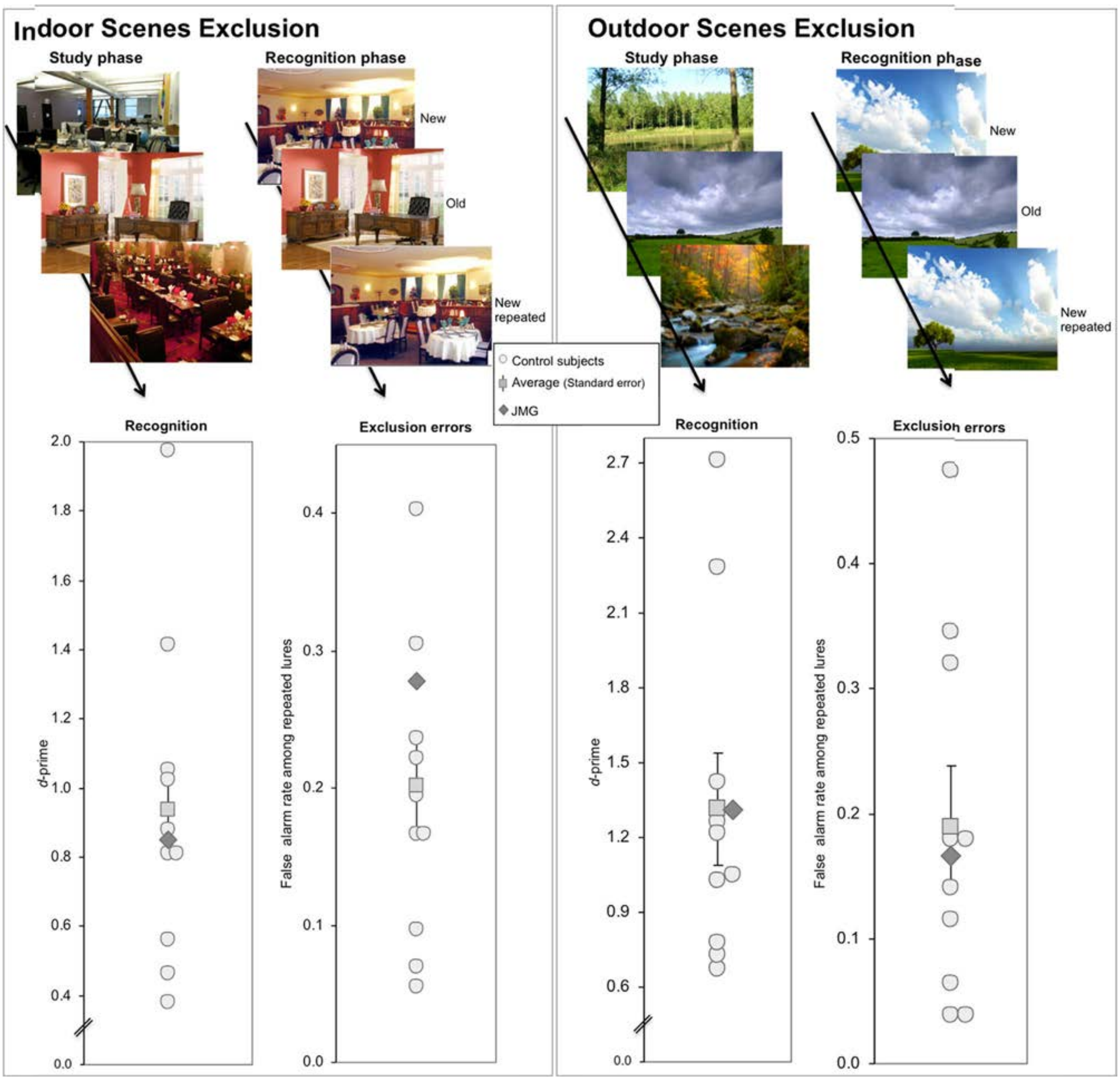

Fig. 10. Experiments 13 and 14 – Indoor and outdoor exclusion task. Experimental design and JMG results compared controls results.

3.3.3.2. Control participants. Ten participants were tested (Table 1).

3.3.3.3. Results. JMG's performed at the level of control subjects (*d*-prime: JMG: 1.26, control subjects' mean: 1.42, SD: 0.82, t (9) = −0.19, p = 0.43) (Fig. 11). Both familiarity and recollection estimates were in the normal range (familiarity: JMG: 1.16; control subjects' mean: 0.63, SD: 0.73, p = 0.25; recollection: JMG: 0.32; control subjects' mean: 0.40, SD: 0.19, p = 0.35). These results are consistent with previous results in that they show preserved recognition performance but also preserved familiarity and recollection for scenes.

3.3.3.4. Summary of scene recognition memory tasks. The effect size indexes (z_{cc}) varied from −0.28 (Experiment 13) to 0.0 (Experiment 15) for this set of recognition experiments. Overall, there was no significant difference between JMG and controls' performance across the three scene recognition memory tasks and his performance was above the level of some control subjects in all experiments (Fig. 12).

3.4. Summary of the findings

In order to provide a summary of JMG's and control subjects' performance across all experiments, we calculated aggregate scores for every individual participant across the experiments of each of the three parts of this study (thus ending up with three aggregate scores for each participant including JMG). We first computed the *t*-value (using the formula of the modified *t*-test, (Crawford and Howell, 1998)) for each subject compared with all other participants, including JMG, for each experiment. We then averaged these *t*-values for individual subjects across all experiments, considering the three parts of our study separately. Note that the number of tasks included in the mean *t*-values was not the same because of the design of tasks (d' estimate for the single item tasks was based on experiments 6–11; familiarity estimate for single item tasks was based on experiments 8 and 12; recollection estimate for single item tasks was based on experiments 7–10; familiarity estimate for scene tasks was based on experiment 15). Fig. 12 shows that JMG's mean *t*-values in the single-item recognition memory tasks were lower than those of all individual control subjects, revealing

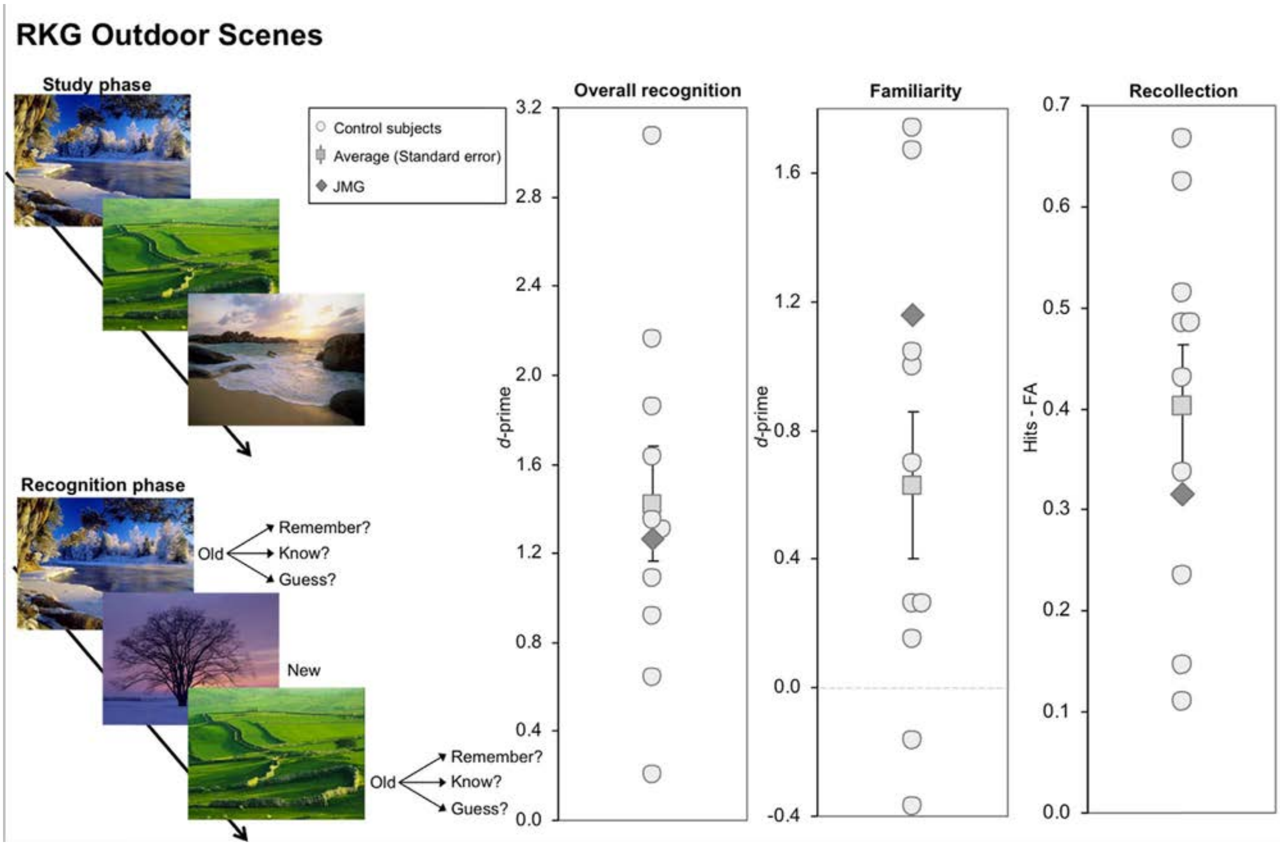

Fig. 11. Experiment 15 – RKG outdoor scenes. The experimental design of the task is described and performance of JMG's and age/level-matched controls' ones are presented.

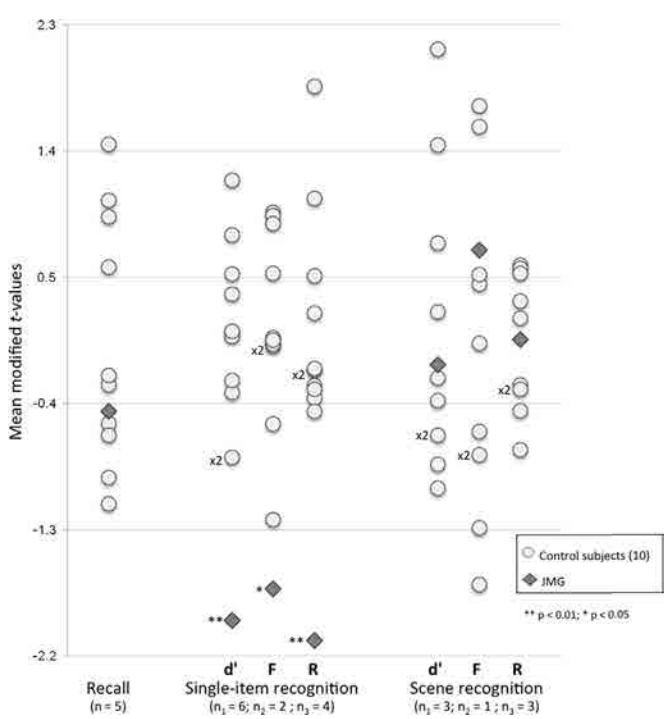

Fig. 12. Dispersion of the mean t-values for recall, single-item and scenes memory recognition experiments for each individual subject. Each circle represents the mean modified t-value of one of the ten control subjects (x2 means that two controls are represented by the same circle). The grey diamond represents JMG's mean modified t-value. n = number of tasks included in the mean t-values.

impaired *d*-prime, familiarity and recollection. In contrast, his *t*-values for the recall and scenes recognition memory tasks were clearly in the normal range, including familiarity and recollection.

Finally, we tested dissociations between several types of experiments using the distribution of differences in controls (Crawford and Garthwaite, 2005; Crawford et al., 2010). A dissociation was observed between JMG's *t*-values for recall and single stimuli recognition experiments ($t\,(9) = 3.21$, p (two-tailed) < 0.05 – $z_{Dcc} = 3.85$). Likewise, a second dissociation was highlighted between single stimuli and scene recognition *t*-values ($t\,(9) = 2.90$, p (two-tailed) < 0.05 – $z_{Dcc} = -3.40$).

4. General discussion

We report in this study on a patient, JMG, with a highly atypical pattern of lesions. Among all left and right MTL structures only the right hippocampus is preserved, together with remnants of right medial parahippocampal cortex. We first demonstrated that JMG is able to recall a significant amount of visual material. Such a pattern of performance in a patient with very large MTL lesions is in itself interesting as it supports the idea that amnesia following MTL lesions is not related to the size but to the site of the lesion.

We next showed that JMG performed very poorly on all visual recognition memory tasks for single-items, such as objects and abstract pictures. This impairment is likely due to the bilateral damage in anterior extrahippocampal structures. In addition, neither familiarity nor recollection was found to be completely preserved for these tasks, suggesting that both processes depend on operations performed in extrahippocampal structures when recognition memory for single items is probed.

Last, we showed that JMG's impairments in recognition memory do not extend to scenes. In three experiments that employed such stimuli, he performed in the normal range. Moreover, both familiarity assessment and recollection were preserved for these stimuli. Together with evidence from other patient studies, this pattern of results clearly indicates that a unitary view of MTLs structures with reference to declarative memory appears inadequate to account for the functional specificity of lesion effects in the MTL. Critically, however, the dissociation we observed cannot be easily accounted for by a popular dual-process view of MTL organization, which considers a role for perirhinal cortex in familiarity assessment and argues that the hippocampus supports recollection (Aggleton and Brown, 1999; Yonelinas, 2002). Instead, the pattern of results we observed in JMG appears to provide support for proposals of MTL of organization that emphasize the nature of different stimulus representations in different MTL structures (Bussey and Saksida, 2007; Cowell et al., 2006; Murray et al., 2007).

4.1. Preserved recall for visual material

JMG is able to recall a significant amount of visual information (Experiments 1–5). The encoding instruction (incidental or intentional), the type of material or the time between encoding and delayed recall did not seem to strongly influence his performances. We also explored, informally, whether JMG was slower than control subjects in his performance. However, there appeared to be no consistent pattern in the data; he performed slower on some but in normal range on other tasks. Overall, these findings are consistent with the observation that JMG is not amnesic in day-to-day life, and they suggest that his right hippocampus is largely functional.

That JMG shows a dissociation between preserved recall and impaired recognition is a highly unusual pattern. In the one task where we used the same stimuli for recognition and recall (Experiments 5 and 11), JMG was impaired on the recognition part of the task, while performing at the level of control subjects on the recall part, reinforcing the idea of a dissociation. Of course, the finding that recall is preserved while recognition is impaired within the same task appears highly counterintuitive at first. However, one needs to remember that the visual items that are used in recall tasks are geometric shapes made of black lines *(i.e.,* these stimuli don't have the perceptive complexity of the objects) and abstract patterns used in the other tasks. Furthermore, JMG was able to recognize the two items he was able to recall. To our knowledge, only one study presented a patient with a similar pattern of preserved recall and impaired recognition (Delbecq-Derouesné et al., 1990). The authors reported the case of RW, presenting large areas of hypodensity of the medial parts of the frontal lobes, larger in the right hemisphere. Within medial lobe structures, lesions involved the fusiform and parahippocampal gyri while the hippocampi were interestingly probably preserved. He presented a similar pattern of results to JMG - *i.e.,* his scores were in the normal range on recall tests, whereas he performed below control subjects on recognition memory tests. Like JMG his performance on the Wechsler Memory Test (first version) was in the normal range (MQ = 94) and he apparently was not amnesic in day-to-day life. RW pattern of response was interpreted as reflecting preserved active and strategic search process but impaired familiarity-based recognition, which appear compatible with what is observed in JMG. In this context, JMG remains an outstanding case because of his extensive lesions of the medial temporal lobes, wider than is seen in many cases of severe amnesia and what appears to be a good preservation of his recall abilities. Overall, this suggests that a syndrome related to large MTL lesions but preserved hippocampus can occur in some patients.

From a neuroanatomical perspective, these results are intriguing considering that the hippocampus is usually viewed as receiving information mainly from extrahippocampal structures through the entorhinal cortex (Suzuki and Amaral, 1994). JMG's right hippocampus should be dysfunctional since his entorhinal cortices were largely damaged (Buckmaster et al., 2004). At this stage we cannot exclude the possibility that the remaining patches of cortex in the MTL along the right hippocampus support the transmission of some information. But these patches are residual and by usual standards cannot be considered as fully efficient. However, it was recently reported that bilateral lesions of the entorhinal cortex in the rat reduced but did not abolish place cells firing (Van Cauter et al., 2008) suggesting alternative routes to the hippocampus. Information could reach JMG's right hippocampus through the right medial parahippocampal cortex that appeared preserved. Direct connections from this structure to the hippocampus have indeed been reported in non-human primates (Rockland and Van Hoesen, 1999; Yukie, 2000). The medial parahippocampal cortex receives strong inputs from the retrosplenial cortex, which was preserved in JMG bilaterally (Blatt et al., 2003). This region itself receives inputs from the parietal lobe and is also involved in spatial cognition (Epstein, 2008; Vann et al., 2009). In addition, there are also direct parietal and frontal cortical inputs to the hippocampus (Goldman-Rakic et al., 1984; Rockland and Van Hoesen, 1999), as well as direct connections from the hippocampus to these areas (Barbas and Blatt, 1995; Insausti and Muñoz, 2001). Taken together, these findings from prior studies suggest that a network of posterior regions, which include the parahippocampal cortex, restrosplenial cortex and the parietal lobes may interact with the right hippocampus to support recall even when entorhinal cortex and anterior medial structures are damaged. Such result also suggest that the functional hierarchy often postulated to characterize MTL organization (Lavenex and Amaral, 2000; Mishkin et al., 1997) may not hold true for recall. This appears to be consistent with recent views of the hippocampus as belonging to an “extended hippocampal system” and as being connected to a set of structures (diencephalon, medial frontal and medial parietal lobes), presumably preserved in JMG, that regulate hippocampal activity (Aggleton, 2014). It is also possible that some forms of plasticity or reorganization took place in JMG, for example in relation to his right hippocampus, which appears unusually thick (Fig. 2). However, this clearly remains speculative at present.

4.2. Impaired familiarity and recollection for single items

JMG was impaired at visual recognition memory tasks for single items (Experiments 6–12) as he performed most of the time below all control subjects. JMG's performance appeared low even on tasks that showed a ceiling effect in control subjects (Experiment 11). Efforts to improve performance relative to control subjects using contextual information or repetition failed. In fact, repetition helped control subjects but appeared to have a deleterious effect on JMG's performance (Experiment 8). There was one exception to this overall pattern of impairment for single items as JMG performed at the level of control subjects in a task that involved the PDP procedure (Experiment 8 without repetition). The exact reason for this result is unclear, but a possibility is that the task was particularly boring for control subjects. The motivation of some may thus have been low.

Because we showed that the right hippocampus is able to support visual recall, the observed pattern of result also suggests that the hippocampus cannot support recognition for single items in the absence of input from anterior extrahippocampal structures. The type of operations performed by anterior extrahippocampal structures have been proposed to be related to object discrimination and recognition when processing of complex feature conjunctions is required to distinguish targets from distractors (Lee and Rudebeck, 2010; O'Neil et al., 2013). This is in line with proposals suggesting that the perirhinal cortex is at the top of the hierarchy of the visual ventral stream and processes items at the exemplar level (Kravitz et al., 2013; Murray and Bussey, 1999). In other words, following the view that the MTL participate in high-level perception, as well as in memory discrimination (Barense, 2005; Bussey et al., 2003; Lee et al., 2005), what may be impaired in JMG is not memory for single-items *per se*, but his ability to form suitable representations of the items (Cowell et al., 2006).

Interestingly, JMG's performance, even if clearly impaired, was above chance in all experiments, sometimes close to chance (*e.g.,* Experiment 6), sometimes much better (*e.g.,* Experiment 10). In this context, it seemed reasonable to assess whether his performance could be explained by partly preserved recollection, as his performance on recall tasks suggested this may be preserved. However, despite the use of different paradigms, there never was any indication of preserved recollection. Even using a spatial context, which could theoretically have helped following the idea that the right hippocampus may play a role in spatial context, did not improve recollection (Experiment 7). Ecological assessment of recollection by virtue of introduction of scene context, developed with the aim of avoiding having to resort to complex or abstract reasoning, was of no help either (Experiments 10 and 11). Furthermore, it appears that familiarity was also impaired for single items as indicated by his low performance on all tasks requiring a simple old/new judgment, but also on a task recently designed to assess familiarity specifically (Experiment 12). Overall, such a pattern of result suggests that performance was generally too low to evidence preservation of either familiarity or recollection. Moreover, it hints that the hippocampus cannot support recollection for single items without some degree of integrity of anterior extrahippocampal structures.

Bowles et al. (2007) reported impaired familiarity but preserved recollection for verbal single items in a patient (NB), who had undergone a surgical resection of the left anterior temporal lobe that included large parts of the perirhinal and entorhinal cortex that spared the hippocampus. Despite this lesion, the patient performed within the normal range on tasks of verbal recognition memory except when familiarity was probed. The authors suggested that preserved input from remaining left temporal structures may have been sufficient to support task performance based on recollection (Bowles et al., 2011). These results seem at odd with those of the present study. However, the size of the lesions in NB were much smaller than in JMG. Some anterior subhippocampal inputs to the hippocampus may have been spared in NB while this was not the case in JMG. Furthermore, NB was tested with words, which are highly familiar material by themselves, whereas JMG was tested with visual material composed of new stimuli. The reliance of these two types of material on either the left or right subhippocampal structures may be different. This suggests that it might be relevant to take into account the hemispheric laterality of the lesions in future studies.

It is interesting that JMG did not benefit from repetition, unlike healthy subjects. A possibility could be that this improvement requires interactions between the hippocampus and the cortex, which was no longer possible in JMG. An alternative is that repetition of the same item increases interference and thus diminishes the robustness of the memory trace (for related results Bartko et al., 2010).

4.3. *Preserved scene recognition contrasting with impaired single-item recognition*

The only MTL structures that were preserved in JMG were the right hippocampus and medial right parahippocampal cortex. Both structures have been found to be critical for spatial memory and for spatial navigation, especially in the right hemisphere (Aguirre and D'Esposito, 1999; Epstein, 2008; Habib and Sirigu, 1987; Iaria et al., 2007; Kravitz et al., 2011; Maguire et al., 2000). We thus hypothesized that JMG's performance might be preserved on recognition memory tasks for scenes. In three experiments, we demonstrated that this is indeed the case (Experiments 13–15). In each case JMG performed at the level of the mean of control subjects. These results are also in line with anecdotal observations that JMG does not have any difficulty with spatial cognition in day-to-day life. For example, he is able to drive to the hospital, more than an hour's drive, without any help in navigation. Furthermore, one of his favourite leisure activities is to bike long distances (> 1000 km / month), including in unfamiliar environments.

JMG's pattern of performance for scenes thus differs markedly from his performance for single-items and represents yet another functional dissociation. This pattern of result was predicted given his pattern of lesions, and given differences in connectivity between different MTL structures with the ventral and the dorsal visual pathway. Interestingly, both familiarity and recollection appeared preserved when processing of scenes was required. This appears to suggest that familiarity assessment may also depend on other structures than the perirhinal cortex as some authors have found for scenes in fMRI experiments (Lee et al., 2008). As such our findings provide strong support for proposals that emphasize the nature of stimuli (objects *versus* scenes) and corresponding demands for representation, rather than types of processes (familiarity vs recollection), in characterizing the functional role of different MTL structures (Cowell et al., 2010; Graham et al., 2006; Kravitz et al., 2011).

Given that recall is preserved in JMG, it may be tempting to conclude from this that the hippocampus is preferentially involved in recall (Aggleton and Shaw, 1996). However, representational accounts do not postulate that the hippocampus has a specific role in recall (Cowell et al., 2010). In fact, a recent fMRI study tested this idea and found that recall of scenes required engagement of the hippocampus. In contrast, recall of objects (and scenes) required engagement of the perirhinal cortex. Critically, an effective connectivity analysis showed that information did not flow out of the hippocampus during recall of objects (Ross et al., 2017).

5. Conclusion

The findings presented in JMG reveal several dissociations that are of theoretical importance. As such, JMG helps advance our understanding of the unique functional roles played by different structures in the MTL. Beyond their theoretical importance, the present findings also have implications for surgical treatment of neurological conditions that affect the MTL, as they point to structures that may continue to support key aspects of declarative memory functioning in the presence of large lesions.

Acknowledgments

The authors would like to thank JMG for his dedicated involvement in our studies.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2017.07.032.

References

Aggleton, J.P., 2013. Understanding amnesia – Is it time to forget HM? Psychologist 26 (8), 612–615.
Aggleton, J.P., 2014. Looking beyond the hippocampus: old and new neurological targets for understanding memory disorders. Proc. Biol. Sci. / R. Soc. 281 (1786). http://dx.doi.org/10.1098/rspb.2014.0565.
Aggleton, J.P., Brown, M.W., 1999. Episodic memory, amnesia, and the hippocampal-anterior thalamic axis. Behav. Brain Sci. 22 (3) (425-44-89. Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/11301518〉.
Aggleton, J.P., Shaw, C., 1996. Amnesia and recognition memory: a re-analysis of psychometric data. Neuropsychologia 34 (1), 51–62. http://dx.doi.org/10.1016/0028-3932(95)00150-6.
Aggleton, J.P., Vann, S.D., Denby, C., Dix, S., Mayes, A.R., Roberts, N., Yonelinas, A.P., 2005. Sparing of the familiarity component of recognition memory in a patient with hippocampal pathology. Neuropsychologia 43 (12), 1810–1823. http://dx.doi.org/10.1016/j.neuropsychologia.2005.01.019.
Aguirre, G.K., D'Esposito, M., 1999. Topographical disorientation: a synthesis and taxonomy. Brain: J. Neurol. 122 (Pt 9), 1613–1628. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/10468502〉.
Baddeley, A., Vargha-Khadem, F., Mishkin, M., 2001. Preserved recognition in a case of developmental amnesia: implications for the acquisition of semantic memory? J. Cogn. Neurosci. 13 (3), 357–369. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/11371313〉.
Barbas, H., Blatt, G.J., 1995. Topographically specific hippocampal projections target functionally distinct prefrontal areas in the rhesus monkey. Hippocampus 5 (6), 511–533. http://dx.doi.org/10.1002/hipo.450050604.

Barbeau, E.J., Felician, O., Joubert, S., Sontheimer, A., Ceccaldi, M., Poncet, M., 2005. Preserved visual recognition memory in an amnesic patient with hippocampal lesions. Hippocampus 15, 587–596. http://dx.doi.org/10.1002/hipo.20079.

Barbeau, E.J., Taylor, M., Régis, J., Chauvel, P., Liégeois-Chauvel, C., 2008. Spatio-temporal dynamics of face recognition. Cereb. Cortex 18 (5), 997–1009.

Barbeau, E.J., Pariente, J., Felician, O., Puel, M., 2011. Visual recognition memory: a double anatomo-functional dissociation. Hippocampus 21 (9), 929–934. http://dx.doi.org/10.1002/hipo.20848.

Barense, M.D., 2005. Functional specialization in the human medial temporal lobe. J. Neurosci. 25 (44), 10239–10246. http://dx.doi.org/10.1523/JNEUROSCI.2704-05.2005.

Bartko, S.J., Cowell, R.A., Winters, B.D., Bussey, T.J., Saksida, L.M., 2010. Heightened susceptibility to interference in an animal model of amnesia: impairment in encoding, storage, retrieval – or all three? Neuropsychologia 48 (10), 2987–2997. http://dx.doi.org/10.1016/j.neuropsychologia.2010.06.007.

Bastin, C., Linden, M., Charnallet, A., Denby, C., Montaldi, D., Roberts, N., Andrew, M., 2004. Dissociation between recall and recognition memory performance in an amnesic patient with hippocampal damage following carbon monoxide poisoning. Neurocase 10 (4), 330–344. http://dx.doi.org/10.1080/13554790490507650.

Besson, G., Ceccaldi, M., Didic, M., Barbeau, E.J., 2012. The speed of visual recognition memory. Vis. Cogn. 20 (10), 1131–1152. http://dx.doi.org/10.1080/13506285.2012.724034.

Besson, G., Ceccaldi, M., Tramoni, E., Felician, O., Didic, M., Barbeau, E.J., 2015. Fast, but not slow, familiarity is preserved in patients with amnestic mild cognitive impairment. Cortex 65, 36–49. http://dx.doi.org/10.1016/j.cortex.2014.10.020.

Blatt, G.J., Pandya, D.N., Rosene, D.L., 2003. Parcellation of cortical afferents to three distinct sectors in the parahippocampal gyrus of the rhesus monkey: an anatomical and neurophysiological study. J. Comp. Neurol. 466 (2), 161–179. http://dx.doi.org/10.1002/cne.10866.

Bowles, B., Crupi, C., Mirsattari, S.M., Pigott, S.E., Parrent, A.G., Pruessner, J.C., Köhler, S., 2007. Impaired familiarity with preserved recollection after anterior temporal-lobe resection that spares the hippocampus. Proc. Natl. Acad. Sci. USA 104 (41), 16382–16387. http://dx.doi.org/10.1073/pnas.0705273104.

Bowles, B., O'Neil, E.B., Mirsattari, S.M., Poppenk, J., Köhler, S., 2011. Preserved hippocampal novelty responses following anterior temporal-lobe resection that impairs familiarity but spares recollection. (n/a-n/a) Hippocampus 21 (8). http://dx.doi.org/10.1002/hipo.20800.

Brandt, K.R., Eysenck, M.W., Nielsen, M.K., von Oertzen, T.J., 2016. Selective lesion to the entorhinal cortex leads to an impairment in familiarity but not recollection. Brain Cogn. 104, 82–92. http://dx.doi.org/10.1016/j.bandc.2016.02.005.

Brown, M.W., Aggleton, J.P., 2001. Recognition memory: what are the roles of the perirhinal cortex and hippocampus? Nat. Rev. Neurosci. 2 (1), 51–61. http://dx.doi.org/10.1038/35049064.

Buckmaster, C. a., Eichenbaum, H., Amaral, D.G., Suzuki, W. a., Rapp, P.R., 2004. Entorhinal cortex lesions disrupt the relational organization of memory in monkeys. J. Neurosci.: Off. J. Soc. Neurosci. 24 (44), 9811–9825. http://dx.doi.org/10.1523/JNEUROSCI.1532-04.2004.

Bussey, T.J., Saksida, L.M., 2007. Memory, perception, and the ventral visual-perirhinal-hippocampal stream: thinking outside of the boxes. Hippocampus 17 (9), 898–908. http://dx.doi.org/10.1002/hipo.20320.

Bussey, T.J., Saksida, L.M., Murray, E.A., 2003. Impairments in visual discrimination after perirhinal cortex lesions: testing "declarative" vs. "perceptual-mnemonic" views of perirhinal cortex function. Eur. J. Neurosci. 17 (3), 649–660. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/12581183〉.

Cohen, N., Squire, L.R., 1980. Preserved learning and retention of pattern-analyzing skill in amnesia: dissociation of knowing how and knowing that. Science 210 (4466), 207–210. http://dx.doi.org/10.1126/science.7414331.

Cowell, R.A., Bussey, T.J., Saksida, L.M., 2006. Why does brain damage impair memory? A connectionist model of object recognition memory in perirhinal cortex. J. Neurosci.: Off. J. Soc. Neurosci. 26 (47), 12186–12197. http://dx.doi.org/10.1523/JNEUROSCI.2818-06.2006.

Cowell, R.A., Bussey, T.J., Saksida, L.M., 2010. Components of recognition memory: dissociable cognitive processes or just differences in representational complexity? Hippocampus 20 (11), 1245–1262. http://dx.doi.org/10.1002/hipo.20865.

Crawford, J.R., Garthwaite, P.H., 2002. Investigation of the single case in neuropsychology: confidence limits on the abnormality of test scores and test score differences. Neuropsychologia 40 (8), 1196–1208. http://dx.doi.org/10.1016/S0028-3932(01)00224-X.

Crawford, J.R., Garthwaite, P.H., 2005. Testing for suspected impairments and dissociations in single-case studies in neuropsychology: evaluation of alternatives using monte carlo simulations and revised tests for dissociations. Neuropsychology 19 (3), 318–331. http://dx.doi.org/10.1037/0894-4105.19.3.318.

Crawford, J.R., Howell, D.C., 1998. Comparing an individual's test score against norms derived from small samples. Clin. Neuropsychol. (Neuropsychol. Dev. Cogn.: Sect. D.) 12 (4), 482–486. http://dx.doi.org/10.1076/clin.12.4.482.7241.

Crawford, J.R., Garthwaite, P.H., Porter, S., 2010. Point and interval estimates of effect sizes for the case-controls design in neuropsychology: rationale, methods, implementations, and proposed reporting standards. Cogn. Neuropsychol. 27 (3), 245–260. http://dx.doi.org/10.1080/02643294.2010.513967.

Curran, T., Hintzman, D.L., 1995. Violations of the independence assumption in process dissociation. J. Exp. Psychol. Learn. Mem. Cogn. 21 (3), 531–547. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/7602260〉.

Delbecq-Derouesné, J., Beauvois, M.F., Shallice, T., 1990. Preserved recall versus impaired recognition. Brain 113 (4), 1045–1074. http://dx.doi.org/10.1093/brain/113.4.1045.

Della Sala, S., Gray, C., Baddeley, A., Allamano, N., Wilson, L., 1999. Pattern span: a tool for unwelding visuo–spatial memory. Neuropsychologia 37 (10), 1189–1199. http://dx.doi.org/10.1016/S0028-3932(98)00159-6.

Epstein, R.A., 2008. Parahippocampal and retrosplenial contributions to human spatial navigation. Trends Cogn. Sci. 12 (10), 388–396. http://dx.doi.org/10.1016/j.tics.2008.07.004.

Epstein, R.A., Kanwisher, N., 1998. A cortical representation of the local visual environment. Nature 392 (6676), 598–601. http://dx.doi.org/10.1038/33402.

Epstein, R.A., Ward, E.J., 2010. How Reliable Are Visual Context Effects in the Parahippocampal Place Area? Cereb. Cortex 20 (2), 294–303. http://dx.doi.org/10.1093/cercor/bhp099.

Gardiner, J.M., 1988. Functional aspects of recollective experience. Mem. Cogn. 16 (4), 309–313. http://dx.doi.org/10.3758/BF03197041.

Goldman-Rakic, P.S., Selemon, L.D., Schwartz, M.L., 1984. Dual pathways connecting the dorsolateral prefrontal cortex with the hippocampal formation and parahippocampal cortex in the rhesus monkey. Neuroscience 12 (3), 719–743. http://dx.doi.org/10.1016/0306-4522(84)90166-0.

Graham, K.S., Scahill, V.L., Hornberger, M., Barense, M.D., Lee, A.C.H., Bussey, T.J., Saksida, L.M., 2006. Abnormal categorization and perceptual learning in patients with hippocampal damage. J. Neurosci.: Off. J. Soc. Neurosci. 26 (29), 7547–7554. http://dx.doi.org/10.1523/JNEUROSCI.1535-06.2006.

Habib, M., Sirigu, A., 1987. Pure topographical disorientation: a definition and anatomical basis. Cortex 23 (1), 73–85. http://dx.doi.org/10.1016/S0010-9452(87)80020-5.

Hannula, D.E., Libby, L.A., Yonelinas, A.P., Ranganath, C., 2013. Medial temporal lobe contributions to cued retrieval of items and contexts. Neuropsychologia 51 (12), 2322–2332. http://dx.doi.org/10.1016/j.neuropsychologia.2013.02.011.

Holdstock, J.S., Mayes, A.R., Gong, Q.Y., Roberts, N., Kapur, N., 2005. Item recognition is less impaired than recall and associative recognition in a patient with selective hippocampal damage. Hippocampus 15, 203–215. http://dx.doi.org/10.1002/hipo.20046.

Iaria, G., Chen, J.-K., Guariglia, C., Ptito, A., Petrides, M., 2007. Retrosplenial and hippocampal brain regions in human navigation: complementary functional contributions to the formation and use of cognitive maps. Eur. J. Neurosci. 25 (3), 890–899. http://dx.doi.org/10.1111/j.1460-9568.2007.05371.x.

Insausti, R., Muñoz, M., 2001. Cortical projections of the non-entorhinal hippocampal formation in the cynomolgus monkey (Macaca fascicularis). Eur. J. Neurosci. 14 (3), 435–451. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/11553294〉.

Kravitz, D.J., Peng, C.S., Baker, C.I., 2011. Real-world scene representations in high-level visual cortex: it's the spaces more than the places. J. Neurosci.: Off. J. Soc. Neurosci. 31 (20), 7322–7333. http://dx.doi.org/10.1523/JNEUROSCI.4588-10.2011.

Kravitz, D.J., Saleem, K.S., Baker, C.I., Ungerleider, L.G., Mishkin, M., 2013. The ventral visual pathway: an expanded neural framework for the processing of object quality. Trends Cogn. Sci. 17 (1), 26–49. http://dx.doi.org/10.1016/j.tics.2012.10.011.

Lavenex, P., Amaral, D.G., 2000. Hippocampal-neocortical interaction: a hierarchy of associativity. Hippocampus 10 (4), 420–430. http://dx.doi.org/10.1002/1098-1063(2000)10:4 < 420::AID-HIPO8 > 3.0.CO;2-5.

Lee, A.C.H., Rudebeck, S.R., 2010. Human medial temporal lobe damage can disrupt the perception of single objects. J. Neurosci.: Off. J. Soc. Neurosci. 30 (19), 6588–6594. http://dx.doi.org/10.1523/JNEUROSCI.0116-10.2010.

Lee, A.C.H., Buckley, M.J., Pegman, S.J., Spiers, H., Scahill, V.L., Gaffan, D., Graham, K.S., 2005. Specialization in the medial temporal lobe for processing of objects and scenes. Hippocampus 15 (6), 782–797. http://dx.doi.org/10.1002/hipo.20101.

Lee, A.C.H., Scahill, V.L., Graham, K.S., 2008. Activating the medial temporal lobe during oddity judgment for faces and scenes. Cereb. Cortex (New Y., N. Y.: 1991) 18 (3), 683–696. http://dx.doi.org/10.1093/cercor/bhm104.

Lee, A.C.H., Yeung, L.-K., Barense, M.D., 2012. The hippocampus and visual perception. Front. Hum. Neurosci. 6, 91. http://dx.doi.org/10.3389/fnhum.2012.00091.

Maguire, E.A., Burgess, N., Donnett, J.G., Frackowiak, R.S.J., Frith, C.D., O'Keefe, J., 1998. Knowing where and getting there: a human navigation network. Science 280 (5365), 921–924. http://dx.doi.org/10.1126/science.280.5365.921.

Maguire, E.A., Gadian, D.G., Johnsrude, I.S., Good, C.D., Ashburner, J., Frackowiak, R.S.J., Frith, C.D., 2000. Navigation-related structural change in the hippocampi of taxi drivers. Proc. Natl. Acad. Sci. 97 (8), 4398–4403. http://dx.doi.org/10.1073/pnas.070039597.

Manns, J.R., Squire, L.R., 1999. Impaired recognition memory on the Doors and People Test after damage limited to the hippocampal region. Hippocampus 9 (5), 495–499. http://dx.doi.org/10.1002/(SICI)1098-1063(1999)9:5 < 495::AID-HIPO2 > 3.0.CO;2-O.

Manns, J.R., Hopkins, R.O., Reed, J.M., Kitchener, E.G., Squire, L.R., 2003. Recognition memory and the human hippocampus. Neuron 37 (1), 171–180. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/23382181〉.

Martin, C.B., Mirsattari, S.M., Pruessner, J.C., Pietrantonio, S., Burneo, J.G., Hayman-Abello, B., Köhler, S., 2012. Déjà vu in unilateral temporal-lobe epilepsy is associated with selective familiarity impairments on experimental tasks of recognition memory. Neuropsychologia 50 (13), 2981–2991. http://dx.doi.org/10.1016/j.neuropsychologia.2012.07.030.

Mayes, A.R., Holdstock, J.S., Isaac, C.L., Hunkin, N.M., Roberts, N., 2002. Relative sparing of item recognition memory in a patient with adult-onset damage limited to the hippocampus. Hippocampus 12 (3), 325–340. http://dx.doi.org/10.1002/hipo.1111.

Mishkin, M., Suzuki, W. a., Gadian, D.G., Vargha-Khadem, F., 1997. Hierarchical organization of cognitive memory. Philos. Trans. R. Soc. Lond. Ser. B, Biol. Sci. 352 (1360), 1461–1467. http://dx.doi.org/10.1098/rstb.1997.0132.

Montaldi, D., Mayes, A.R., 2010. The role of recollection and familiarity in the functional differentiation of the medial temporal lobes. Hippocampus 20 (11), 1291–1314. http://dx.doi.org/10.1002/hipo.20853.

Murray, E.A., Bussey, T., 1999. Perceptual-mnemonic functions of the perirhinal cortex. Trends Cogn. Sci. 3 (4), 142–151. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/10322468〉.

Murray, E.A., Bussey, T.J., Saksida, L.M., 2007. Visual perception and memory: a new view of medial temporal lobe function in primates and rodents. Annu. Rev. Neurosci. 99–122. http://dx.doi.org/10.1146/annurev.neuro.29.051605.113046.

O'Craven, K.M., Kanwisher, N., 2000. Mental imagery of faces and places activates corresponding stimulus-specific brain regions. J. Cogn. Neurosci. 12 (6), 1013–1023. http://dx.doi.org/10.1162/08989290051137549.

O'Neil, E.B., Barkley, V. a., Köhler, S., 2013. Representational demands modulate involvement of perirhinal cortex in face processing. Hippocampus 23 (7), 592–605. http://dx.doi.org/10.1002/hipo.22117.

Pazzaglia, A.M., Dube, C., Rotello, C.M., 2013. A critical comparison of discrete-state and continuous models of recognition memory: implications for recognition and beyond. Psychol. Bull. 139 (6), 1173–1203. http://dx.doi.org/10.1037/a0033044.

Quamme, J.R., Yonelinas, A.P., Widaman, K.F., Kroll, N.E., Sauvé, M.J., 2004. Recall and recognition in mild hypoxia: using covariance structural modeling to test competing theories of explicit memory. Neuropsychologia 42 (5), 672–691. http://dx.doi.org/10.1016/j.neuropsychologia.2003.09.008.

Ranganath, C., 2010. A unified framework for the functional organization of the medial temporal lobes and the phenomenology of episodic memory. Hippocampus 20 (11), 1263–1290. http://dx.doi.org/10.1002/hipo.20852.

Reed, J.M., Squire, L.R., 1997. Impaired recognition memory in patients with lesions limited to the hippocampal formation. Behav. Neurosci. 111 (4), 667–675. http://dx.doi.org/10.1037/0735-7044.111.4.667.

Rey, A., 1959. Manuel du test de copie et de reproduction de mémoire de figures géométriques complexes. Centre de Psychologie Appliquée, Paris.

Rockland, K.S., Van Hoesen, G.W., 1999. Some temporal and parietal cortical connections converge in CA1 of the primate hippocampus. Cereb. Cortex 9 (3), 232–237. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/10355903〉.

Ross, D.A., Sadil, P., Wilson, D.M., Cowell, R.A., 2017. Hippocampal engagement during recall depends on memory content. Cereb. Cortex 1–14. http://dx.doi.org/10.1093/cercor/bhx147.

Sauvage, M.M., Beer, Z., Eichenbaum, H., 2010. Recognition memory: adding a response deadline eliminates recollection but spares familiarity. Learn. Mem. (Cold Spring Harb., N. Y.) 2 (17), 104–108. http://dx.doi.org/10.1101/lm.1647710.

Schneider, W., Eschman, A., Zuccolotto, A., 2002. E-Prime Reference Guide. Psychology Software Tools, Inc, Pittsburgh (Retrieved from). 〈http://step.psy.cmu.edu/materials/manuals/reference.pdf〉.

Shimamura, A.P., 2010. Hierarchical relational binding in the medial temporal lobe: the strong get stronger. Hippocampus 20 (11), 1206–1216. http://dx.doi.org/10.1002/hipo.20856.

Snodgrass, J.G., Corwin, J., 1988. Pragmatics of measuring recognition memory: applications to dementia and amnesia. J. Exp. Psychol. Gener. 117 (1), 34–50. http://dx.doi.org/10.1037/h0029531.

Stefanacci, L., Buffalo, E. a., Schmolck, H., Squire, L.R., 2000. Profound amnesia after damage to the medial temporal lobe: a neuroanatomical and neuropsychological profile of patient E. P. J. Neurosci.: Off. J. Soc. Neurosci. 20 (18), 7024–7036. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/10995848〉.

Suzuki, W.A., Amaral, D.G., 1994. Perirhinal and parahippocampal cortices of the macaque monkey: cortical afferents. J. Comp. Neurol. 350 (4), 497–533. http://dx.doi.org/10.1002/cne.903500402.

Taylor, L.B., 1969. Localisation of cerebral lesions by psychological testing. Clin. Neurosurg. 16, 269–287. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/5811709〉.

Tompary, A., Duncan, K., Davachi, L., 2016. High-resolution investigation of memory-specific reinstatement in the hippocampus and perirhinal cortex. Hippocampus 26 (8), 995–1007. http://dx.doi.org/10.1002/hipo.22582.

Turriziani, P., 2004. Recognition memory for single items and for associations in amnesic patients. Neuropsychologia 42 (4), 426–433. http://dx.doi.org/10.1016/j.neuropsychologia.2003.10.003.

Van Cauter, T., Poucet, B., Save, E., 2008. Unstable CA1 place cell representation in rats with entorhinal cortex lesions. Eur. J. Neurosci. 27 (8), 1933–1946. http://dx.doi.org/10.1111/j.1460-9568.2008.06158.x.

Vann, S.D., 2010. Re-evaluating the role of the mammillary bodies in memory. Neuropsychologia 48 (8), 2316–2327. http://dx.doi.org/10.1016/j.neuropsychologia.2009.10.019.

Vann, S.D., Aggleton, J.P., Maguire, E. a., 2009. What does the retrosplenial cortex do. Nat. Rev. Neurosci. 10 (11), 792–802. http://dx.doi.org/10.1038/nrn2733.

Wechsler, D., 2000. Echelle d'Intelligence de Wechsler pour Adulte III (WAIS-III). Les éditions du Centre de Psychologie appliquée, Paris.

Wechsler, D., 2001. Echelle clinique de mémoire de Wechsler MEM-III (WMS-III). Les éditions du Centre de Psychologie appliquée, Paris.

Wixted, J.T., 2007. Dual-process theory and signal-detection theory of recognition memory. Psychol. Rev. 114 (1), 152–176. http://dx.doi.org/10.1037/0033-295X.114.1.152.

Wixted, J.T., Mickes, L., Squire, L.R., 2010. Measuring recollection and familiarity in the medial temporal lobe. Hippocampus 20 (11), 1195–1205. http://dx.doi.org/10.1002/hipo.20854.

Wolk, D.A., Signoff, E.D., DeKosky, S.T., 2008. Impairment: a global decline in recognition memory. Neuropsychologia 46 (7), 1965–1978. http://dx.doi.org/10.1016/j.neuropsychologia.2008.01.017.Recollection.

Yonelinas, A.P., 2001. Consciousness, control and confidence: the 3 Cs of recognition memory. J. Exp. Psychol. 130 (3), 361–379. http://dx.doi.org/10.1037/0096-3445.130.3.361.

Yonelinas, A.P., 2002. The nature of recollection and familiarity: a review of 30 years of research. J. Mem. Lang. 46 (3), 441–517. http://dx.doi.org/10.1006/jmla.2002.2864.

Yonelinas, A.P., Jacoby, L.L., 1995. The relation between remembering and knowing as bases for recognition: effects of size congruency. J. Mem. Lang. 34 (5), 622–643. http://dx.doi.org/10.1006/jmla.1995.1028.

Yonelinas, A.P., Aly, M., Wang, W.-C., Koen, J.D., 2010. Recollection and familiarity: examining controversial assumptions and new directions. Hippocampus 20 (11), 1178–1194. http://dx.doi.org/10.1002/hipo.20864.

Yukie, M., 2000. Connections between the medial temporal cortex and the CA1 subfield of the hippocampal formation in the Japanese monkey (Macaca fuscata). J. Comp. Neurol. 423 (2), 282–298. (Retrieved from). 〈http://www.ncbi.nlm.nih.gov/pubmed/10867659〉.