

## False memories to emotional stimuli are not equally affected in right- and left-brain-damaged stroke patients

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### ABSTRACT

Previous research has attributed to the right hemisphere (RH) a key role in eliciting false memories to visual emotional stimuli. These results have been explained in terms of two right-hemisphere properties: (i) that emotional stimuli are preferentially processed in the RH and (ii) that visual stimuli are represented more coarsely in the RH. According to this account, false emotional memories are preferentially produced in the RH because emotional stimuli are both more strongly and more diffusely activated during encoding, leaving a memory trace that can be erroneously reactivated by similar but unstudied emotional items at test. If this *right-hemisphere hypothesis* is correct, then RH damage should result in a reduction in false memories to emotional stimuli relative to left-hemisphere lesions. To investigate this possibility, groups of right-brain-damaged (RBD,  $N = 15$ ), left-brain-damaged (LBD,  $N = 15$ ) and healthy (HC,  $N = 30$ ) participants took part in a recognition memory experiment with emotional (negative and positive) and non-emotional pictures. False memories were operationalized as incorrect responses to unstudied pictures that were similar to studied ones. Both RBD and LBD participants showed similar reductions in false memories for negative pictures relative to controls. For positive pictures, however, false memories were reduced only in RBD patients. The results provide only partial support for the right-hemisphere hypothesis and suggest that inter-hemispheric cooperation models may be necessary to fully account for false emotional memories.

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### 1. Introduction

Emotional stimuli are remembered better and more vividly than non-emotional stimuli (Hamann, 2001; Kensinger, 2004). This phenomenon, known as the *emotional enhancement of memory*, has been replicated across a range of paradigms and stimulus types (e.g., Borsutzky, Fujiwara, Brand, & Markowitsch, 2010; Bradley, Greenwald, Petry, & Lang, 1992; Kensinger & Corkin, 2004; Nagae & Moscovitch, 2002; Talmi, Anderson, Riggs, Caplan, & Moscovitch, 2008) and is particularly robust for arousing events (e.g., Anderson, Yamaguchi, Grabski, & Lacka, 2006; Christman, Propper, & Dion, 2004; Ochsner, 2000; Schaefer, Pottage, & Rickart, 2011).

However, not all aspects of memory are enhanced by emotional stimuli (Bradley et al., 1992). Peripheral features of visual scenes are remembered less well when an emotional item is present in the scene than when only non-emotional items are present (Kensinger, Garoff-Eaton, & Schacter, 2007a; Talmi et al., 2008). In addition, memory for scene details can be impaired by emotionality, even when these details belong to a central element of the scene (Adolphs, Denburg, & Tranel, 2001; Denburg, Buchanan, Tranel, & Adolphs, 2003). For example, participants may remember well a picture of a dead body compared to a picture of a living person (*gist memory*), but they may remember less well the spatial orientation of the body than the orientation of the living person (memory for scene *details*) (Adolphs, Denburg, et al., 2001; but see Kensinger, 2009, for a different perspective).

Perhaps more surprisingly, emotional stimuli can also induce more false memories than non-emotional stimuli (Dehon, Laroi, & Van der Linden, 2010; Porter, Spencer, & Birt, 2003). For example, Porter et al. (2003) showed negative, positive or neutral pictures to different groups of participants and asked them a few questions,

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some of which contained misleading information about the pictures (e.g., that there was a large animal). When asked to recall the pictures 1 h later, twice as many participants in the negative group falsely recalled the misleading information compared to participants in the positive and neutral groups. This apparent paradox – that negative emotion can simultaneously improve and impair memory – has been repeatedly found in recognition memory experiments with word stimuli (Brainerd, Stein, Silveira, Rohenkohl, & Reyna, 2008; Grassi-Oliveira, Gomes, & Stein, 2011; Maratos, Allan, & Rugg, 2000), even when potential confounds, such as concreteness or semantic cohesiveness, are taken into account (Dehon et al., 2010; McNeely, Dywan, & Segalowitz, 2004). Thus, results from studies using words and complex scenes suggest that highly arousing negative stimuli can increase both true and false memories.

Research into the neural correlates of emotional memories (LaBar & Cabeza, 2006) and false memories (Schacter & Slotnick, 2004) started uncovering a network of brain structures that are commonly involved in these phenomena, including amygdala, hippocampus, pre-frontal, orbitofrontal and parietal cortices. Less is known, however, about the neural structures underlying *false emotional memories* and whether or not, like emotional processing, these networks show some degree of *lateralization*. In the following, we briefly review the literature implicating right-hemisphere structures in both emotional processing and false memories and outline the main goals and hypotheses of the present study.

### 1.1. Right hemisphere and emotional processing

The right brain hemisphere (RH) has been consistently linked to a preferential processing of emotional stimuli in comparison to the left hemisphere (LH) (Abbott, Cumming, Fidler, & Lindell, 2013; Borod, Bloom, Brickman, Nakhtina, & Curko, 2002; Demaree, Everhart, Youngstrom, & Harrison, 2005; Kucharska-Pietura, 2006; Witteman, van IJzendoorn, van de Velde, van Heuven, & Schiller, 2011). However, there is still debate about which processes (expression vs. perception) and types (negative vs. positive) of emotion are best supported by right-hemisphere networks. For emotional perception, two main hypotheses have been put forward. The *right-hemisphere hypothesis* posits that the RH specializes in processing both positive and negative emotions (e.g., Borod et al., 2002). The *valence-specific hypothesis*, on the other hand, posits that the RH specializes in negative emotions, whereas the LH specializes in positive emotions (e.g., Davidson, 1992).

Consistent with the right-hemisphere hypothesis, Borod et al. (1998) found that perception of emotional faces, prosody and written words was impaired in right-brain-damaged patients compared to left-brain-damaged patients and healthy controls, who did not differ from each other. Similarly, Alves, Aznar-Casanova, and Fukusima (2009) showed that perception of emotional faces in healthy participants was faster when the faces were presented to participants' RH (via their left visual field) than when the faces were presented to participants' LH (via their right visual field), suggesting that emotional stimuli are preferentially processed in the RH.

By contrast, Natale, Gur, and Gur (1983) showed that participants judged faces with negative expressions as more negative when they were presented to the RH than when they were presented to the LH. Conversely, participants judged faces with positive expressions as more positive when they were presented to the LH than when they were presented to the RH. These results directly supported the valence-specific hypothesis. Additional evidence for the valence-specific hypothesis came from neuroimaging and electrophysiological studies. Canli, Desmond, Zhao, Glover, and Gabrieli (1998) found in a functional magnetic resonance imaging (fMRI) study that brain activation was stronger in the RH when

participants saw a sequence of negative pictures and stronger in the LH when they saw a sequence of positive pictures. Likewise, Davidson (1992) found in several electroencephalogram (EEG) studies that brain activity was higher in right frontal electrodes when participants reacted to negative film clips and higher in left frontal electrodes when they reacted to positive clips.

More recent results, however, suggest that these hypotheses may not capture the complexity of emotional processing. In an fMRI study, Killgore and Yurgelun-Todd (2007) presented sad and happy chimeric faces very briefly to normal participants who were only required to determine the sex of the face (but were not asked to make any overt emotional judgement). The pattern of brain activations, which was linked to the non-conscious perception of affective faces presented to either hemisphere, showed that not only the RH was more responsive than the LH to both face types (a result consistent with the right-hemisphere hypotheses) but also that the LH was more responsive to sad faces than to happy faces (a result inconsistent with both the right-hemisphere and the valence-specific hypotheses).

More surprisingly, Paradiso, Anderson, Ponto, Tran, and Robinson (2011) reported a group of patients with stable right-hemisphere lesions who showed an impairment relative to healthy controls in their ability to judge the emotionality of positive pictures but no impairment in their ability to judge negative pictures, a result that supports only partially the right-hemisphere hypothesis and directly contradicts the valence-specific hypothesis.

Taken together, these results indicate a lack of consensus regarding laterality and emotional processing, which might be a result of different experimental paradigms, sample characteristics and stimulus types across studies. However, as most evidence supports a *relative specialization* of the RH towards emotion perception (Abbott et al., 2013; Adolphs, Jansari, & Tranel, 2001; Borod et al., 2002; Charbonneau, Scherzer, Aspirot, & Cohen, 2003; Kucharska-Pietura, Phillips, Gernand, & David, 2003; Nijboer & Jellema, 2012), we adopt this view to derive our predictions.

### 1.2. Right hemisphere and false memories

In addition to its role in emotional processing, the RH has also been implicated in the production of false memories (e.g., Marchewka, Jednrog, Nowicka, Brechmann, & Grabowska, 2009; Westerberg & Marsolek, 2003). Patients undergoing the intracarotid amobarbital sodium procedure, which selectively anesthetizes only one hemisphere at a time, show a marked increase in false alarms during recognition memory tests following LH injection (Loring, Lee, & Meador, 1989). That is, patients incorrectly say more often that an unstudied test item has been studied when the RH is operational and the left is anesthetized than when the LH is operational and the right is anesthetized, suggesting that false alarms are generated by processes at play in the RH.

Patients with RH lesions, particularly in frontal regions, have also been shown to produce more false memories than controls in studies using words (Delbecq-Derouesne, Beauvois, & Shallice, 1990), faces (Rapcsak, Polster, Glisky, & Comer, 1996), and pictures (Schacter, Curran, Galluccio, Milberg, & Bates, 1996). Consistent with these results, a structural neuroimaging study has shown that healthy participants who generated the highest levels of false memories in a recognition memory test using pictures also possessed the lowest densities of gray matter in their right frontal gyrus (Marchewka et al., 2009).

In healthy participants, most evidence that the RH is preferentially involved in producing false memories comes from studies combining the divided visual field technique (Bourne, 2006) with the DRM paradigm (Roediger & McDermott, 1995). In the DRM paradigm, participants study lists of words (e.g., candy, sugar, tooth) that are all related to a single unstudied word (e.g., sweet). In a

subsequent recognition test, participants often incorrectly believe that the related word was present in the study list. The DRM paradigm has been widely used to investigate false memories in normal and patient groups alike (Gallo, 2010). When the DRM paradigm is coupled with the divided field technique, the common finding is that false memories are higher when test words are presented to the left visual field (right hemisphere) than when they are presented to the right visual field (left hemisphere) (Ben-Artzi, Faust, & Moeller, 2009; Faust, Ben-Artzi, & Harel, 2008; Giammattei & Arndt, 2012; Marchewka et al., 2009; Schmitz, Dehon, & Peigneux, 2013; Westerberg & Marsolek, 2003).

These results have been interpreted in the context of *fine-coarse coding theory* (Beeman et al., 1994; Jung-Beeman, 2005). According to this theory, input stimuli activate semantic networks that have different structural and functional properties in the left and right hemispheres. In the LH, stimuli strongly activate small semantic networks that represent the dominant meaning of the input. In the RH, stimuli weakly activate large networks that represent the meanings of the input and of its semantic associates. In this view, stimulus representation is fine in the LH and coarse in the RH (but see Marsolek, 1999; Marsolek & Burgund, 2008, for a different account). Although the theory was originally developed in the context of language comprehension, recent evidence from divided visual field studies has extended its applicability to verbal memory (Ben-Artzi et al., 2009; Faust et al., 2008) and picture comprehension (Lovseth & Atchley, 2010).

Fine-coarse coding theory can account for false memories in the RH because studied stimuli, words or pictures, are more likely to activate the representations of related stimuli in the (gist-based) right hemisphere than in the (veridical) left hemisphere. The activation of the unstudied, related stimuli in the RH can then increase the likelihood of participants falsely accepting them as if they had been previously studied. Thus, a number of studies in both healthy participants and brain damaged patients indicate that the RH plays a prominent role in the creation of false memories, a phenomenon that can be accounted for by the right-hemisphere's coarser representation of studied stimuli.

### 1.3. Present study

Despite the wealth of evidence implicating the RH in both emotional processing and false memories, there is surprisingly little research into the role of the RH in false emotional memories. In the few studies that have investigated the lateralization of emotional memories, only data for true memories was reported (Mneimne et al., 2010; Nagae & Moscovitch, 2002). To our knowledge, only one study has directly examined the lateralization of false emotional memories (Marchewka et al., 2008).

In Marchewka et al.'s (2008) fMRI study, participants saw a mixture of negative and neutral complex scenes taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) and then completed a recognition memory test. The pictures were briefly presented (400 ms) to participants' left or right visual fields at both encoding and retrieval stages, and fMRI scans were obtained during the retrieval stage. Two interesting findings emerged from that study. The first was that false-alarm rates were equivalent between the hemispheres when the pictures were neutral, but were higher in the RH when the pictures were negative. The second result was that false-alarm rates were associated with stronger activation in the *right* pre-frontal cortex relative to correct rejections (when participants answer "no" for a picture that has not been previously presented), and that this activation was also stronger for negative than for neutral pictures. Marchewka et al.'s (2008) results are consistent with both the right-hemisphere hypothesis and valence-specific hypothesis of

hemispheric specialization of emotional processing. Their results are also consistent with the fine-coarse coding account of false memories.

In the present study, we investigate hemispheric asymmetries in emotional memories by testing groups of right-brain-damaged (RBD), left-brain-damaged (LBD) and healthy control (HC) participants in a recognition memory task. False memories were operationalized as the false-alarm rate to related, unstudied pictures. This definition is commonly used in memory research (for reviews, see Schacter, Norman, & Koutstaal, 1998; Schacter & Slotnick, 2004) and represents the proportion of novel items that are wrongly interpreted as "old" by participants. By construction, novel items are related to studied items and, consequently, share with them semantic and/or perceptual features. For example, participants may see at study a picture of an angry dog and at test a picture of a different angry dog. Because studied and tested pictures share conceptual and perceptual characteristics, participants may incorrectly think at test that the picture was previously seen at study. To the extent that novel, related test items are mistaken for previously studied items, they can be used to gauge false memories. This type of false memory, also called *gist-based false recognition* (Garoff-Eaton, Kensinger, & Schacter, 2007; Gutches & Schacter, 2012), has been shown to increase with age (Koutstaal & Schacter, 1997) and as a result of frontal-lobe lesions (Curran, Schacter, Norman, & Galluccio, 1997; Rapcsak et al., 1996) and represents only one among several manifestations of false-memory phenomena (Brainerd & Reyna, 2002; Gallo, 2010; Kopelman, 1999; Schacter & Slotnick, 2004).

This study extends Marchewka et al.'s (2008) work by including both negative and positive emotional pictures, which allows us to contrast directly the right-hemisphere hypothesis with the valence-specific hypothesis. Moreover, we report and analyze not only data for false memories but also data for hits (true memories) and for false alarms to unrelated, unstudied pictures (a measure of response bias). Both, true memories and response bias are important in helping to constrain potential accounts of false-memory data (Wixted & Stretch, 2000).

If the right-hemisphere hypothesis is correct, then RBD patients should produce fewer false memories to emotional stimuli than both LBD patients and healthy controls. The prediction follows from the assumption that the RH (i) specializes in processing emotions in general (both negative and positive) and (ii) specializes in representing stimuli in a coarse manner. Lesions to the RH should thus reduce false memories more in the case of emotional pictures (negative and positive) than in the case of neutral pictures, because the stronger but coarser representations of emotional stimuli in the RH, which enhance false memories, are more degraded in RBD than in LBD patients.

If, on the other hand, the valence-specific hypothesis is correct, then RBD patients should produce fewer false memories to negative stimuli than both LBD and healthy controls, whereas LBD patients should produce fewer false memories to positive stimuli than RBD patients and controls. These predictions follow from the assumption that the RH specializes in processing negative emotions and the LH specializes in processing positive emotions. Lesions to the RH should thus reduce false memories to negative pictures, because the representations of negative stimuli are degraded. By contrast, lesions to the LH should reduce false memories to positive pictures, because the representations of positive stimuli are degraded.

Finally, following fine-coarse coding theory, it is predicted that false memories to neutral items should be lower in RBD than in LBD patients, because the more veridical LH is intact in RBD patients, which should contribute to reduce false memories, but is degraded in LBD patients, which should contribute to increase false memories.

## 2. Method

### 2.1. Participants

A total of 60 participants (30 HC, 15 RHD, 15 LHD), aged between 27 and 75 years ( $M = 55.8$ ,  $SD = 11.3$ ), completed the study. The initial sample consisted of 67 participants, but 7 were excluded either because they did not attend the test phase (2 HC, 2 RHD, 1 LHD), or because the interval between study and test was longer than one week (1 RHD, 1 LHD).

Brain damaged individuals were recruited from hospitals in the Greater Porto Alegre metropolitan area (Rio Grande do Sul state, Brazil). Healthy controls were recruited from university outreach groups (e.g., choir, language classes) and the community at large. Testing was conducted at the Department of Psychology of the Pontifical Catholic University of Rio Grande do Sul (PUC-RS) or at the patients' homes. Written informed consent was obtained from all participants and the experimental procedure was approved by PUC-RS Research Ethics Committee. All participants took part in the experiment voluntarily and were reimbursed for transportation costs when applicable.

Participants were native Portuguese speakers with no history of dementia, drug abuse or depression. Handedness was determined by self-report and through the Edinburgh Handedness Inventory (Oldfield, 1971). All patients were right handed, except for one RBD patient who was ambidextrous. To check whether the pattern of emotional ratings and memory performance of this participant differed from the rest of the group, we produced boxplots with data from the RBD group. If the ambidextrous participant differed systematically from the rest of the group, some of his data scores should exceed the upper or lower limits of the sample distribution. The boxplots, however, revealed no evidence that the ambidextrous participant was any different from the others, as none of his scores exceeded 1.5 times the sample inter-quartile range, which is the standard criterion for flagging outliers in a data sample. In addition, we checked if this participant's performance lay within 2 standard deviations from the mean (95% of the sample distribution). It did. Thus, we believe that the inclusion of an ambidextrous RBD patient in a group of right-handed RBD group did not change significantly the nature of this group.

Patients were included if they were diagnosed with a unilateral stroke as a result of a hemorrhagic or ischemic cerebrovascular accident at least one month prior to taking part in the study. Time post-stroke was similar for both patient groups [Median(RBD) = 9 months (range: 3–77), Median(LBD) = 12 months (1–55); Mann-Whitney test:  $U = 111.5$ ,  $p = .97$ ;  $t$ -test:  $t < 1$ ,  $p = .76$ ]. Patients were excluded if they suffered from moderate or severe aphasia, assessed by completion of the Oral Language subtest from the Brazilian Brief Neuropsychological Assessment Battery (Neupsilin; Fonseca, Salles, & Parente, 2008, 2009). Patients were also excluded if they had untreated sensorial disturbances and if they had taken part in any neuropsychological rehabilitation program prior to the study.

The location of brain lesions was confirmed by computer tomography or magnetic resonance imaging scans. For those participants whose lesion site could not be confirmed by neuroimaging methods (one RBD and four LBD participants), the side of their lesion was determined by clinical examination from a neurologist. Table 1 summarizes the location of RBD and LBD participants' lesions.

### 2.2. Demographics

Participants in HC, RHD and LHD groups were matched on age ( $F < 1$ ,  $p = .96$ ), gender (male-to-female ratio:  $\chi^2(2) = 3.93$ ,  $p = .14$ )

and educational level (school years:  $F < 1$ ,  $p = .82$ ). In addition, RHD and LHD patients were matched on socioeconomic status ( $F < 1$ ,  $p = .33$ ), measured with the Brazilian Criterion of Economic Classification (CCEB, 2003), which takes into account the quantity and quality of assets owned by individuals. Table 2 summarizes these demographic data.

### 2.3. Neuropsychological assessment

Participants were assessed for general cognitive abilities, emotional communication abilities and depression. Table 2 describes these data. Cognitive abilities were assessed with a Brazilian version (Chaves & Izquierdo, 1992) of the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), a widely used cognitive screening measure. The MMSE comprises 11 items that assess orientation in time and space (2 items), verbal encoding (1 item), working memory (1 item), verbal recall (1 item) and language functions (6 items). The test concentrates on the cognitive functions, excluding questions about mood and abnormal mental states. The maximum total score in the MMSE is 30 and the test is not timed. All participants, except one RBD, took the test. A one-way ANOVA on MMSE test scores revealed a main effect of group [ $F(2,56) = 5.71$ ,  $p < .01$ ,  $\eta_p^2 = .17$ ], such that HC participants scored significantly higher than LBD participants ( $p < .001$ ) and RBD participants scored marginally higher than LBD participants ( $p = .06$ ). The scores of HC and RBD participants did not differ ( $p = .27$ ). The disadvantage of LBD participants remained significant even when education and age were taken into account [ $F(2,54) = 7.05$ ,  $p < .01$ ,  $\eta_p^2 = .21$ ]. Closer inspection revealed that the difference across groups was mainly driven by the *recall* subtest [ $F(2,56) = 7.83$ ,  $p = .001$ ,  $\eta_p^2 = .22$ ]. Scores on the remaining subtests did not differ across groups. The memory deficit observed in LBD patients was likely to be restricted to *retrieval* operations, since their scores in the encoding and working memory subtests did not differ from controls. Importantly, RBD and LBD groups performed as well as controls in the language subtests, suggesting that language production and comprehension was relatively spared in both lesion groups. Also, because some of the tasks in the MMSE required reading and writing, general visual disturbances could be easily spotted; none was detected.

Patients were screened for depression, as previous research suggested that sad moods can reduce false memories (Storbeck & Clore, 2005, 2011). Depression was assessed with the Brazilian version (Almeida & Almeida, 1999) of the Geriatric Depression Scale (GDS-15), a short form of the original GDS-30 scale (Yesavage et al., 1983), which has been translated into many languages and validated in Brazil. The scale consists of 15 questions. Scores range from 0 to 15, with scores above 11 being indicative of severe depression. No difference was found between the GDS-15 scores of RBD and LBD groups [ $F < 1$ ,  $p = .45$ ].

### 2.4. Materials

Stimuli consisted of 59 color pictures extracted from IAPS (International Affective Picture System), a widely used image database that has been normed for stimulus emotionality (Lang et al., 2008). The emotionality measures in IAPS are based on the dimensional perspective of emotion (Barrett & Russell, 1998; Mauss & Robinson, 2009; Russell, 1980), according to which the affective content of pictures can be described in terms of two distinct dimensions, namely, valence (which varies from 1 = *unpleasant* to 9 = *pleasant*) and arousal (which varies from 1 = *relaxing* to 9 = *exciting*) (Kensinger, 2004). Valence ratings can then be used to group pictures into three categories: negative (valence of 1–3.99), neutral (4–5.99) and positive (6–9) (Kensinger & Corkin, 2004). The original valence and arousal

**Table 1**

Location of patients' lesions.

Patient	Hemisphere	Brain stem	Frontal lobe	Temporal lobe	Parietal lobe	Occipital lobe	Basal ganglia	Internal capsule	Insula
1	Right			C + S				S	
2	Right						S		
3	Right		C	C					
4	Right		S		S				
5	Right		C	C	C				
6	Right		C						
7	Right			C + S	C + S				
8	Right	S		S	S		S		
9	Right		S	S	S				S
10	Right	–	–	–	–	–	–	–	–
11	Right		C						
12	Right		C						
13	Right			C	C				
14	Right					C			
15	Right		C						
16	Left	S				S			
17	Left						S	S	
18	Left				C				
19	Left	–	–	–	–	–	–	–	–
20	Left						S		
21	Left			C					
22	Left		S				S		
23	Left							S	
24	Left		C + S	C + S	C + S				C + S
25	Left				C				
26	Left	–	–	–	–	–	–	–	–
27	Left		S						
28	Left	–	–	–	–	–	–	–	–
29	Left		C + S	C + S					
30	Left	–	–	–	–	–	–	–	–

Note. C = Cortical lesion, S = Subcortical lesion, C + S = Cortical and Subcortical lesion, – = Non-specified, subcortical, lateralized lesion.

**Table 2**

Demographic and neuropsychological data for healthy controls (HC), right-brain-damaged (RBD) and left-brain-damaged patients (LBD).

	HC		RBD		LBD	
	M	SD (N)	M	SD (N)	M	SD (N)
Age (years)	56.20	11.83 (30)	55.60	7.73 (15)	55.93	14.57 (15)
Education (school years)	10.03	4.50 (30)	10.33	5.42 (15)	10.93	3.22 (15)
Gender (male/female)	6 M, 24 F		7 M, 8 F		6 M, 9 F	
Mental state (MMSE)**	27.63	2.19 (30)	26.79	2.61 (14)	24.53	3.91 (15)
Depression (GDS-15)	–	–	4.50	4.09 (14)	5.73	4.18 (15)
Post-onset time (months)	–	–	18.33	19.26 (15)	16.40	15.19 (15)
Socioeconomic status (CCEB)	–	–	25.21	7.59 (14)	28.13	8.18 (15)

Note. N = number of participants contributing data; MMSE = Mini Mental State Examination (\*\*  $p < .01$ , HC vs. LBD; difference driven by recall subscale); GDS-15 = Geriatric Depression Scale; CCEB = Measure of purchase power and educational level developed by the Brazilian Association of Research Enterprises; – = data not available.

norms for IAPS pictures have been adapted to Brazilian samples (IAPS-BR; Ribeiro, Pompéia, & Bueno, 2004, 2005) and these were the norms adopted in this study. Valence scores differed significantly across emotional categories [ $F(2,33) = 167.62$ ,  $p < .001$ ,  $\eta^2_p = .91$ ; negative < neutral < positive,  $ps < .001$ ].

Similarly, arousal scores differed significantly across categories [ $F(2,33) = 25.54$ ,  $p < .001$ ,  $\eta^2_p = .61$ ; neutral < positive < negative,  $ps \leq .001$ ]. Table 3 presents means and standard deviations of valence and arousal scores for the pictures used during the encoding phase.

**Table 3**

Valence and arousal ratings given by healthy controls (HC), right brain-damaged (RBD) and left brain-damaged patients (LBD) to stimuli presented at study.

	HC		RBD		LBD		IAPS-BR Norms		
	M	SD	M	SD	M	SD	M	SD	
Valence	Negative	2.48	0.76	2.97	1.63	2.23	0.75	2.77	0.59
	Neutral	5.85	0.87	6.25	1.11	6.09	1.24	5.09	0.46
	Positive	7.06	0.77	7.37	0.77	7.47	1.14	7.27	0.74
Arousal	Negative	6.70	1.63	6.23	2.11	7.04	1.46	6.75	0.70
	Neutral	4.48	1.38	5.20	1.32	5.19	1.41	4.30	0.43
	Positive	5.98	1.64	6.44	1.67	6.55	1.56	5.63	1.04

Note. Valence = unpleasant to pleasant (range: 1–9); Arousal = relaxing to exciting (range: 1–9); Negative (valence < 4), positive (valence  $\geq 6$ ) and neutral ( $4 \leq$  valence  $< 6$ ). Valence categories were defined according to norms from IAPS-BR (Brazilian norms for pictures in the International Affective Picture System; Ribeiro et al., 2004).

Valence and arousal ratings were also collected from HC, RBD and LBD participants during the encoding phase. Ratings were obtained using the SAM (*Self-Assessment Manikin*) scale, a 9-point pictorial scale developed to measure feelings of pleasantness and arousal elicited by emotional pictures (Bradley & Lang, 1994).

## 2.5. Procedure

Participants were tested individually in two sessions (study and test phases). In the study phase participants were shown 36 pictures from IAPS (12 negative, 10 neutral, 14 positive). Each picture was displayed for 4 s. Participants were asked to judge each picture with respect to their valence and arousal by pointing to the corresponding image in the SAM scale, following standard instructions (Lang et al., 2008). The inter-stimulus interval varied from trial to trial, depending on the time taken by the participant to produce the valence and arousal judgments. Instructions were repeated whenever necessary to remind the participants of the meaning of valence and arousal.

Participants returned one week later for the recognition memory test. In the test phase, they were shown 39 pictures from IAPS (13 negative, 12 neutral, 14 positive). Each picture was displayed for 4 s. Test pictures were classified as *targets* (pictures presented in the study phase; e.g., a snake), *related lures* (pictures not presented in the study phase but related to presented pictures; e.g., a different snake) and *unrelated lures* (pictures not studied and not related to studied pictures). Following IAPS valence norms, test pictures were also classified as negative (5 targets, 5 related lures, 3 unrelated lures), neutral (5 targets, 4 related lures, 3 unrelated lures), and positive (6 targets, 5 related lures, 3 unrelated lures). Test pictures were matched such that normed valence and arousal scores (Ribeiro et al., 2004, 2005) were similar across targets, related lures and unrelated lures.

Participants were asked to respond "Yes" if they thought they had seen the picture at study and "No" otherwise. Responses were self-paced. Participants were also explicitly told that some pictures at test were similar but different from the pictures they have studied; they were told to respond "No" in such cases. After the test, all participants completed the MMSE. Participants in the lesion groups also completed the CCEB and GDS-15 tasks.

## 2.6. Data analyses

### 2.6.1. True and false memories

Memory performance was analyzed with raw measures of correct and incorrect trials (proportion of "Yes" responses) and with a derived measure of discriminability ( $d'$ ). The raw proportion of "Yes" responses was used to calculate hits (correct trials) and false alarms (incorrect trials). *Hit rate* is the proportion of "Yes" responses to *targets* and represent a measure of true memories. *False-alarm rate* is the proportion of "Yes" responses to *lures* (both related and unrelated). False alarms to related lures were taken as a measure of false memories (e.g., saying that a snake was studied when in fact a different snake was studied), whereas false alarms to unrelated lures were taken as a measure of response bias (i.e., a general trend to say "Yes", irrespective of the picture's memory status).

### 2.6.2. Discriminability ( $d'$ )

The index  $d'$  combines hit rates and false-alarm rates into a single performance measure. In addition,  $d'$  assumes that the distribution of the memory strengths associated with the studied items is normal (i.e., few pictures end up weakly represented in memory; few become strongly represented; most pictures end up represented with some intermediate level of strength). Discriminability  $d'$  is defined as  $z(HR) - z(FAR)$ , where  $HR$  is the hit rate,  $FAR$  is the

false-alarm rate and  $z(P)$  is the value in a standardized normal distribution ( $\mu = 0$ ,  $\sigma = 1$ ) that corresponds to proportion  $P$ . In other words,  $z(P)$  is the inverse of the normal distribution function. High values of  $d'$  represent good memory performance, since it indexes the ability to maximize hits and minimize false alarms.

More importantly,  $d'$  provides a measure of recognition memory that is corrected for response bias. In this study, *d'-target* refers to the ability to correctly accept targets when response bias is controlled; *d'-target* is given by  $z(HR) - z(FAR_{unr})$ , where  $FAR_{unr}$  is the false-alarm rate to unrelated lures. By contrast, *d'-related* refers to the ability to accept related lures as if they were targets, an error of commission; *d'-related* is given by  $z(FAR_{rel}) - z(FAR_{unr})$ , where  $FAR_{rel}$  is the false-alarm rate to related lures. Undefined  $z$  values, which occur when hit rates or false-alarm rates are 0 or 1, were corrected with the log-linear rule (Hautus, 1995).

### 2.6.3. Post-onset times

The potential confounding effects of general cognitive abilities and differential post-stroke recovery times were controlled by including MMSE scores and post-onset times, respectively, as covariates in the analyses with discriminability measures.

### 2.6.4. Lesion locations

Neuroimaging and neuropsychological studies have implicated specific brain regions in the creation and modulation of false memories (e.g., Gutches & Schacter, 2012; Schacter & Slotnick, 2004). Right pre-frontal lesions may increase false memories (Schacter et al., 1996), whereas medial temporal lobe and right parietal lobe lesions may reduce false memories (Drowos, Berryhill, Andre, & Olson, 2010; Schacter, Verfaellie, & Pradere, 1996). In addition, cortical and subcortical structures may contribute differently to memory performance: Previous results suggest that errors of omission (i.e., abnormally low hit rates) are associated with both cortical and subcortical structures, whereas errors of commission (i.e., abnormally high false-alarm rates) are more likely linked only with cortical structures (Braun, Delisle, Guimond, & Daigneault, 2009).

Due to the high heterogeneity and small sample size of our patient groups, however, it is difficult to make strong inferences linking lesion location to memory performance. Nevertheless, we conducted a series of chi-square ( $\chi^2$ ) tests to assess whether true and false memory performance was influenced by lesion site (frontal, temporal, parietal, and occipital lobes) and by subcortical structures (cortical vs. subcortical comparison), following a procedure similar to that described by Braun et al. (2009).

First, we created for each lesion site a variable ("lesion presence") that coded for the "presence" (1) or "absence" (0) of a lesion in that site. Second, we split both RBD and LBD patients into two groups according to their memory performance, a variable we called "memory group". Patients' true memory performance was coded as "low" if their *d'-target* scores were lower than or equal to the average *d'-target* score from healthy controls and as "high" otherwise. Similarly, patients' false memory performance was coded as "low" if their *d'-related* scores were lower than or equal to the average *d'-related* scores from controls and as "high" otherwise. Third, we further categorized participants in terms of "corticality": they were coded as "subcortical" if at least one of their brain lesions involved subcortical structures (e.g., basal ganglia), "cortical" if at least one of the lesions involved cortical structures, and "both" if both types of lesions were present.

Chi-square tests of association were conducted separately for each lesion site (frontal, temporal, parietal, and occipital), memory type (true vs. false memories) and patient group (RBD vs. LBD), with memory group (low vs. high) and lesion presence (present vs. absent) as the categorical test variables. These tests allowed us to assess whether or not memory performance was associated with lesion site. Lesion site was not included as a categorical

variable because several participants had lesions spanning more than one site (Table 1), which violated the test's independence assumption. Likewise,  $\chi^2$  tests were run separately for true and false memories because the same patients contributed data for both types of memory.

Three sets of  $\chi^2$  tests were run. In the first set, the variable "memory group" was based on data collapsed across valence. In the second set, "memory group" was created separately for each valence (negative, neutral, positive), allowing us to evaluate more specifically possible associations between memory and lesion loci as a function of stimulus emotionality. Finally, an additional set of  $\chi^2$  tests was carried out to test the role of subcortical structures on memory. In this case, test variables were memory type (low vs. high) and corticality (cortical, subcortical, both). Significance thresholds were set at .05 and  $\chi^2$  tests were one-tailed.

### 3. Results

In the following, we first describe the results of the emotional judgment task. Next, we present the results of the recognition memory test in terms of proportion of "Yes" responses (hit rates and false-alarm rates). Finally, we describe the recognition test results using the  $d'$  for true memories ( $d'$ -target) and for false memories ( $d'$ -related).

#### 3.1. Emotional judgment task

##### 3.1.1. Valence ratings

The judgments of valence were submitted to a 3 (normed valence: negative, neutral, positive)  $\times$  3 (group: HC, RBD, LBD) mixed-design ANOVA. The analysis revealed a main effect of valence [ $F(2,114) = 402.9, p < .001, \eta_p^2 = .88$ ] but no effect of group and no interaction [ $Fs < 1.86, ps > .17$ ]. A post hoc LSD (Least Significant Difference) test showed that the judgments of valence differed significantly for negative ( $M = 2.56, SE = 0.14$ ), positive ( $M = 7.30, SE = 0.12$ ) and neutral pictures ( $M = 6.07, SE = 0.14$ ; all  $ps < .001$ ). The results show that participants in all three groups judged valence in the predicted manner, rating positive pictures higher than neutral pictures and neutral pictures higher than negative pictures. Table 3 presents means and standard deviations for valence.

To assess whether the valence ratings in this sample behaved differently from the norm, we computed a difference score for each picture by subtracting the picture's normed rating from the picture's average sample rating. This difference score was then entered into a 3 (normed valence)  $\times$  3 (group) ANOVA. The analysis yielded only a main effect of valence [ $F(2,114) = 26.0, p < .001, \eta_p^2 = .31$ ], indicating that neutral stimuli deviated from the norm more than negative and positive stimuli [95% confidence intervals for difference scores: Negative (-0.49, 0.08), neutral (0.70, 1.26), positive (-0.21, 0.27)]. In other words, participants in this sample judged the neutral pictures more positively than expected given the IAPS-BR norms. The results suggest that the processing of emotional valence by RBD and LBD patients was within the normal range. In addition, patients' valence ratings followed closely the ratings from healthy controls, even when they deviated from the norm.

##### 3.1.2. Arousal ratings

A 3 (emotional category: negative, neutral, positive)  $\times$  3 (group: HC, RBD, LBD) mixed-design ANOVA on arousal ratings revealed a main effect of category [ $F(2,114) = 21.4, p < .001, \eta_p^2 = .27$ ] but no effect of group and no interaction [ $Fs < 1.31, ps > .28$ ]. A post hoc LSD test showed that negative ( $M = 6.66, SE = 0.23$ ) and positive pictures ( $M = 6.33, SE = 0.22$ ) were judged as more arousing than

neutral pictures ( $M = 4.95, SE = 0.19; ps < .001$ ) but did not differ from each other ( $p = .31$ ). Table 3 presents these data.

Arousal ratings from the sample were also compared to normed ratings. As with valence, a difference arousal score was calculated for each picture and then entered into a 3 (emotional category)  $\times$  3 (group) mixed-design ANOVA. The analysis revealed a main effect of category [ $F(2,114) = 5.14, p < .01, \eta_p^2 = .08$ ], showing that positive and neutral stimuli deviated from the norm more than negative stimuli [95% CI: Negative (-0.56, 0.38), neutral (0.28, 1.03), positive (0.25, 1.13)]. Participants in all three groups judged positive and neutral pictures as more arousing than predicted by the IAPS-BR norms. As with valence, the results suggest that arousal was experienced (or at least judged) by patients and controls in a similar manner, even when those judgments deviated from the published norms.

Overall, the results from the emotional judgment task indicate that RBD and LBD patients did not differ from controls in their subjective experience of emotional pictures.

#### 3.2. Hit rates and false-alarm rates

Table 4 summarises the results for hits and false alarms. To assess the impact of stimulus emotionality on true memories, a 3 (valence: negative, neutral, positive)  $\times$  3 (group: HC, RBD, LBD) mixed-design ANOVA was carried out on hit rates. The results revealed a main effect of valence [ $F(2,114) = 11.95, p < .001, \eta_p^2 = .17$ ] and a marginal main effect of group [ $F(2,57) = 2.82, p = .07, \eta_p^2 = .09$ ] but no interaction [ $F < 1, p = .85$ ]. Post-hoc LSD (Least Significant Difference) tests showed that hit rates were higher for negative pictures ( $M_{HR} = .83, SE = .03$ ) than for neutral pictures ( $M_{HR} = .69, SE = .03$ ), and higher for positive ( $M_{HR} = .80, SE = .03$ ) than for neutral pictures ( $ps < .001$ ). Hit rates for negative and positive pictures did not differ from each other ( $p = .23$ ). The marginal effect of group was due to higher hit rates among controls ( $M_{HR} = .84, SE = .03$ ) relative to RBD patients ( $M_{HR} = .70, SE = .05$ ). Thus, valence affected true memories in the expected manner, with emotional pictures being associated with more hits. This increase, however, was similar across groups: Neither right- nor left-hemisphere lesions modulated the emotional enhancement of true memories.

The impact of stimulus emotionality on false memories was assessed with a 3 (valence)  $\times$  3 (group) mixed-design ANOVA on false-alarm rates to related lures. The results revealed a main effects of valence [ $F(2,114) = 14.76, p < .001, \eta_p^2 = .21$ ] and a marginal main effect of group [ $F(2,57) = 2.77, p = .07, \eta_p^2 = .09$ ]. Post-hoc LSD tests showed that false-alarms were higher for negative pictures ( $M_{FARrel} = .48, SE = .03$ ) than for positive pictures ( $M_{FARrel} = .30, SE = .04$ ), and higher for negative than for neutral pictures ( $M_{FARrel} = .30, SE = .04, ps < .001$ ). False alarms did not differ between positive and neutral pictures ( $p = .97$ ). The marginal effect of group was driven by more a higher false-alarm rate among controls ( $M_{FARrel} = .44, SE = .04$ ) than among RBD patients ( $M_{FARrel} = .30, SE = .05$ ).

The ANOVA also yielded a marginal valence  $\times$  group interaction [ $F(4,114) = 2.37, p = .06, \eta_p^2 = .08$ ]. Because the sample sizes were small, which reduces statistical power, and because this interaction is of theoretical relevance, we decided to explore it further, bearing in mind that these false-alarm rates have not been corrected for response bias (see  $FAR_{unr}$  analysis below). Separate one-way ANOVAs for each valence across groups were conducted on  $FAR_{rel}$ . For negative pictures,  $F(2,57) = .89, p = .03, \eta_p^2 = .12$ , healthy controls produced more false memories than RBD ( $p = .02$ ) and LBD participants ( $p = .03$ ), who did not differ from each other ( $p = .88$ ). For neutral pictures, by contrast, there were no differences across groups,  $F < 1, p = .89$ . More surprisingly, for positive pictures,  $F(2,57) = 4.74, p = .01, \eta_p^2 = .14$ , RBD patients

**Table 4**

Proportion of "Yes" responses in the recognition memory test for healthy controls (HC), right-brain-damaged patients (RBD) and left brain-damaged patients (LBD).

		HC		RBD		LBD	
		M	SD	M	SD	M	SD
Target	Negative	.88	.16	.75	.24	.87	.20
	Neutral	.77	.22	.61	.30	.68	.27
	Positive	.87	.17	.73	.32	.79	.25
Related lure	Negative	.59	.18	.41	.28	.43	.27
	Neutral	.33	.27	.30	.27	.28	.33
	Positive	.41	.28	.16	.17	.35	.27
Unrelated lure	Negative	.00	.00	.02	.09	.09	.15
	Neutral	.00	.00	.00	.00	.02	.09
	Positive	.07	.16	.04	.12	.04	.12

Note. Target = Studied picture, Related lure = Picture not studied but similar to studied picture, Unrelated lure = Picture not studied and not related to studied pictures.

produced fewer false memories than both controls ( $p < .01$ ) and LBD participants ( $p < .05$ ), who did not differ from each other ( $p = .46$ ). Thus, participants with lesions in the RH were better able to reject unstudied positive pictures compared to left-hemisphere patients and healthy controls. This relative immunity to false memories was restricted to positive pictures, as there were no differences between RBD and LBD patients in false memories for negative and neutral pictures.

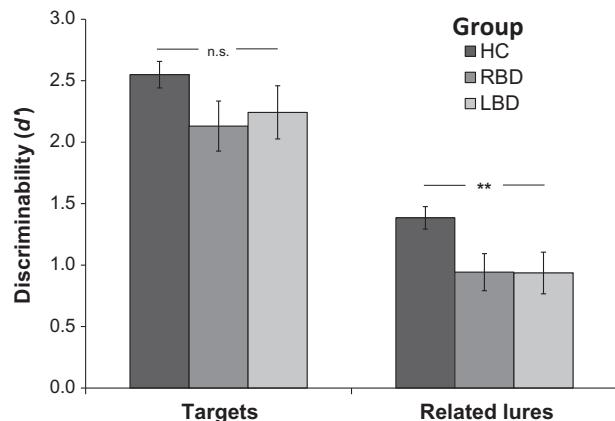
The effects of valence and group on true and false memories need to be corrected for possible response biases. To assess whether non-mnemonic "Yes" responses varied across experimental conditions, three Kruskal-Wallis tests were conducted, one for each picture type. This non-parametric test was chosen instead of the standard ANOVA because the sample distribution of false-alarm rates to unrelated lures was highly skewed towards zero (Shapiro-Wilk's test of normality:  $Ws < .56$ ,  $ps < .001$ ). The Kruskal-Wallis tests showed no difference in false alarms across groups for both positive [ $\chi^2(2) = 0.17$ ,  $p = .92$ ] and neutral unrelated lures [ $\chi^2(2) = 3.00$ ,  $p = .22$ ]. For negative pictures, however, a significant difference was found [ $\chi^2(2) = 9.23$ ,  $p = .01$ ,  $\eta^2 = .16$ ]. Subsequent Mann-Whitney tests showed that the difference was restricted to the comparison between HC and LBD participants ( $Z = -2.93$ ,  $p < .01$ ), such that  $FAR_{unr}$  was higher in the LBD group than in the control group. Thus, the results suggest that LBD patients were slightly more liberal in their "Yes" responses than RBD patients and healthy controls.

### 3.3. Discriminability ( $d'$ )

#### 3.3.1. True memories ( $d'$ -targets)

Two analyses were conducted on  $d'$ -targets. In the first analysis,  $d'$  was calculated from hit rates collapsed across valence; a one-way ANOVA on  $d'$ -target was then carried out. In the second analysis,  $d'$  values were calculated from separate hit rates, one for each valence; a two-way ANOVA on  $d'$ -target was then carried out with picture valence (negative, positive, neutral) and experimental group (HC, RBD, LBD) as the independent variables. The reason for collapsing valence in the former analysis is that the associated  $d'$  estimates are more stable (more trials per HR for each group), yielding a more powerful between-subjects test. In addition,  $d'$  is a non-linear estimator, meaning that  $d'$  calculated from the average of  $HR_{neg}$ ,  $HR_{neu}$  and  $HR_{pos}$  is different from the average of  $d'$ s calculated from each of  $HR_{neg}$ ,  $HR_{neu}$  and  $HR_{pos}$  separately, which is the way  $d'$  is calculated in the latter analysis (Macmillan & Creelman, 2005). The results are illustrated in Fig. 1 (where valence is collapsed) and Fig. 2 (where separate bars represent different valences).

The first analysis (one-way ANOVA on  $d'$ -target) showed no significant differences across groups ( $F = 2.05$ ,  $p = .14$ ;  $d'_{HC} = 2.55$ ,



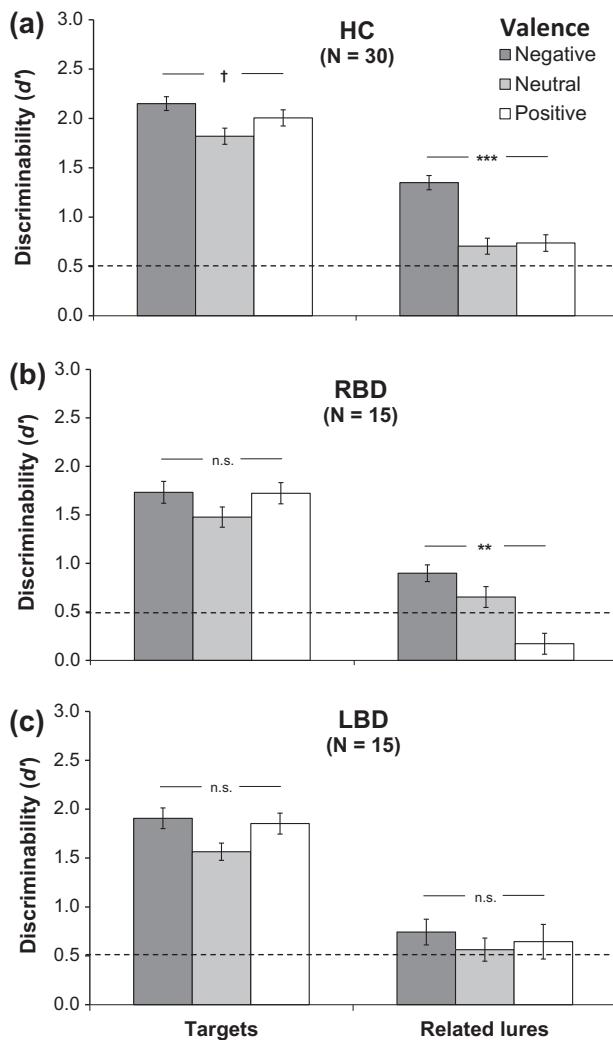
**Fig. 1.** Discriminability ( $d'$ ) for targets (studied pictures, *true memories*) and related lures (unstudied pictures similar to studied ones, *false memories*) collapsed across valence. Bars show the standard error of the mean. n.s. non-significant, \*\* $p = .01$ .

$d'_{RBD} = 2.13$ ,  $d'_{LBD} = 2.24$ ). The second analysis (two-way ANOVA) revealed only a main effect of valence [ $F(2,114) = 5.44$ ,  $p = .01$ ,  $\eta_p^2 = .09$ ], such that true memories were higher for negative ( $d' = 1.93$ ,  $SE = 0.08$ ) and positive pictures ( $d' = 1.86$ ,  $SE = 0.10$ ) relative to neutral pictures ( $d' = 1.62$ ,  $SE = 0.09$ ,  $ps < .02$ ). True memories for negative and positive pictures did not differ from each other ( $p = .51$ ). Trend analysis confirmed these results. An ordinal version of valence (neg < neu < pos) was entered as the independent variable, resulting in a significant quadratic trend on  $d'$ -target,  $F(1,57) = 10.66$ ,  $p = .002$ ,  $\eta_p^2 = .16$ . The trend suggests a U-shaped relationship between valence levels and  $d'$ -target. There was no effect of group ( $F = 2.28$ ,  $p = .11$ ) and no interaction ( $F < 1$ ,  $p = .98$ ). These results replicate previous findings showing that highly arousing negative and positive stimuli increase memory accuracy (*true memories*) (Hamann, 2001; LaBar & Cabeza, 2006).

#### 3.3.2. False memories ( $d'$ -related)

A similar two-pronged strategy was used to analyze the false-memory data. The first analysis (one-way ANOVA on  $d'$ -related) revealed a main effect of group [ $F(2,57) = 4.68$ ,  $p = .01$ ,  $\eta_p^2 = .14$ ], such that false memories were higher for controls ( $d' = 1.38$ ,  $SE = 0.10$ ) than RBD ( $d' = 0.94$ ,  $SE = 0.15$ ) and LBD patients ( $d' = 0.94$ ,  $SE = 0.15$ ,  $ps < .02$ ). Overall false-memory rates (collapsed across valences) were very similar between RBD and LBD patients ( $p = .97$ ).

The second analysis (two-way ANOVA) revealed a main effect of valence [ $F(2,114) = 10.58$ ,  $p < .001$ ,  $\eta_p^2 = .16$ ; Linear trend:  $F(1,57) = 18.19$ ,  $p < .001$ ,  $\eta_p^2 = .24$ ] and a marginal main effect of group [ $F(2,57) = 3.16$ ,  $p = .05$ ,  $\eta_p^2 = .10$ ]. Post-hoc LSD tests showed



**Fig. 2.** Discriminability ( $d'$ ) for targets (true memories) and related lures (false memories) separated by picture valence for (a) HC (Healthy Controls), (b) RBD (Right-Brain-Damaged) patients, and (c) LBD (Left-Brain-Damaged) patients. Traced line was included to facilitate visual comparisons across groups. Bars show the standard error corrected for within-subject designs (Cousineau, 2005). n.s. non-significant,  ${}^{\dagger}p = .06$ ,  ${}^{**}p < .01$ ,  ${}^{***}p < .001$ .

that false memories were higher for negative pictures ( $d' = 1.00$ ,  $SE = 0.08$ ) than for positive ( $d' = 0.52$ ,  $SE = 0.10$ ) and neutral pictures ( $d' = 0.64$ ,  $SE = 0.10$ ;  $p < .001$ ), which did not differ from each other ( $p = .31$ ). False memories were also higher in the control group ( $d' = 0.93$ ,  $SE = 0.09$ ) than in the RBD ( $d' = 0.58$ ,  $SE = 0.13$ ,  $p = .03$ ) and LBD groups ( $d' = 0.65$ ,  $SE = 0.13$ ,  $p = .08$ ), but were not significantly different between RBD and LBD groups ( $p = .68$ ).

More importantly, however, the two-way ANOVA on  $d'$ -related also yielded a significant valence  $\times$  group interaction [ $F(4, 114) = 2.52$ ,  $p = .04$ ,  $\eta_p^2 = .08$ ], suggesting that the pattern of false memories across valence was not the same for each experimental group. To confirm this suggestion, separate one-way ANOVAs for each group were conducted on  $d'$ -related. The results showed that, for healthy controls,  $F(2, 58) = 13.90$ ,  $p < .001$ ,  $\eta_p^2 = .32$ , there were more false memories to negative ( $d' = 1.35$ ,  $SE = 0.08$ ) than to positive ( $d' = 0.74$ ,  $SE = 0.14$ ,  $p < .001$ ) and neutral pictures ( $d' = 0.71$ ,  $SE = 0.12$ ,  $p < .001$ ), which were similar to each other ( $p = .83$ ). Both linear [ $F(1, 29) = 20.77$ ,  $p < .001$ ,  $\eta_p^2 = .42$ ] and quadratic trends [ $F(1, 29) = 7.67$ ,  $p = .01$ ,  $\eta_p^2 = .21$ ] were significant. The finding that false memories in healthy controls were higher to negative pictures than to neutral pictures replicates

Marchewka et al. (2008). By contrast, for RBD patients,  $F(2, 28) = 8.94$ ,  $p = .001$ ,  $\eta_p^2 = .39$ , there were fewer false memories to positive pictures ( $d' = 0.17$ ,  $SE = 0.19$ ) relative to negative ( $d' = 0.90$ ,  $SE = 0.14$ ,  $p = .001$ ) and neutral ( $d' = 0.65$ ,  $SE = 0.17$ ,  $p = .03$ ) pictures, which did not significantly differ from each other ( $p = .15$ ). These results showed a linear trend,  $F(1, 14) = 19.64$ ,  $p = .001$ ,  $\eta_p^2 = .58$ . For LBD patients, there were no differences in false memories across valences ( $F < 1$ ,  $p = .77$ ). The overall valence  $\times$  group interaction above remained significant even after controlling for general cognitive abilities (MMSE scores),  $F(4, 110) = 2.55$ ,  $p = .04$ ,  $\eta_p^2 = .09$ . Fig. 2 illustrates these different patterns of false alarms across groups.

The same valence  $\times$  group interaction was also assessed by directly comparing false memories across groups. Separate one-way ANOVAs across groups were carried out for each valence. For negative pictures, there was a significant difference across groups,  $F(2, 57) = 5.87$ ,  $p < .01$ ,  $\eta_p^2 = .17$ , such that false memories were higher in controls ( $d' = 1.35$ ,  $SE = 0.11$ ) than RBD ( $d' = 0.90$ ,  $SE = 0.16$ ,  $p = .02$ ) and LBD patients ( $d' = 0.74$ ,  $SE = 0.16$ ,  $p < .01$ ), which did not differ from each other ( $p = .49$ ). For positive pictures, there was also a significant difference across groups,  $F(2, 57) = 3.34$ ,  $p = .04$ ,  $\eta_p^2 = .11$ , but the pattern was different, with fewer false memories for RBD patients ( $d' = 0.17$ ,  $SE = 0.18$ ) compared to healthy controls ( $d' = 0.74$ ,  $SE = 0.13$ ,  $p = .01$ ) and LBD patients ( $d' = 0.65$ ,  $SE = 0.18$ ,  $p = .07$ ), who did not significantly differ from each other ( $p = .68$ ). The difference between RBD and LBD patients remained significant after controlling for the effects of post-onset recovery times,  $F(1, 27) = 4.40$ ,  $p < .05$ ,  $\eta_p^2 = .14$ . For neutral pictures, there were no differences across groups ( $F < 1$ ,  $p = .82$ ), showing that the reduction in false memories in the patient groups were specific to emotional (negative and positive) stimuli.

### 3.4. Lesion locations

Table 5 shows the proportion of RBD and LBD patients with lobar lesions (frontal, temporal, parietal and occipital) as a function of memory type (true vs. false) and memory performance (low vs. high; collapsed across stimulus valence). Note that all participants contributed counts to more than one cell in Table 5, since all participants produced data for both true and false memories and since some patients had lesions in more than one lobe.

#### 3.4.1. Collapsed across valence

For true memories, a significant association between lesion presence and memory performance was observed only in the parietal lobe and only for RBD patients [ $\chi^2(1) = 3.11$ ,  $p = .04$ ]. There were proportionately fewer RBD patients in the “high” true memory group than in the “low” group when a lesion was present in the parietal lobe. For false memories, an association between lesion presence and memory was found only when the lesions included the temporal lobe [ $\chi^2(1) = 4.20$ ,  $p = .02$ ] or the parietal lobe [ $\chi^2(1) = 3.11$ ,  $p = .04$ ] and only in RBD patients. The proportions of RBD patients were lower in the “high” false memory group than in the “low” group when they had temporal or parietal lesions.

#### 3.4.2. Separated by valence

For true memories, an association between lesion and memory was observed only for neutral stimuli and only with parietal lesions for both RBD [ $\chi^2(1) = 3.11$ ,  $p = .04$ ] and LBD patients [ $\chi^2(1) = 3.23$ ,  $p = .04$ ]. The effect, however, was opposite between patient groups: whereas right parietal lesions were linked to a smaller “high” true memory group, left parietal lesions were linked to a larger “high” true memory group. For false memories, associations between lesion loci and memory were found for negative and neutral stimuli. In the case of negative stimuli, the “high” false memory group was smaller when temporal lesions were present.

**Table 5**

Proportion of right- and left-brain damaged patients as a function of lesion loci, memory type and memory performance (collapsed across stimulus valence).

Memory type	Lesion group	Memory group	Lesion site			
			Frontal	Temporal	Parietal	Occipital
True	RBD	Low	.50	.50	<b>.50</b>	.00
		High	.75	.25	<b>.00</b>	.25
	LBD	Low	.43	.29	.14	.14
		High	.50	.25	.50	.00
False	RBD	Low	.60	<b>.60</b>	<b>.50</b>	.00
		High	.50	<b>.00</b>	<b>.00</b>	.25
	LBD	Low	.50	.38	.25	.13
		High	.33	.00	.33	.00

Note: Lesion group: RBD = right-brain damaged patients, LBD = left-brain-damaged patients; Memory type: True =  $d'$ -target (sensitivity to studied stimuli), False =  $d'$ -related (sensitivity to unstudied stimuli); Memory group: Low =  $d'$ -target or  $d'$ -related scores lower than the corresponding measure for the healthy controls, High =  $d'$ -target or  $d'$ -related scores higher than the corresponding measure for the healthy controls. Significant results in boldface ( $\chi^2$  test: group  $\times$  memory  $\times$  site associations;  $p < .05$ ).

This was found in RBD patients [ $\chi^2(1) = 2.94$ ,  $p = .04$ ] and, to a lesser extent, in LBD patients [ $\chi^2(1) = 2.36$ ,  $p = .06$ ]. When RBD and LBD patients were collapsed into one, larger, temporal lesion group, the resulting, more powerful  $\chi^2$  test yielded a clearly significant lesion  $\times$  memory association,  $\chi^2(1) = 4.89$ ,  $p = .01$ . For neutral stimuli, the “high” false memory group was also smaller when a temporal lesion was present, but here the change was observed only with RBD patients [ $\chi^2(1) = 2.94$ ,  $p = .04$ ].

#### 3.4.3. Corticality

The corticality tests yielded no significant association between the presence of subcortical lesions and memory performance.

## 4. Discussion

In this study, recognition memory for emotional and non-emotional pictures was compared across groups of right-brain-damaged, left-brain-damaged, and healthy participants. The data were analyzed separately for true memories (hits) and false memories (false alarms to related lures). The results for true memories replicated the emotional enhancement of memory, showing that emotional stimuli (both negative and positive) were correctly recognized more often than neutral stimuli, with no significant differences across groups.

The results for false memories showed that RBD and LBD patients produced significantly fewer false memories than healthy controls, suggesting that overall gist-based memory was equally impaired in both clinical groups. When analysis was broken down by valence, however, a different pattern emerged: for negative pictures, both RBD and LBD groups showed a similar level of false memories, whereas for positive pictures RBD patients showed a greater reduction in false memories compared to LBD patient and healthy controls. Neutral stimuli behaved in the same way across groups, showing that the memory differences observed between patients and controls were restricted to emotional stimuli.

The differences in false-memory performance between patients and controls cannot be easily attributed to general cognitive deficits in patients. First, there were no differences between patients and controls in memories for neutral pictures, showing that patients' performance with respect to non-emotional stimuli was within normal range. Second, the valence  $\times$  group interaction on false memories ( $d'$ -related), which differentiated the three groups, remained significant after controlling for general cognitive abilities (MMSE scores). Thus, it is unlikely that a general deficit in the patient groups could account for these results.

In addition, the finding that false memories to positive pictures were lower in RBD than in LBD patients is not easily explained by differential post-stroke recovery times between the groups. First, there was no significant difference in mean post-onset times

between groups. Second, the difference in false memories between RBD and LBD groups remained significant even after including post-onset times as a covariate in the analysis.

#### 4.1. Lesion location and memory

The association tests for lesion loci and memory performance replicated previous neuropsychological data. Parietal lesions were associated with a reduction in both true (Haramati, Soroker, Dudai, & Levy, 2008) and false recognition (Davidson et al., 2008; Drowos et al., 2010), especially if the lesions were restricted to the right hemisphere. Temporal lesions were also linked to lower levels of false memories (Schacter et al., 1996; Van Damme & d'Ydewalle, 2009; Verfaellie, Page, Orlando, & Schacter, 2005). These results indicate that brain regions involved in true recognition are also involved in false recognition (Schacter & Slotnick, 2004). The results also suggest that our picture-based, false-memory task was sensitive to neuropsychological processes normally engaged in more traditional false-memory paradigms (see Gallo, 2010, for a review of the DRM paradigm).

Interestingly, no association was found between frontal lobe damage and memory performance. Frontal lesions have been implicated in post-retrieval monitoring processes, which are important to reduce false recognition (Budson et al., 2002; Curran et al., 1997). Because lesions to the frontal lobe in our sample did not affect false recognition, it is possible that our false-memory task loaded less heavily on post-retrieval processes than the classic DRM paradigm (Gallo, 2010).

One surprising aspect of the encoding data is that the emotional ratings of pictures were similar across groups. Even when patients and controls deviated from published norms of valence and arousal, they did so in tandem. This could suggest that emotional processing was unaffected in the patient groups. However, differences across groups emerged during the recognition test and were restricted to emotional stimuli. This indicates that some aspects of emotional processing were affected by the unilateral lesions.

#### 4.2. Theoretical implications

The overall pattern of results for true and false memories across groups (Fig. 1) is consistent with models that make a distinction between memory for the gist (or central theme) of the stimulus and memory for the details (or item-specific information) of the stimulus (Brainerd & Reyna, 2002; Brainerd et al., 2008; Gutchess & Schacter, 2012; Koutstaal & Schacter, 1997). In these models, true memories are generated by retrieving the stimulus' details, its gist, or both, whereas false memories are generated mainly by retrieving the stimulus' gist. Such gist-based false memories then occur because the gist representation of the studied stimulus is

inadvertently activated when a different but gist-related stimulus is presented at test. The results in Fig. 1 show a non-significant reduction in memories for targets (true memories) in the patients' groups coupled with a highly significant reduction in memories for related lures (false memories) in the patients' groups. To the extent that gist-based memory contributes more to eliciting false memories than true memories (e.g., Brainerd et al., 2008; Koutstaal & Schacter, 1997), the results suggest that gist memory, but not memory for details, was reduced in the patients' groups (see also Adolphs, Tranel, & Buchanan, 2005, for similar results in patients with amygdala damage).

The false-memory results did not agree entirely with predictions from fine-coarse coding theory (Beeman et al., 1994; Bellamy & Shillcock, 2007; Jung-Beeman, 2005; Lovseth & Atchley, 2010).<sup>1</sup> The theory predicted that false memories to neutral stimuli should be lower in RBD than in LBD patients. There were, however, no differences in true and false memories to neutral stimuli between the patient groups and no differences between the patient groups and controls. Because lesion side did not affect false memories to neutral stimuli, it seems that differences in representation coarseness between left and right hemispheres are unlikely to explain the difference in false memories to positive stimuli observed between RBD and LBD patients in our sample.

The results broken down by emotional valence (Fig. 2) provide only mixed support for the hemispheric asymmetry hypotheses. The right-hemisphere hypothesis predicted that RBD patients should generate fewer false memories to emotional stimuli than LBD patients, but no significant difference between the groups was found. Moreover, both RBD and LBD patients showed a substantial reduction in false memories compared to healthy controls. Thus, it appears that gist-based false memories for negative stimuli are less dependent on right-hemisphere integrity than predicted by the right-hemisphere hypothesis.

The other asymmetry hypothesis tested in this study, the valence-specific hypothesis, predicted that RBD patients should produce fewer false memories to negative stimuli than LBD patients. There was, however, no difference between the patient groups. In addition, there were fewer false memories to positive stimuli in the RBD group than in the LBD group. These results do not fully support the valence-specific hypothesis, at least not in the standard form it has been presented in the literature (i.e., relative specialization of RH to negative stimuli and LH to positive stimuli; Demaree et al., 2005; Killgore & Yurgelun-Todd, 2007).

An alternative valence-specific account, however, could accommodate some of these findings. According to the *inter-hemispheric inhibition account*, the LH is biased to process positive emotions and the RH is biased to process negative emotions. Unlike the standard valence-specific hypothesis, in the inter-hemispheric inhibition account one hemisphere actively inhibits the other

<sup>1</sup> Fine-coarse coding theory is related to gist-detail theories (Brainerd & Reyna, 2002; Kensinger, 2009; Koutstaal, 2003) in that in both frameworks a distinction is made between accurate, perceptually-driven, memory judgements and inaccurate, semantic-driven, memory judgements. However, there appears to be less convergence in the gist-detail literature than in the fine-coarse literature with respect to *hemispheric asymmetries*. Although there is evidence in the gist-detail literature suggesting more engagement of the right than the left hemisphere during false recognition (e.g., Gutchess & Schacter, 2012), there are also studies showing the opposite pattern (e.g., Garoff, Slotnick, & Schacter, 2005; Kensinger & Choi, 2009; Kensinger, Garoff-Eaton, & Schacter, 2007b; see also Section 4.3 below for a discussion of the implications of simple vs. complex visual stimuli for laterality effects). In the fine-coarse coding literature, however, evidence is more consistent with respect to (a) the laterality of verbal (Alfano & Cimino, 2008; Atchley, Burgess, & Keeney, 1999) and non-verbal representations (Calvo & Avero, 2008; Lovseth & Atchley, 2010) and (b) the laterality of verbal (Bellamy & Shillcock, 2007; Ben-Artzi et al., 2009; Faust et al., 2008; Ito, 2001; Schmitz et al., 2013) and non-verbal false-memory representations (Marchewka et al., 2008). These considerations led us to favor fine-coarse coding theory instead of gist-detail theories to derive our hypotheses, design the experiment, and frame our discussion.

(Braun, 2007; Silberman & Weingartner, 1986). Consequently, lesions in the LH should potentiate responses to negative stimuli in the RH, whereas lesions in the RH should potentiate responses to positive stimuli in the LH. Evidence for this account came from studies using the intracarotid amobarbital sodium procedure, which showed that injections in the right carotid produce euphoric reactions (e.g., laughing, sense of well-being), whereas injections in the left carotid produce dysphoric reactions (e.g., crying, worries about the future). These results have been interpreted as evidence of the release of one hemisphere from the contralateral inhibitory influence of the other.

The inter-hemispheric inhibition account could explain the decrease in false memories to positive stimuli in the RBD group. That is because a lesion to the RH should release the positively-biased LH to better process the positive aspects of input stimuli. This enhanced processing should enable RBD patients to reject false positive stimuli more effectively than their LBD and HC counterparts. The inhibition account could also accommodate the lack of differences across groups for neutral stimuli, since inter-hemispheric inhibition takes place mostly for arousing stimuli (Silberman & Weingartner, 1986). The inhibition account, however, cannot easily explain the lack of differences in negative false memories between RBD and LBD patients.

#### 4.3. Limitations and further directions

There are some limitations in this study that prevent us for making more conclusive claims about the results. The main limitations are related to sample characteristics, in particular the small sample sizes and the great variability in patients' ages, lesion sites and post-stroke times. The sample characteristics also influenced design features, such as the use of central rather than divided-field displays and the use of pictures rather than words. These design features may have contributed to further reduce effect sizes.

Stimuli were displayed centrally (rather than separately in each visual field) and for a long time (4000 ms rather than 400 ms or less) during both encoding and retrieval. This was necessary given the high percentage of elderly participants in our sample and the fact that age reduces processing speed (Salthouse, 1996). Such long display times, however, may have facilitated inter-hemispheric transfer, thereby reducing our chances of detecting group differences. Age can also decrease cerebral asymmetries (e.g., Schmitz et al., 2013) and may have thus also contributed to the similarity in RHD and LHD patients' memory profiles.

Another factor that could have worked to reduce effect sizes is the possibility of partial recovery (or decline) of emotional processing abilities in stroke patients (Nakhutina, Borod, & Zgaljardic, 2006; Zgaljardic, Borod, & Sliwinski, 2002). Given the long and variable post-onset times in our patients (Median = 11 months; 1–77), it is possible that emotional processing differences were masked (e.g., Abbott, Wijeratne, Hughes, Perre, & Lindell, 2014). Long post-stroke times may have allowed the systematic engagement of different strategies, possibly involving an altogether different pattern of inter-hemispheric communication relative to normal controls. Although such strategies were not sufficient to achieve normal performance, they may nonetheless have been good enough to disguise potential differences between right- and left-brain lesions.

The use of complex pictures in the present experiment may have not been a fair test on fine-coarse coding theory, as most evidence supporting this account comes from studies using verbal stimuli (Bellamy & Shillcock, 2007; Jung-Beeman, 2005). Unlike studies using verbal stimuli, studies using single visual objects tend to support the opposite view, namely, that the RH encodes object representations that are more precise (veridical) than representations encoded in the LH (Marsolek, 1999; Marsolek & Burgund, 2008). In fact, it has been recently shown that pictures of single objects

presented at test to the RH of healthy participants are recognized more accurately than pictures of objects presented to the LH (Kensinger & Choi, 2009). Because our stimuli consisted of complex scenes containing people, objects and animals, it is possible that both verbal representations (which tend to be more diffuse in the RH) and visual object representations (which tend to be more precise in the RH) could cancel each other out, reducing the hypothesized inter-hemispheric differences. The fact that a previous fMRI study (Marchewka et al., 2008) used stimuli similar to ours and found specific activation in the RH following false memory responses speaks against this possibility. Further research using more specialized stimuli (e.g., words vs. objects) may help clarify this issue.

Recent studies started unveiling a functional network of emotional processing regions that involve both brain hemispheres (e.g., Killgore & Yurgelun-Todd, 2007). Thus, the assumption that one hemisphere specializes in all emotional processing or that each hemisphere specializes in processing valence-specific stimuli may fail to capture the complex inter-hemispheric interactions necessary to decode emotional information. False-memory studies, in particular, have shown that when the interaction between the hemispheres is artificially increased in the normal brain – for example by asking participants to repeatedly move their eyes sideways during the retention interval – there is a marked reduction in false memories (Christman et al., 2004; Parker, Buckley, & Dagnall, 2009; Parker & Dagnall, 2007). These studies have concentrated mostly on non-emotional stimuli. Given the assumed asymmetries in emotional processing, an interesting avenue for future research may involve the investigation of emotional memories combining the divided field technique with eye-movement manipulations that increase inter-hemispheric communication.

## Author notes

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