

Remembering 1500 pictures: The right hemisphere remembers better than the left

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Abstract

We hypothesized that the right hemisphere would be superior to the left hemisphere in remembering having seen a specific picture before, given its superiority in perceptually encoding specific aspects of visual form. A large set of pictures ($N = 1500$) of animals, human faces, artifacts, landscapes, and art paintings were shown for 2 s in central vision, or tachistoscopically (for 100 ms) in each half visual field, to normal participants who were then tested 1–6 days later for their recognition. Images that were presented initially to the right hemisphere were better recognized than those presented to the left hemisphere. These results, obtained with participants with intact brains, large number of stimuli, and long retention delays, are consistent with previously described hemispheric differences in the memory of split-brain patients.

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1. Introduction

It is commonly thought that the human brain has a vast, perhaps unlimited, memory for pictures. This notion is based on a series of classic studies conducted in the 1960s and 1970s, where subjects viewed several hundred or even thousand of images, each image for just a few seconds, and were then tested, after variable delays (ranging from hours to several days), for their picture recognition. In these studies, memory was found to be close to perfect, with error rates estimates of just 2% in a study by Shepard (1967) or accuracy rates of individual participants ranging from 85 to 96% (Standing, 1973; Standing, Conezio, & Haber, 1970).

It is also well known that perceptual and cognitive abilities are not uniformly distributed in the human brain. For example, the speech output control system is genetically constrained to develop in the left hemisphere rather than in the right (Corballis, 1991). Similarly, the knowledge

database based on semantic and verbal memory (containing facts and words) appears more dependent on processing in the left hemisphere (LH) than in the right hemisphere (cf. Caramazza & Shelton, 1998; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Gazzaniga, 1983). In contrast, the right hemisphere (RH) is known for its ability to process visual–spatial information, e.g. the metrics of space (Laeng, Chabris, & Kosslyn, 2003) and depth perception (Carmon & Bechtold, 1969; Danta, Hilton, & O’Boyle, 1978), as well as color vision (Davidoff, 1976) and the control of visual attention (Corbetta et al., 1993; Heilman and Van Den Abell, 1980). Thus, the two hemispheres can be distinguished according to the various types of information processing or computations that they support. On the basis of such knowledge, one would likely conclude that the RH encodes the types of representations that seem most relevant for remembering specific visual information contained in pictures.

Several findings within the neurosciences are already consistent with this hypothesis that the RH is superior to the LH in remembering having seen a specific picture before. Neuroimaging studies have shown a RH’s specific

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role in memory for visual textures or pictures of faces (Kelley et al., 1998; McDermott, Buckner, Petersen, Kelley, & Sanders, 1999; Wagner et al., 1998). Several neuroimaging studies have also revealed a RH's role for the processing of specific visual form information (e.g., Garoff, Slotnick, & Schacter, 2005; Koutstaal et al., 2001; Simons, Koutstaal, Prince, Wagner, & Schacter, 2003). Reductions in brain activation can be seen in specific areas of the RH when the same exemplar is repeated compared to when a different exemplar from the same class is presented (Vuilleumier, Henson, Driver, & Dolan, 2002); such "adaptation" effects for specific visual forms can be as detailed as a reduced response to a particular viewpoint of the exemplar. Studies of patients with brain damage have shown that lesions to the LH can disrupt memory for pictures (Goldstein et al., 2004; Incisa della Rocchetta, Gadian, Connelly, & Polkey, 1995), but it appears that damage to the RH's temporal lobe disrupts the memory of specific pictures of objects even more (De Renzi, 1968; Milner, 1968; Nunn et al., 1999; Vilkkii, 1987; Whitehouse, 1981). Finally, studies with "split-brain" patients have indicated a RH's memory superiority (Metcalfe, Funnell, & Gazzaniga, 1995) in recognizing specific patterns. When series of pictures of common scenes or faces were shown to these patients and then each hemisphere was tested for their recognition, the RH appeared to support a "literal" or "veridical" memory for pictures and an ability to reject "lures" or "decoys" whereas the LH frequently confused, as previously seen, novel pictures that were similar to the old ones or consistent with the events common to a particular scene (Phelps & Gazzaniga, 1992; Metcalfe et al., 1995). In these split-brain studies the stimuli were first studied in free vision for a few seconds and their recognition was then tested in the same session with lateralized, tachistoscopic (e.g., 150 ms), presentations of the studied items and of similar but foil items in a yes/no recognition paradigm.

2. Experiment 1

The main goal of the present experiment was to test the hypothesis of a RH's superiority for the long-term memory for pictures with the divided-visual-fields (DVF) method in normal subjects. Specifically, although studies with the DVF method have been used for more than 30 years and the topic of long-term memory is one of the central themes within cognitive neuroscience, no DVF studies have been conducted on normal brains to assess hemispheric differences in picture memory for either large set of stimuli or long retention delays of several days. The DVF method is the same used in the split-brain studies discussed above (e.g., Phelps & Gazzaniga, 1992), with the difference that in the present study participants have intact callosal connections between the cerebral hemispheres. An additional difference from the split-brain studies was that, in the present experiment, the memory tests did not follow immediately or within the same session after the learning phase but at rather longer delays (ranging from 1 to 6 days, as done in

some of Standing and colleagues' experiments). Specifically, by initially presenting the images in free view and then flashing them briefly in each visual hemifield, in a yes/no recognition test, we should be able to determine if the hemisphere score differently in visual memory tasks. Moreover, we also used the reversed paradigm as an additional experimental condition, where pictures were initially flashed in the learning phase (thus limiting the encoding of the pictures to one hemisphere initially), while recognition was tested by presenting the pictures (and foils) in free vision. By comparing recognition performance in the two conditions (i.e., pictures lateralized at study versus lateralized at test), we should be able to assess possible hemispheres' differences that are attributable to the levels of visual detail that are available at either the learning stage or when a memory match needs to be performed.

Interestingly, a number of studies suggest the existence of separate brain regions specialized for either encoding or retrieval (e.g., Babiloni et al., 2006; Habib, Nyberg, & Tulving, 2003; Nyberg et al., 1996). Specifically, the "hemispheric encoding-retrieval asymmetry" (HERA) model, proposed by Tulving and colleagues (e.g., Tulving, Kapur, Craik, Habib, & Houle, 1994), hypothesizes that a region within the left hemisphere (LH) is involved in encoding episodes, whereas a region within the right hemisphere (RH) is crucial for the retrieval of the same information. Hence, on the basis of the HERA model one would expect that, in the present DVF study, the visual field advantages should differ depending on whether the lateralized presentation of the picture occurred during encoding or at the time of retrieval. Specifically, the HERA model would suggest a LH advantage when images are lateralized at the encoding stage and a RH advantage when images are lateralized at the recognition stage.

However, one would also expect that memory would be better in the hemisphere that is already superior in perceptually encoding specific aspects of visual form (i.e., the RH); hence, one could expect better picture memory for such a hemisphere in both the case when images are lateralized at learning (encoding) and when lateralized at test (retrieval). Additionally, one would expect that memory would be better when a relatively more detailed representation is learned first and later a more schematic representation can be matched to it, than in the reverse condition when a relatively more schematic representation gets stored and only later on the detailed image can be perceived. Thus, it is possible that only the more difficult lateralized condition will reveal hemispheric differences in memory.

Finally, in a third condition that closely replicates the paradigm of classic studies of Standing and colleagues or Shepard's (1967), pictures were shown centrally in free vision for 2 s, both at learning and at test. We label the three conditions used in this experiment as the Lateralized at Study, Lateralized at Test, and Free Vision conditions. The present study also used a more varied sample of pictures than those used in previous studies: Animals, human faces, artifacts, landscapes, and art paintings.

2.1. Methods

2.1.1. Participants

A total of 36 participants, 18 females, all right handed by self-report, and of mean age = 25 ($SD = 7.5$), were recruited from the student population at the University of Tromsø. The participants participated in a lottery where one person would win an mp3 music player.

2.1.2. Stimuli and apparatus

All stimuli consisted of high quality color photographs. The images were compiled from several sources, mainly from Internet image databases (e.g., from the www.google.com image search engine), but also high-resolution images from Microsoft Office XP media content (CD # 2), as well as from Corel 11 media content (CD # 4). All the images can be classified in five main categories: animals, human faces, artifacts, landscapes, and art paintings; the latter comprising a variety of themes (e.g., portraits, landscapes, and still life scenes) and the other categories being high-resolution color photographs. Next, the images were reduced in size, with either the height or the width of the image equaling 400 pixels. Fig. 1 shows a few samples of the pictures used. Participants sat at a distance of 60 cm from the screen so that the longest side of each image would correspond to 9.5° of visual angle and the edge closest to the fixation point was at a distance of 2° .

The experiment was driven with SuperLab® pro 2.0. An IBM Thinkpad T20 laptop PC, with a 13.1 in. TFT monitor was used to present the stimuli and collect the responses. The “C” and “N” keys on the QWERTY keyboard were labeled with “Ja” and “Nei” respectively (i.e., “Yes” and “No”) at test.

Procedure. The experiment consisted of two parts: the “learning phase” and the delayed “recognition phase,” performed from 1 to 6 days later (Mean interval = 2.24 days, $SD = 1.28$ days). Participants were simply asked to return for testing at any convenient date within the period of one week from the first presentation of the pictures. Specifically, 8 participants were tested for recognition 1 day after learning and the same number of participants after 2 days; 7 participants after 3 days; 4 participants after 4 days and the same number of participants after 5 days; and 5 participants after 6 days. A total of 500 images were initially used in each of the three conditions of the learning phase so that each participant was asked to memorize a total of 1500 different pictures.

In the learning phase of the Free Vision and Lateralized at Test conditions, each image was shown centrally for 2000 ms, followed by a blank screen for 500 ms, followed by the next picture to be learned. However, in the Lateralized at Study condition, the images could be located either to the left or to the right of the center of the image canvas. In this condition, half of the pictures were presented in the left visual field (RH) and half in the right visual field (LH) and the side of presentation was randomized among trials within the block. The presentations of the images were lim-

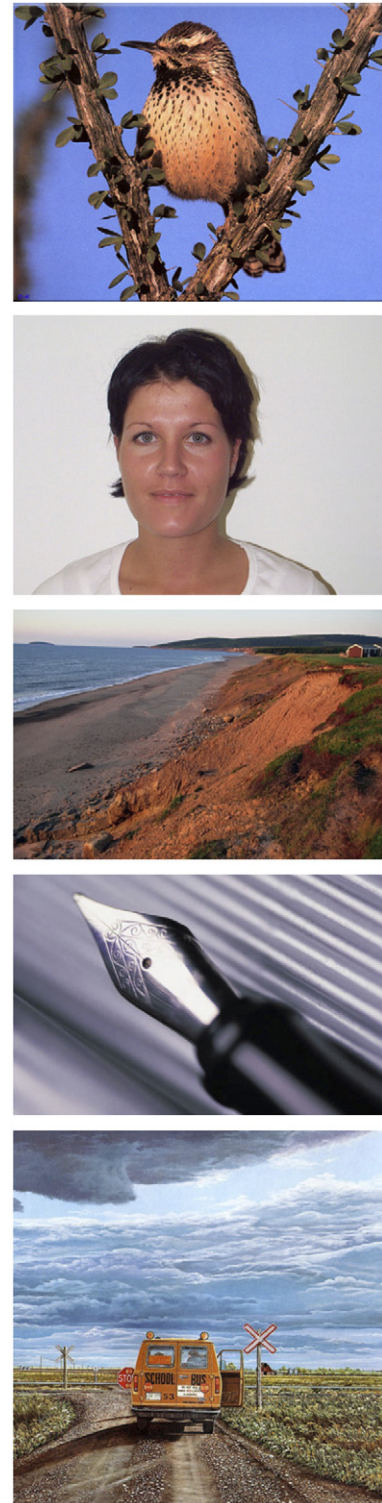


Fig. 1. Samples of the pictures from each of the stimulus categories (from the top, Animals, Faces, Landscapes, Objects, and Paintings).

ited to 100 ms to prevent saccadic eye movements, which normally happen after 200 ms of the initial presentation, and ensure the initial presentation of the image to the corresponding hemisphere. A small black fixation cross was present in the center of the monitor, and the participants were instructed to hold their focus on this cross, which

remained visible at all times. In sum, at study 2/3 of the pictures (1000 pictures) were shown centrally while the remaining 1/3 were presented in the left (250 pictures) and right (250 pictures) visual field. Conditions (i.e., Lateralized at Learning, Lateralized at Test, and Free Vision) were presented in blocks and the ordering of these blocks was counterbalanced across participants. Within each block of 500 images the participants viewed the pictures in a randomized order, which was generated anew for each participant. Pictures were also randomly assigned to each the three conditions for each participant, hence rotation of the stimuli across participants occurred randomly through the three conditions.

In the delayed recognition phase, 300 of the images that had been seen earlier were presented again. Specifically, 100 of the already-seen pictures were selected randomly from each previous condition; but care was taken that an approximately equal number of stimuli from each category was included within each of the blocked conditions. All subjects were told that they would be presented with a number of images, some of which they had seen in the learning phase of the experiment (the “old” pictures), and some novel pictures which they had never seen before (the “new” pictures). There were 100 new pictures (matched by category to each of the 100 already-seen pictures) within each block. The participants viewed all (200) images within each block in a randomized order. The generation of a response automatically led to the presentation of the next image. For both the Free Vision and Lateralized at Study conditions, each image was shown centrally for 2000 ms, followed by a blank screen for 500 ms, and then the next picture; whereas, in the Lateralized at Test condition, half of the pictures were presented in either the left visual field (RH) or half in the right visual field (LH), the presentations of the images were limited to 100 ms, and the side of presentation was randomized among the trials. In the lateralized conditions, participants were reminded to keep central fixation at all times. The ordering of blocks in the recognition phase was kept the same to the specific ones used for each participant in the learning phase.

2.2. Results

We first computed each participant’s mean percent error rates for new or old pictures and, in the lateralized conditions, for pictures presented in the left visual field (or initially to the RH) and in the right visual field (or initially to the LH). In addition, for correct trials only, we computed the mean response times (RTs) for the same conditions. The above-described data were used in separate repeated-measures ANOVAs with Mean % errors and RTs as the dependent variables. Preliminary analyses were conducted using Sex of Participant (female, male) as a factor, which revealed no main effect or interactive effects with other factors. Hence, we removed this factor from subsequent analyses.

The first ANOVA was performed on the Free Vision data only, with New/Old pictures as the within-subject fac-

tor. The analysis on Mean % errors showed that misses (i.e., old pictures rated as new; Mean = 45.1, $SD = 15.4$) were significantly more frequent than false alarms (i.e., new pictures rated as old; mean = 23.9, $SD = 11.2$), $F(1,34) = 27.5$, $p < .0001$; Cohen’s $d = 1.6$; effect size $r = .62$. There was also a slightly significant difference in RTs for New/Old pictures in correct trials, $F(1,34) = 4.02$, $p < 0.05$, with faster RTs to old pictures (mean RT = 462, $SD = 177$) than the new ones (mean RT = 496, $SD = 189$) Cohen’s $d = -0.19$; effect size $r = -.09$.

A separate ANOVA was performed with Condition (Lateralized at Study vs. Lateralized at test), Hemisphere (LH vs. RH) and New/Old pictures as the within-subject factors and Mean % errors as the dependent variable. The analysis revealed a significant effect of Condition, $F(1,35) = 78.9$, $p < .0001$: that is, more errors were committed in the Lateralized at Study than in the Lateralized at Test condition. In other words, fewer pictures were correctly judged as old or new when the pictures were only glimpsed in the learning phase (Mean % error = 49.1, $SD = 20$) than when they were seen for 2 s in the study phase and then glimpsed at test (Mean % error = 39.7, $SD = 22$); Cohen’s $d = 0.45$; effect size $r = .22$. In addition, there was a significant effect of Hemisphere, $F(1,35) = 35.7$, $p < .0001$. Pictures presented to the RH were remembered better (Mean % error = 40.8, $SD = 22.4$) than those presented to the LH (Mean % error = 48.5, $SD = 20.4$); Cohen’s $d = -0.36$; effect size $r = -.18$. This hemispheric effect was comparable for the two conditions (i.e., pictures glimpsed in the encoding phase or seen for 2 s in the encoding phase and then glimpsed at test), given that there was no significant interaction of Condition and Hemisphere, $F(1,35) = 1.8$. Thus, the present results are more consistent with a model predicting that the hemisphere superior in perceptually encoding specific aspects of visual form (i.e., the RH) has better picture memory than the HERA model that would have predicted a significant interactive effect of pictures lateralized at learning (encoding) versus lateralized at test (retrieval). However, Habib et al. (2003) have pointed out that the demonstration of a RH advantage for encoding non-verbal material should not be taken as definitive evidence that other lateralization models should be preferred over HERA. Specifically, they suggested that in order to test HERA inequalities it is most relevant to compare the effects of encoding in relation to the effects of retrieval for each hemisphere. Such a comparison, when applied to a DVF study, would consist in comparing the differences of each hemisphere’s error rates for the encoding and retrieval conditions. One would expect the LH to show a negative difference (i.e., more errors at retrieval) whereas the RH should show a positive difference (i.e., more errors at encoding). However, in the present study, both differences were positive (LH’s encode-retrieve: Mean % error difference = 8.9, $SD = 7.8$; RH’s encode-retrieve: Mean % error difference = 9.8, $SD = 7.6$). Most importantly, a paired t -test on these difference scores revealed no significant effect of Hemisphere ($p = .52$).

Whether pictures had been correctly recognized as seen before or judged as new also mattered, as revealed by a main effect of the New/Old factor, $F(1,35) = 37.4$, $p < .0001$. Interestingly, there was also an interactive effect of New/Old and Hemisphere, $(1,35) = 16.3$, $p < .0003$. This was due to a 10% increase in false alarms in the LH (Mean % error = 35.7, $SD = 14$) compared to the RH (Mean % error = 25.8, $SD = 14$), Cohen's $d = 0.71$; effect size $r = -.33$, whereas the difference in misses of previously seen pictures was about 5% (LH: Mean % error = 60.1, $SD = 16$; RH: Mean % error = 55.9, $SD = 16$); Cohen's $d = 0.26$; effect size $r = .13$. Confidence intervals (95%) were computed according to Loftus and Masson's (1994) formula for within-subject design and these revealed that there were significantly more erroneous 'old' responses after LH presentations (C.I. = $\pm 4.4\%$) than after RH presentations (C.I. = $\pm 4.5\%$) as well as more erroneous 'new' responses after LH presentations (C.I. = $\pm 3.3\%$) than after RH presentations (C.I. = $\pm 3.2\%$). Again, the tendency of the LH to commit false alarms was comparable in both the lateralized Lateralized at Study and Lateralized at Test conditions, given that there was no interactive effects of Condition with New/Old and Hemisphere $F(1,35) = 0.6$. Fig. 2 illustrates these effects.

Additionally, we performed a signal detection analysis of the accuracy data so as to reveal possible differences in sensitivity or discrimination performance (d') between the two hemispheres. Hits (i.e., recognizing a picture that had already been presented) and false alarms rates (i.e., falsely recognizing a picture that was actually novel) were obtained for each participant in each Hemisphere condition (LH vs. RH) and presentation Condition (Lateralized at Study vs. Lateralized at Test). We computed each participant's d' scores for Hemisphere and Condition using Macmillan and Creelman's (2004) formula for the Yes-No paradigm; we then used the obtained d' scores as the dependent variable in an ANOVA, with Hemisphere and

Condition as the within-subject variables. This analysis revealed a significant main effect of Hemisphere, $F(1,35) = 12.3$, $p = .0013$. Sensitivity was greater in the RH (mean $d' = 0.563$) than in the LH (mean $d' = 0.276$). There was also a main effect of Condition, $F(1,35) = 33.4$, $p < .0001$. Sensitivity was greater when pictures were Lateralized at Test (mean $d' = 0.634$) than when they were Lateralized at Study (mean $d' = 0.205$). Most interestingly, there was a significant interactive effect between Hemisphere and Condition, $F(1,35) = 7.8$, $p = .009$. As illustrated in Fig. 3, sensitivity was greater for the RH and for the Lateralized at Test condition than any of the other conditions, which did not differ significantly from each other. Again, in the light of possible HERA inequalities (Habib et al., 2003), comparing the differences of each hemisphere's sensitivity for the encoding and retrieval conditions should reveal greater sensitivity for the LH at encoding, whereas the RH should show greater sensitivity at retrieval. However, both hemisphere showed negative values between the differences between d' scores at encoding and retrieval (LH's encode-retrieve: Mean % error difference = -0.22 , $SD = 0.8$; RH's encode-retrieve: Mean % error difference = -0.64 , $SD = 0.4$), which suggests a better sensitivity for the retrieval condition for both hemispheres. Nevertheless, considering the data-limited characteristics of the DVF method, one may be better able to match a relatively more detailed representation that was learned first to a later perceived schematic representation than to match an initial schematic representation to a detailed image perceived later. Hence, one could instead expect larger sensitivity at retrieval for the RH than the one shown by the LH; indeed, consistently with this expectation from the HERA model, the signal detection analysis yielded a RH's superior sensitivity at retrieval (see Fig. 3). A paired t -test confirmed a significant difference of Hemisphere for the encoding-retrieval difference of d' scores, $t(35) = -2.8$, $p = .009$. In contrast, an ANOVA performed on the 'response bias' or C scores as the dependent variable and with Hemisphere and

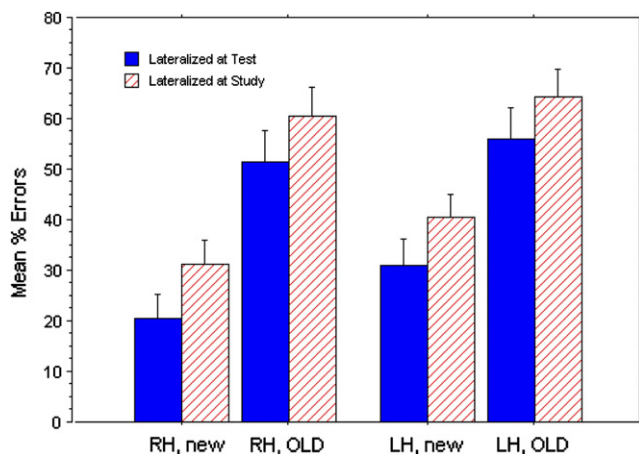


Fig. 2. Mean % errors (error bars are 95% confidence intervals) of "new" and "old" pictures (i.e., false alarms and misses) for each hemisphere (LH, left hemisphere; RH, right hemisphere) and in both conditions (Lateralized at Study or Lateralized at Test).

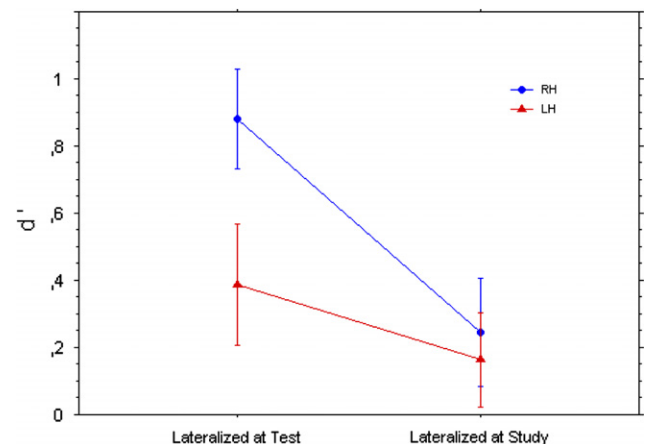


Fig. 3. Mean d' scores (error bars are 95% confidence intervals) for each hemisphere (LH, left hemisphere; RH, right hemisphere) and in both conditions (Lateralized at Study or Lateralized at Test).

Table 1

Top panel, *Free Vision*: Mean % errors (SD within parentheses) of “new” and “old” pictures (i.e., false alarms and misses)

Free vision	New pictures		Old pictures	
Animals	27.8 (12)		41.3 (14)	
Faces	13.3 (15)		35.7 (12)	
Landscapes	20.4 (13)		54.2 (11)	
Objects	29.4 (15)		45.1 (17)	
Paintings	25.3 (12)		49.3 (13)	
Lateralized at study	New pictures		Old pictures	
	LH	RH	LH	RH
Animals	37.4 (14)	28.5 (12)	65.1 (23)	62.8 (26)
Faces	35.4 (16)	22.5 (11)	62.2 (25)	59.8 (25)
Landscapes	45.5 (17)	39.5 (18)	66.5 (22)	60.5 (24)
Objects	36.6 (12)	22.6 (11)	59.7 (19)	55.5 (20)
Paintings	47.1 (22)	42.5 (23)	68.4 (24)	67.1 (23)
Lateralized at test	New pictures		Old pictures	
	LH	RH	LH	RH
Animals	26.9 (16)	18.6 (13)	52.8 (17)	46.8 (11)
Faces	27.4 (13)	17.1 (12)	51.4 (11)	49.5 (17)
Landscapes	35.1 (12)	23.4 (11)	48.5 (16)	42.8 (14)
Objects	28.2 (11)	17.8 (12)	51.5 (10)	50.2 (10)
Paintings	37.0 (21)	26.0 (12)	62.1 (19)	54.4 (14)

Bottom panel, *Lateralized at study* and *Lateralized at test* conditions: Mean % errors (SD within parentheses) of “new” and “old” pictures (i.e., false alarms and misses) in each category and for hemisphere’s presentation (LH, left hemisphere; RH, right hemisphere).

Condition as the within-subject variables failed to reveal any significant effects, $0.01 < F(1,35) < 1.24$.

In addition, a separate ANOVA was performed with Condition (Lateralized at Study vs. Lateralized at Test), Hemisphere (LH vs. RH), New/Old pictures as the within-subject factors and with RTs as the dependent variable. The results were very similar to those described in the previous analysis of % error rates, the only remarkable difference being that there was no significant main effect of Condition on RTs, $F(1,35) = 0.8$. That is, pictures were correctly judged as old or new at about the same speed whether the pictures were only glimpsed in the encoding phase or they were seen for 2 s in the encoding phase and then glimpsed at test. There was a significant effect of Hemisphere, $F(1,35) = 6.3$, $p < .02$. The RH (mean RT = 862, $SD = 226$) made faster correct judgments than the LH (mean RT = 903, $SD = 255$); Cohen’s $d = -0.17$; effect size $r = -.08$. Correct rejections (mean RT = 858, $SD = 236$) were made faster than correct recognitions (mean RT = 906, $SD = 245$), $F(1,35) = 6.3$, $p < .02$; Cohen’s $d = -0.19$; effect size $r = -.10$. Again, there was an interactive effect of New/Old and Hemisphere, $F(1,35) = 12.8$, $p < .001$. The effect was accounted for by longer RTs of the LH when making correct ‘old’ responses (mean RT = 942, $SD = 238$) compared to the RH’s responses (mean RT = 870, $SD = 170$) or either hemisphere’s correct ‘new’ responses (LH: mean RT = 854, $SD = 222$; RH: mean RT = 863, $SD = 220$); Cohen’s $d = 0.35$; effect size $r = .17$. Confidence intervals (95%) were computed according to Loftus and Masson’s (1994) formula for within-subject design, which confirmed that ‘old’ responses after LH presentations (C.I. = ± 67 ms) were slower than any of the other

three conditions, which did not differ significantly from each other.

Finally, an ANOVA with Mean % error as the dependent variable, Category (Animals, Faces, Landscapes, Objects, and Paintings) as the within-subject factor, revealed that landscapes and paintings were the categories recognized with more difficulty whereas faces and animals were the easiest, $F(1,35) = 14.3$, $p < .0001$. Additional ANOVAs with the other variables (i.e., Condition, New/Old and Hemisphere) showed no interactive effects with Category. Table 1 shows the means and SDs for all of these experimental conditions.

3. Experiment 2

The first experiment showed that the RH is superior to the LH in remembering having seen a specific picture before: The observed hemispheric difference was hypothesized on the basis of the known RH’s superiority in perceptually encoding specific aspects of visual form. However, one could be skeptical about whether the right hemisphere advantage obtained in the present study actually reflects a RH advantage in picture memory. One may expect the same results by positing that (1) the two hemispheres have equal abilities in remembering pictures or both provide their knowledge to a common, bilaterally-organized, memory store (for contrary evidence to the latter possibility, see Hornak, Oxbury, Oxbury, Iversen, & Gaffan, 1997); and (2) that the RH’s better performance, as measured in recognition tasks, is nothing else than an artifact of superior perceptual ability in limited input conditions. Indeed, strong constraints are imposed by the DVF method itself, since stimuli presented laterally from fixation and tachistoscopically are not only “glimpsed” but also fall outside of the high-resolution area of the fovea. Thus, the DVF method is inherently data-limited and the processing of complex scenes is necessarily curtailed and constrained.

However, the force of the above argument in interpreting the results of the previous experiment rests on demonstrating that the source of the hemispheric difference we observed was to be found in one hemisphere showing significantly poorer perceptual performance than the other during the lateralized presentations of the pictures. To assess this account directly, in a second experiment, we asked a new group of participants to view in DVF conditions random samples of the same pictures used in the previous experiment. This time, participants performed a same vs. different matching task in which they were shown, right after each picture presentation, either the same picture or a similar but different one. If the previously described differences of the two hemispheres in either accuracy or RTs were entirely due to their ability to immediately match identical pictures, then we should be able to reveal a difference in performance between the two hemispheres also in an immediate recognition test with same visual stimuli. However, a null finding would rule out the possibility that the previously observed hemispheric differences in the

long-term memory task of could be explained away as one hemisphere's superiority in extracting visual information from the same visual stimuli in data-limited conditions.

3.1. Methods

3.1.1. Participants

A total of 14 new participants, 6 females, all right handed by self-report, and of mean age = 24 ($SD = 5.4$), from the student population at the University of Tromsø.

3.1.2. Stimuli and apparatus

These were the same as in Experiment 1.

3.1.3. Procedure

These were kept similar to those of the previous experiment. However, this time participants viewed for 100 ms—while they fixated a central cross on screen—lateralized presentations of 150 pictures (75 in each visual field) consisting of 30 pictures randomly extracted from each of the 5 stimulus categories used in Experiment 1. A new random sample was generated for each participant. A blank screen appeared after each lateralized presentation, followed after 2 s by another picture that appeared centrally on screen until the participant made a response. The participants had to report, by key presses, whether the picture was the same or different from the lateralized picture just seen. Half of the time the central picture would be different (though each foil was always a picture extracted from the same category of the lateralized picture).

3.2. Results

The mean accuracy rate was 99.1% correct and the remaining error rate was evenly divided (0.45%) between left and right presentations. No participants made more than 2% errors and several participants reported, when these errors occurred, that they had made a mistaken key press. Moreover, all participants reported, when queried after this experiment, that despite the fast presentation the lateralized pictures were all clearly perceived and nameable. A repeated-measures ANOVA on the mean response times (RTs) to the correct trials was conducted with Hemisphere (LH vs. RH) and Same/Different pictures as the within-subject factors. The analysis revealed only a significant effect of the Same/Different factor; i.e., participants were faster in Same than in Different trials, $F(1,13) = 16.2$, $p < .001$; Cohen's $d = 1.4$; effect size $r = .56$. Importantly, differences in RTs for the Hemisphere presentations ranged between 2 and 4 ms (Same trials: LH: Mean RT = 615, $SD = 107$; RH: 619; $SD = 65$; Different trials: LH: Mean RT = 722, $SD = 88$; RH: 720; $SD = 86$) and were non-significant, $F < 1$.

4. General discussion

In a recognition memory task, images that were presented initially to the right hemisphere, either when seen the

first time or a second time for recognition after a long delay (from 1 to 6 days), yielded lower error rates compared to those presented to the left hemisphere. The reason for this right hemisphere's superiority in picture recognition can be interpreted as follows: the RH encodes multiple aspects of visual forms that may provide optimal input for access to specific representations of these patterns and of their metric spatial relations (Garoff et al., 2005). In other words, the RH's ability to encode more specific object features than the LH allows this hemisphere to keep detailed and separate memory records, reducing mutual interference when multiple, highly similar, pictures are first presented all together and then tested at a later stage for their recognition. Also, it is unlikely that the described difference between two hemispheres were an artifact of the RH's superior perceptual ability in the data-limited conditions imposed by the DVF method itself. In fact, when the same pictures had to be recognized immediately in a short-term memory DVF experiment, accuracy was nearly perfect for both hemispheres and no differences were observed in speed of matching. Hence, there was no evidence that an original perceptual bias due to the lateralized tachistoscopic presentations per se was responsible for the observed superior long-term memory performance of the RH with the same pictures.

In addition, the present findings, collected with the divided-visual-field method and with normal participants, converge with the conclusion of Metcalfe et al. (1995) of a RH's memory superiority, at least for visual or pictorial material, which was observed with a split-brain patient. Their study (as well as Metcalfe et al., 1995, also on split-brain patients) revealed that the disconnected LH had also a tendency to make false positive recognition in memory tasks (i.e., it interpreted as "old" pictures that were lures and decoys, i.e. similar to the pictures previously shown but in fact new to the patient). In contrast, the disconnected RH showed a more "veridical" or "literal" recognition performance. The present study also observed a twofold increase in false alarms of normal participants when pictures were presented to the LH than to the RH. This phenomenon occurred both after the Lateralized at Study and Lateralized at Test conditions. Moreover, the LH was slower in making correct 'old' responses than the RH, which can also be interpreted as indicating greater effort of the LH in the retrieval or the matching of specific pictures. However, the present results only partially supported the HERA model (Habib et al., 2003). Based on this model, one would have expected a LH's superiority when encoding pictorial information (i.e., in the Lateralized at Study condition) versus a RH's superiority for the retrieval of the same information (i.e., in the Lateralized at Test condition). Comparisons of error rates between the two hemispheres for the two presentation conditions showed no difference. However, a signal detection analysis of the two hemispheres' sensitivity scores was at least partially consistent with predictions based on HERA inequalities, since the RH hemisphere showed a

significant larger sensitivity for the retrieval than encoding than that shown by the LH.

Not surprisingly, in the present study, the lateralized presentations of glimpses of the images (in either the Lateralized Encoding or the Lateralized at Test conditions) led to large decreases in memory performance, compared to the Free Vision condition; an indication of the difficulty of processing in full detail the complex stimuli at these short durations. More interestingly, although we expected the Lateralized at Study condition to lead to a lower performance than the Lateralized at Test condition, we observed no difference in hemispheric advantages for either accuracy or speed of response. These null interactive effects of picture presentation condition and hemisphere may suggest that whether the level of visual detail available at learning is greater than that available at the match stage (i.e., at test) or the reverse plays no major role in each hemisphere's ability to match a stored representation to one previously perceived. Thus, it would seem that, despite their fast presentations of stimuli (typically of about 100 ms), DVF studies allow attention to dwell long enough on the image (and also on its sensory representation after the actual image has disappeared) so as to process the stimulus in quite some detail. However, the signal detection analysis did capture a difference in sensitivity between the two hemispheres by indicating a RH's superiority for the Lateralized at Test condition. In general, one would expect that memory would be better when a relatively more detailed representation is learned first and later a more schematic representation can be matched to it. Since this occurred only for the RH, one could propose (in the light of the HERA model; [Habib et al., 2003](#)) that the RH is better than the LH in retrieving multiple or richer details of visual episodes. However, despite such a RH's superior retrieval of stored visual information, sufficient levels of visual detail may be available both in the case of images seen first freely for 2 s and later only glimpsed by the RH and in the inverse case, so that no performance (accuracy or speed) difference emerged for the RH between the two stimulus presentation conditions.

As shown in [Table 1](#) (bottom panel), error rates were consistently higher for the LH's presentations than RH's; although in some cases the differences between hemispheres were minimal or negligible (e.g., for single objects). One possibility is that some of the stimuli could be remembered also by use of specific verbal labels. However, one caveat of the present study is that, although a right hemisphere's advantage was observed in memory for pictures, no accompanying left hemisphere's advantage was observed in some other related condition (for example, with word stimuli instead of pictures). The lack of interactive effects between different conditions poses a limit when evaluating the present hemispheric differences (cf. [Hellige, 1983, 1993](#)). Future studies revealing such a double dissociation would rule out alternative explanations of simple effects.

Finally, a surprising finding of the present study was the high error rates in the memory of our participants for pictures presented centrally in free vision for the duration of

2 s. Errors were in the 40–50% range of misses in most categories (see [Table 1](#)); that is, considerably lower than those reported in [Standing's \(1973\)](#) article entitled: *Learning 10,000 pictures*. In that study thousands of pictures were presented one at a time, for the duration of 5 s, and with an inter-stimuli interval of 600 ms. A delayed recognition task showed that the error rates for pictures' memory were approximately 10% for the smaller series (400 pictures yielded an error rate of 11.4% whereas 1000 pictures a 9.2% rate), but errors tended to increase for the larger picture sets, with approximately 30% error for 4000 and 10,000 pictures. [Shepard \(1967\)](#) obtained a 98% correct recognition rate (2% errors); [Standing et al. \(1970\)](#) obtained about 90% correct responses. The present study may have differed in important ways from those of Standing's. However, the nature of the stimuli used can hardly explain the difference, given that Standing used mostly natural objects and landscapes as stimulus material, but these images were very poorly recognized in the present study. In fact, given the wide variety of visual materials included in the present study, our items should have been easier to recognize. Thus, the most important difference between the classic studies and the present one would seem to be methodological. In particular, in the studies done in the 1960s and 1970s, each picture was presented alone during the encoding phase, but during the test phase two pictures were shown side by side, and subjects were asked to choose, in a forced-choice paradigm, which one they thought it might have been presented previously. Such a task is easier compared to a simple yes–no decision when a picture is presented alone. Specifically, whenever a foil stimulus is presented in a forced-choice paradigm, its successful rejection depends not only on noticing the absence in the picture of features that were memorized but also the presence of features that do not match any memory trace (i.e., “negative recognition”; cf. [Brown, Lewis, & Monk, 1977](#)). In fact, one could argue that some of the old stimuli categorized as ‘recognized’ may have actually never been recognized (i.e., features were not sufficient to reach the criterion for explicit recognition) or even learned but that instead the new stimuli or some of the foil's features were successfully rejected (thus leaving the other, correct, old stimulus as the most likely choice). Thus, it is questionable whether the forced-choice method really is a less biased memory test than the yes/no method (see [Shepard, 1967](#)) since it can overestimate the capacity of explicit exemplars' memory (Nota Bene: Negative recognition can occur also for single items in the yes/no method but, differently from the forced-choice method, this cannot inflate the hit rate for old pictures but only reduce the rate of false alarms; hence, negative recognition in the yes/no method does not lead to an overestimation of the capacity of long-term memory). Moreover, there seem to be few ecological situations resembling the forced-choice recognition task, since typically we do not exert our memory by choosing among arrays of objects presented for comparisons. Hence, we are tempted to conclude that picture memory, although remarkably good when compared to other

modalities, may not be in itself as perfect as it is commonly thought.

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