Journal of Cognitive Psychology, 2014
Vol. 26, No. 5, 550–558, http://dx.doi.org/10.1080/20445911.2014.928713

Routledge
Taylor & Francis Group

No strong evidence for lateralisation of word reading and face recognition deficits following posterior brain injury

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Face recognition and word reading are thought to be mediated by relatively independent cognitive systems lateralised to the right and left hemispheres, respectively. In this case, we should expect a higher incidence of face recognition problems in patients with right hemisphere injury and a higher incidence of reading problems in patients with left hemisphere injury. We tested this hypothesis in a group of 31 patients with unilateral right or left hemisphere infarcts in the territory of the posterior cerebral arteries. In most domains tested (e.g., visual attention, object recognition, visuo-construction, motion perception), we found that both patient groups performed significantly worse than a matched control group. In particular, we found a significant number of face recognition deficits in patients with left hemisphere injury and a significant number of patients with word reading deficits following right hemisphere injury. This suggests that face recognition and word reading may be mediated by more bilaterally distributed neural systems than is commonly assumed.

Keywords: Face recognition; Lateralisation; Object recognition; PCA stroke; Word reading.

It is a widely held assumption in cognitive neuroscience that face recognition and word reading are mediated by relatively independent cognitive systems lateralised to the right and left hemispheres, respectively (e.g., Dehaene & Cohen, 2011; Kanwisher & Barton, 2011). This assumption is supported by functional imaging studies showing much greater activation in the left than the right hemisphere during word processing (e.g., Dehaene & Cohen, 2011) and in the right than the left hemisphere during face processing (e.g., Kanwisher & Barton, 2011), and by studies of brain-injured patients showing that pure alexia is almost always associated with left hemisphere lesions (e.g., Leff, Spitsyna, Plant, & Wise, 2006) whereas prosopagnosia mainly follows right hemisphere lesions (e.g., Atkinson & Adolphs, 2011). It is also the case, however, that many functional imaging studies reveal substantial bilateral activation during both word and face processing (e.g., Nestor, Behrmann, & Plaut, 2013), and that deficits in word and face processing are more severe following bilateral compared with unilateral lesions (Behrmann & Plaut, 2013). These findings suggest that each hemisphere may contribute to both word and face processing albeit to different degrees. That the right hemisphere's contribution to word reading and the left hemisphere's contribution to face recognition may not be insignificant is evidenced by a recent study by Behrmann and Plaut (2014). They demonstrated slight but significant face processing problems in

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We acknowledge the contributions by Glyn Humphreys and Hanne Udesen in the planning stages of this research, not to mention the always inspiring presence of F. F. Fakutsi.

putative pure alexics with unilateral left hemisphere lesions and slight but significant word processing problems in putative prosopagnosics with unilateral right hemisphere lesions. Based on this and additional evidence, Behrmann and Plaut (2013) have argued that each hemisphere participates in the recognition of both stimulus classes, even though each hemisphere's contribution may have different weights.

The question of whether the neural correlates of word and face processing overlap, or are independent, is difficult to resolve for at least two reasons: (1) There have been rather few studies in which reading and face processing have been examined to the same extent in the same subjects (Behrmann & Plaut, 2013) and (2) most studies have selected the patients based on symptoms (e.g., difficulties in reading or face processing) rather than on lesion site (for a recent exception, see Martinaud et al., 2012). The latter point is important because investigations based on symptoms only are likely to yield a biased impression of lateralisation as such studies usually represent cases with rather pure/severe deficits.

Here, we present a study which investigated the cognitive deficits associated with unilateral lesions following posterior cerebral artery (PCA) stroke. Accordingly, the patients were selected based on lesion site (right or left posterior ventral brain injury) rather than symptom type. All patients were examined with the same broad test battery. This allowed us to examine whether word reading and face recognition problems follow lesions in *both* the right and the left hemisphere or whether they predominantly follow lesions of a specific hemisphere; the left hemisphere in the case of word reading deficits and the right hemisphere in the case of face recognition deficits. The two most extreme outcomes are the following: (1) If each hemisphere contributes equally to word reading and face processing, we should expect the same incidence and severity of face recognition and word reading deficits following lesions of the right and left hemispheres. (2) If word reading and face recognition are strongly lateralised functions, we should not expect any word reading problems following right hemisphere injury and no face recognition problems following left hemisphere injury. It is of course likely that the results will fall in between these extremes. According to Behrmann and Plaut (2013) we should expect some face recognition problems following left hemisphere lesions and some word reading problems following right hemisphere lesions, but the severity of word reading problems should be greater following left compared with right hemisphere injury whereas the severity of face recognition problems should be greater following right compared with left hemisphere injury.

METHODS

The main criterion for patient inclusion was infarcts confined to the territory of either the left or right PCA as verified by CT scan. The recruitment was based on weekly inspection of the charts of newly hospitalised patients at four stroke units in the period June 1998 till November 2000. Testing was performed within 6 weeks following stroke onset with the exception of four patients who were tested after approximately 3 months. Patients were excluded if one or more of the following criteria were met: evidence of earlier infarcts, lesions confined to the thalamus or brainstem, additional large infarcts in other vascular territories, general cognitive decline [defined as a Mini Mental State Examination (MMSE) score (Folstein, Folstein, & McHugh, 1975) below 15 in the absence of amnesia or aphasia], disturbance of consciousness, or physical disabilities or other diseases preventing cooperation. The project was approved by the Committee for Health Research Ethics and all patients and controls provided written informed consent to participate in the study.

The patient group

A total of 31 patients fulfilling the criteria were identified; 17 had unilateral left hemisphere injury whereas 14 had unilateral right hemisphere injury. The mean age was 72 (range: 51–85 years). The level of education was computed by counting years in school (max. 12) and adding a score for educational level (vocational training), which was rated on a scale from 1 (no formal education) to 5 (academic education). The mean educational level was 11 (range: 7–17). All patients underwent neurological examination including visual field confrontation testing, supplemented in 13 cases by Goldman perimetry. All patients were right-handed. See Table 1 for age, gender, educational level, lesion site and visual field deficit for each of the 31 patients (for detailed information regarding the performance of each patient on all measures see the Supplementary version of Table S1 available online).

TABLE 1
Clinical data for the 31 PCA patients

Age	*Gender*	*Educational level*	*Lesion site*	*Visual field deficit*
67	Female	12	Left	None
68	Female	11	Left	Right hemianopia
68	Female	11	Left	Right hemianopia
71	Female	8	Left	Right hemianopia
71	Female	8	Left	Right hemianopia
72	Female	9	Left	None
75	Female	16	Left	Right lower quadrantanopia
80	Female	11	Left	Right upper quadrantanopia
84	Female	13	Left	Right hemianopia
85	Female	15	Left	Right hemianopia
53	Male	12	Left	Right hemianopia
60	Male	8	Left	None
60	Male	12	Left	Right hemianopia
73	Male	16	Left	Right hemianopia
73	Male	17	Left	Right hemianopia
78	Male	8	Left	None
79	Male	15	Left	Right hemianopia
71	Female	8	Right	Left hemianopia
77	Female	8	Right	Left hemianopia
79	Female	9	Right	Left lower quadrantanopia
80	Female	8	Right	Left hemianopia
51	Male	8	Right	None
51	Male	17	Right	Left hemianopia
65	Male	9	Right	Left hemianopia
66	Male	7	Right	Left hemianopia
73	Male	9	Right	Left hemianopia
73	Male	9	Right	Left hemianopia
77	Male	8	Right	Left hemianopia
78	Male	13	Right	None
80	Male	13	Right	None
81	Male	14	Right	Left lower quadrantanopia

The control group

The method for matching patients and control subjects (n = 31) was to find a control subject (primarily sampled from a database of volunteers) matching each individual patient as closely as possible on age, gender and educational level. Control subjects were paid 200 DKK each for approximately 45 minutes of neuropsychological testing. Prior to assessment they were screened for factors known to influence test performance (e.g., neurological and psychiatric illness, substance abuse). The mean age of the control subjects was 71 (range: 50–83 years), which was not statistically different from that of the patients (Mann–Whitney U test, z = −0.53, p = .60), and the mean educational level was 11 (range: 7–17), also not significantly different from that of the patients (Mann–Whitney U test, z = −0.5, p = .62). The male/female ratio for the control subjects was the same as for the patients (14 female/17 male).

Neuropsychological assessment

Patients and control subjects were assessed with a battery of neuropsychological tests covering the following domains: word reading, face recognition, visual attention/search, perception of degraded material, object recognition, colour recognition, visual memory, visuo-construction and motion perception. See Table 2 for a description of all tests. The tests were chosen to reach a compromise between sensitivity, specificity and time, so that as many patients as possible could be tested and at the same time an assessment of a relatively broad range of functions was obtained. The primary purpose of the tests was to get an overview of the spectrum of occurring cognitive deficits associated with infarcts in the PCA territory rather than to obtain a fine-grained in-depth analysis of individual cases.

Statistical analyses

Four types of comparisons were performed: (1) We compared the average scores of the left hemisphere patients to the average scores of the right hemisphere patients on each test. These comparisons were performed by means of Mann–Whitney U exact test or, if the assumption of homoscedasticity was violated, Kolmogorov–Smirnov Z exact test. (2) To examine how many patients within the left infarct group and how many patients within the right infarct group that performed significantly outside the normal range, we compared the score of each individual patient with the average score of the control group for each test. When there was no evidence of a significant effect of background variables (MMSE score, age or educational level) on the performance of the control subjects, these comparisons were performed using Crawford and Howell's test for comparison of an individual score with that of a small control sample (Crawford & Garthwaite, 2002). On some tests there were significant effects of background variables on the performance of the control sample. In these cases the effects were controlled for by entering them as covariates in the analyses so that the patients' scores were adjusted accordingly (Crawford,

TABLE 2
Description of the test employed

Test	*Description*
Mini Mental State Examination	A brief screening instrument comprising 11 items assessing orientation, attention, verbal memory (recall), calculation, naming, ability to follow verbal and written commands, reading, writing and copying. Max. score: 30 (Folstein, Folstein, & McHugh, 1975)
BIT star cancellation test	Cancellation of 54 small stars interspersed with 52 large stars, 13 randomly positioned letters and 10 short words. Max. score: 54 (Wilson, Cockburn, & Halligan, 1987).
Chimeric faces test	20 chimeric faces (half man/half woman, sex randomly alternating from left to right side). The task is to tell the sex of the face presented. Max. score: 20 (Humphreys & Heinke, 1998).
Pillon test	15 line drawings of overlapping objects (inanimate) Scoring: number identified (named or otherwise indicated within 120 s). Max. score: 15 (Pillon et al., 1989).
Street completion test	Identification of 20 fragmented pictures within a time limit of 10 s. Max. score: 20 (Gade, Udesen, & Mortensen, 1988).
Unusual views test	15 objects (2 animate and 13 inanimate) from the Birmingham Object Recognition Battery unusual views test (foreshortened views). Time limit: 20 s. Max. score: 15 (both naming and recognition scores were obtained) (Riddoch & Humphreys, 1993).
Picture naming test	15 line-drawings of animate objects from categories with structurally similar exemplars such as animals, insects, fruits, and vegetables (prototype views) from the Birmingham Object Recognition Battery. Max. score: 15 (Riddoch & Humphreys, 1993).
Famous faces test	Identification and naming of famous faces (politicians, actors, royalties) within 20 s. Max. score: 20. Both naming and recognition scores were obtained.
Face recognition test	Presentation of five unknown faces with indication of sex and estimation of age. After a short delay the five faces are presented among five new faces, and the task is to indicate whether each face was shown earlier. Scoring: 10 minus number of errors. Max. score: 10 (Wilson, Cockburn, Baddeley, & Hiorns, 1989).
Reading of 10 words test	Reading of 10 regular spelling to sound words (five 3-letter words and five 7-letter words matched for frequency).
Colour naming test	Naming and pointing on verbal confrontation. Stimuli were 10 coloured cards (red, green, blue, purple, black, brown, grey, yellow, orange and pink). A naming and a pointing score were registered. Max. score: 10.
Drawing from memory test	Drawing of three animals with salient features: Giraffe, kangaroo and tiger. From Birmingham Object Recognition Battery. Max. score: 10 (Riddoch & Humphreys, 1993).
Topographical memory test	Localisation of five European capitals marked with black dots on a map. Max. score: 5.
Copy test	Copy of house in three dimensions. Max. score: 3 (Sturb & Black, 1977).
Structure-from-motion test	A random pattern mask in overhead transparency is moved above a slightly fragmented figure, whereby a figure pops out. Time limit: 10 s. Max. score: 6 (Lorenceau & Boucart, 1995).

Garthwaite, & Ryan, 2011). Due to extreme ceiling effects for the control subjects on some of the tests (Chimeric faces, Reading of 10 words, Colour naming and Colour recognition), these approaches could not be applied in all instances. In these cases, a cut-off point was set at one score below the lowest score of the control subjects. In these comparisons one-tailed statistics were used. (3) Based on these frequency data, we examined whether there were differences in the number of individual left and right infarct patients who fell outside the normal range on the tests. These comparisons were performed by means of χ^2 exact tests. (4) Finally, we examined whether performance on the reading test correlated with performance on the Behavioral Inattention Test (BIT) star cancellation and the Chimeric faces test. This was done separately for the left and the right infarct patients in order to examine whether impaired reading performance could be explained by neglect (neglect dyslexia).

RESULTS

The raw data for each individual patient on each of the 18 neuropsychological measures and the MMSE are given in the Supplementary version of Table S1 (available online). The median, mean and *SD* of each test are summarised in Table 3 according to group (left infarct group, right infarct group and the control group). The table also includes test statistics for two of the comparisons performed: Difference in left vs. right infarct group performance (score), and difference in number of patients

TABLE 3

Descriptive statistics for each of the three groups (left infarct group, right infarct group and control group) on each of the 18 neuropsychological measures/background variables and inferential statistics for comparisons between the right and left infarct groups

	Number of patients[a]	*Max. score*	*Left infarct group score*[b]	*Right infarct group score*[b]	*Control group score*[b]	*Difference in score: left vs. right infarct group*[c]	*Frequency of deficits: left infarct group*	*Frequency of deficits: right infarct group*	*Difference in frequency left vs. right infarct group*[d]
Background variables									
Age	31 (L = 17/R = 14)		72 (71.6/8.6)	75 (71.6/10)	71 (70.9/8.7)	NS (p = .76) (z = −0.3)			
Education	31 (L = 17/R = 14)		12 (11.9/3.1)	9 (10/3.0)	10 (11.2/2.9)	NS (p = .11) (z = −1.6)			
Mini Mental State Examination	31 (L = 17/R = 14)	30	27 (26.2/4.5)	27.5 (26.5/3.0)	29 (28.8/1.2)	NS (p = .77) (z = −0.3)	35% (6)	43% (6)	NS (p = .72) (χ^2 = .19)
Tests									
BIT star cancellation test	29 (L = 17/R = 12)	54	53 (51.8/3.5)	47 (41.4/15.3)	54 (53.5/1.2)	NS (p = .061) (z = 1.1)*	18% (3)	58% (7)	p = .046 (χ^2 = 5.2)
Chimeric faces test	30 (L = 16/R = 14)	20	20 (18.9/2.5)	16 (15.6/4.4)	20 (19.9/0.2)	p = .039 (z = 1.2)*	13% (2)	57% (8)	p = .019 (χ^2= 6.7)
Street completion test	31 (L = 17/R = 14)	20	7 (7.2/4.6)	4 (5.9/4.5)	13 (13.3/2.9)	NS (p = .33) (z = −1.0)	53% (9)	64% (9)	NS (p = 72) (χ^2 = .41)
Pillon test	31 (L = 17/R = 14)	15	11 (10.2/4.5)	5 (7.4/4.8)	14 (13.9/1.0)	NS (p = .09) (z = −1.7)	65% (11)	71% (10)	NS (p = .72) (χ^2 = .16)
Unusual views; Recognition	31 (L = 17/R = 14)	15	7 (7.2/3.9)	4 (5.7/4.3)	11 (11.2/1.8)	NS (p = .26) (z = −1.2)	82% (14)	93% (13)	NS (p = .61) (χ^2 = .76)
Unusual views; Naming	31 (L = 17/R = 14)	15	7 (7.1/3.9)	4 (5.7/4.3)	11 (11.2/1.8)	NS (p = .27) (z = −1.1)	82% (14)	93% (13)	NS (p = .61) (χ^2 = .76)
Picture identification; Recognition	31 (L = 17/R = 14)	15	13 (11.8/3.3)	12.5 (12.1/1.9)	14 (13.6/1.0)	NS (p = .74) (z = −0.3)	41% (7)	29% (4)	NS (p = .71) (χ^2 = .53)
Picture identification; Naming	31 (L = 17/R = 14)	15	12 (11.4/3.6)	12.5 (12/1.8)	14 (13.5/1.2)	NS (p = .91) (z = −0.1)	35% (6)	14% (2)	NS (p = .24) (χ^2 = 1.8)
Famous faces; Recognition	31 (L = 17/R = 14)	20	19 (17.2/4.4)	18 (16 /5.1)	20 (19.3/0.9)	NS (p = .26) (z = −1.1)	29% (5)	43% (6)	NS (p = .48) (χ^2 = .61)
Famous faces; Naming	31 (L = 17/R = 14)	20	15 (13.7/6.0)	15 (14.4/5.2)	19 (18.3/1.9)	NS (p = .84) (z = −0.2)	41% (7)	50% (7)	NS (p = .73) (χ^2 = .24)
Face recognition test	31 (L = 17/R = 14)	10	9 (9.2/0.9)	8.5 (8.2/1.8)	10 (9.8/0.5)	NS (p = .11) (z = −1.6)	29% (5)	50% (7)	NS (p = .29) (χ^2 = 1.4)
Reading of 10 words test	31 (L = 17/R = 14)	10	10 (9.2/2.1)	8.5 (7.7/2.6)	10 (10/0.0)	NS (p = .06) (z = −1.8)	29% (5)	57% (8)	NS (p = .16) (χ^2 = 2.4)
Color identification; Recognition	31 (L = 17/R = 14)	10	10 (9.7/0.7)	10 (9.4/1.3)	10 (10/0.0)	NS (p = .38) (z = −1.0)	18% (3)	36% (5)	NS (p = .41) (χ^2 = 1.3)
Color identification; Naming	31 (L = 17/R = 14)	10	10 (8.9/1.5)	9.5 (9.1/1.2)	10 (9.8/0.4)	NS (p = .92) (z = −0.1)	35% (6)	21% (3)	NS (p = .46) (χ^2 = .72)
Drawing from memory test	28 (L = 15/R = 13)	9	5 (4.5/3.1)	2 (2.8/3.0)	6 (6.3/2.1)	NS (p = .16) (z = −1.4)	33% (5)	54% (7)	NS (p = .45) (χ^2 = 1.2)
Topographical memory test	31 (L = 17/R = 14)	5	5 (4.3/1.3)	2.5 (2.6/2.3)	5 (4.9/0.4)	p = .02 (z = 1.2)*	29% (5)	57% (8)	NS (p = .16) (χ^2 = 2.4)
Copy test	30 (L = 17/R = 13)	3	2 (2.2/0.8)	2 (1.5/1.3)	3 (2.7/0.5)	NS (p = .16) (z = −1.5)	24% (4)	54% (7)	NS (p = .13) (χ^2 = 2.9)
Structure-from-motion test	31 (L = 17/R = 14)	6	5 (3.8/2.5)	0 (0.9/1.6)	5 (5.2/1.0)	p = .001 (z = −3.2)	35% (6)	93% (13)	p = .002 (χ^2 = 10.7)

[a]L = Left and R = Right.
[b]Median (Mean/*SD*).
[c]NS = not significant; p values based on Mann–Whitney U Exact test or Kolmogorov–Smirnov Z exact test if the assumption of homoscedasticity was violated as assessed with Levene's test. The latter cases are marked with an asterisk.
[d]NS = not significant; p values based on χ^2 exact test.

with left vs. right infarcts (frequency) who scored outside the normal range.

On most tests the left and right infarct groups did not perform significantly differently from each other in their obtained score. The exceptions were the Chimeric Faces test, the Topographical memory test and the Structure-from-motion test. On all of these tests, the average score of the right infarct group was below that of the left infarct group. A similar trend for lower performance of the right compared with the left infarct group was also observed on the BIT star cancellation test, the Pillon test, the Face recognition test and the Reading of 10 words test. We note that the lower scores of the right compared with the left infarct group cannot be explained by differences in age, educational level or mental state (as measured by the MMSE) as the two groups did not differ significantly on these variables. The differences in score between the left and the right infarct groups were generally also reflected in the number of patients within the two groups falling outside the normal range (frequency). Hence, significantly more patients with right than with left hemisphere injury fell outside the normal range on the BIT star cancellation test, the Chimeric faces test and the Structure-from-motion test. In one case a slight discrepancy is noteworthy: While the right infarct group scored below the average of the left infarct group on the Topographical memory test, the number of patients within each group who fell outside the normal range did not differ significantly on this test. This discrepancy should not, however, be given too much weight considering the small sample sizes combined with the fact that more patients with right than with left hemisphere lesions were impaired. It should be noted that these results were based on statistics uncorrected for multiple comparisons. Hence, the low number of differences found between the left and right infarct groups does not reflect a conservative statistical threshold.

With respect to correlations between reading performance and performance on the BIT star cancellation task and the Chimeric faces test, these were significant in the right infarct group (Spearman's rho $r = .66$, $p = .02$ and $r = .66$, $p = .035$ for BIT star cancellation and Chimeric faces, respectively) but not in the left infarct group (Spearman's rho $r = .37$, $p = .15$ and $r = .35$, $p = .18$, respectively).

DISCUSSION

We tested the performance of 31 patients with pure right ($n = 14$) or left ($n = 17$) hemisphere infarcts in the territory of the posterior cerebral arteries on tests of word reading, face recognition, visual attention/search, perception of degraded material, object recognition, colour recognition, visual memory, visuo-construction and motion perception. It is noteworthy that the degree of abnormality varied considerably across tests. On tests involving degraded stimulus material (Street completion test, Pillon test, and the Unusual views test), more than half of all patients in both the left and the right infarct groups scored outside the normal range. On other tests, such as the Chimeric Faces test, as few as 13% (in the left infarct group) fell outside the normal range. The finding of impairments for both left and right infarct patients in most of the domains tested is somewhat surprising given that many of the measures employed were rather crude (e.g., reading of 10 words with no time limit), and the finding is most readily explained by the fact that the majority of the patients were tested in the subacute phase following stroke (27 of the patients were tested within 6 weeks following stroke onset and the remaining 4 within 3 months).

Of special interest were the findings that a significant number of face recognition deficits (Famous faces test and Face recognition test) were seen following left hemisphere lesions, and that a significant number of reading deficits (Reading of 10 words test) were observed following right hemisphere lesions. While the frequency of deficits should be interpreted with caution due to the small sample sizes, we note that the frequency of deficits within these domains also did not differ significantly between the right and left hemisphere groups. These findings are striking considering the widely held assumption—discussed in the introduction—that face recognition and word reading are mediated by relatively independent cognitive systems lateralised to the right and left hemispheres, respectively. In our opinion the present findings concur with the suggestion that face recognition and word reading may be mediated by more bilaterally distributed neural systems than previously thought (Behrmann & Plaut, 2013).

Because our patients were tested in the subacute phase following stroke it might be argued that our findings are not representative of "stable" functional systems but may instead reflect systems still in a state of shock. Although we do acknowledge that reading deficits may with time be(come) more prominent for patients with left hemisphere injury, and that face recognition deficits with time may become more prominent for patients with right hemisphere injury—as was concluded in a study by Martinaud et al. (2012) who tested 31 PCA patients at least 3 months following stroke[1]—we do not think that this time issue compromises our conclusion regarding a relative bilateral representation of brain systems underlying word reading and face recognition. After all, it is quite likely that a more lateralised pattern of word reading and face recognition deficits, which may arise with time since injury, does in fact *not* reflect the "true" state of lateralisation but rather an adaption of the remaining operational system. This could come about if the right hemisphere's normal contribution to word reading is affected by injury but in time is, at least to some extent, compensated for by left hemisphere mechanisms. The same goes for face recognition: If the left hemisphere's contribution to face recognition is affected by injury it may in time be compensated for by right hemisphere processes.

Even if word reading and face recognition rely on bilaterally represented neural systems, this does not imply that the left and right hemispheres play equal or even similar roles in the two processes. Indeed, in our sample of patients, face recognition deficits did appear to be somewhat more severe following right than left hemisphere injury. It is also likely that the right infarct patients correspondingly had difficulties reading words for different reasons than the left infarct patients, and that the left infarct patients had difficulties recognising faces for different reasons than the right infarct patients (see e.g., Behrmann & Plaut, 2014 for a similar suggestion). Given the crude nature of our measures—which prevents us from identifying the functional or neural locus of the deficits exhibited by individual patients—we had only limited opportunity to examine this important issue. We did, however, examine whether impaired reading performance might reflect neglect (neglect dyslexia). In keeping with the suggestion that deficits in reading and face recognition may reflect at least partially different causes we did find correlations between reading performance and performance on BIT star cancellation/Chimeric faces test (both typical neglect tests) in the right infarct group, whereas no such correlations were significant in the left infarct group. Although the lack of a significant relationship in the left infarct group does not imply that it is absent, it does suggest that the relationship is stronger in the right hemisphere group. This may suggest that the reading deficits observed in the right infarct group reflect attentional deficits. Given that the correlation was not perfect this explanation can only account for some of the variance in reading performance: Some right infarct patients with impaired performance on the BIT star cancellation test and the Chimeric faces test did not exhibit

[1] Martinaud et al. (2012) analysed their data a little differently than we analysed our data. Martinaud et al. considered patients impaired if their score fell 2 *SD*s below the mean of the control sample (two-tailed statistics). On the plausible assumption that patients will perform worse and not better relative to controls, we instead based our comparisons on one-tailed statistics. If we re-analyse the data reported by Martinaud et al. using our approach—as is done later—we find that also in the study by Martinaud et al.: (1) Some impairment in reading is seen in patients with unilateral right hemisphere injury, (2) some impairment in face recognition is seen following unilateral left hemisphere injury and (3) the difference between unilateral right and left infarct patients in terms of reading and face recognition deficits is not significant.

Of the right unilateral infarct patients reported in the study by Martinaud et al. (2012), one had impaired reading in terms of accuracy (No. 25) [falling one percent-point below the worst performance of the control group] whereas five (Nos. 21, 24, 25, 26 and 28) had a word-length effect that was significantly longer than that of the control sample ($p < .05$, one-tailed: Crawford & Garthwaite, 2002). In comparison, 3 out of the 15 left infarct patients were impaired in terms of accuracy (Nos. 8, 9 and 12) whereas 10 (Nos. 1, 3, 6, 8, 9, 11, 12, 13, 14 and 15) showed an abnormal word-length effect ($p < .05$, one-tailed: Crawford & Garthwaite, 2002). In terms of frequency there is no significant difference between the left and right infarct groups in accuracy (χ^2 exact significance = 0.86, $p = .6$) nor in word-length effect (χ^2 exact significance = 0.08, $p = 1$).

On their old/new face discrimination task two patients with unilateral left hemisphere injury (Nos. 2 and 12) performed significantly worse than the control subjects ($p < .05$, one-tailed: Crawford & Garthwaite, 2002). In comparison the same is found for five patients with unilateral right hemisphere injury (Nos. 20, 21, 22, 25 and 26) ($p < .05$, one-tailed: Crawford & Garthwaite, 2002). Again, the difference between left and right infarct patients in frequency of face discrimination problems is not statistically significant (χ^2 exact significance = 2.79, $p = .19$).

Martinaud et al. also examined performance on the Cambridge Face Memory test for their left and right infarct patients and found no significant difference in frequency of impairment on this task (two left vs. three right infarct patients). Adopting our criterion for impaired performance does not change this overall result: three patients with left hemisphere injury (Nos. 8, 10 and 12) vs. four patients with right hemisphere injury (Nos. 22, 25, 26 and 27); a difference that is not significant (χ^2 exact significance = .43, $p = .67$).

impaired reading, whereas some patients with left hemisphere lesions were also impaired on both the reading test and the BIT star cancellation test and/or the Chimeric faces test. To this we must also add that we actually observed more patients with reading deficits in the right than in the left infarct group (8 vs. 5). Thus, and hypothetically, even if some of the right infarct patients had reading impairments due to neglect dyslexia whereas none of the left hemisphere patients had, it would still be hard to maintain a strong version of reading lateralisation where reading is a left hemisphere function only.

Even though we recruited patients from four stroke units in a large city (>600,000 inhabitants) for two and a half years, only 31 patients fulfilled the criteria for inclusion in the study. With only 31 observations it makes sense to ask whether we can detect true differences in frequency if they exist? This of course depends on the effect size which we do not know. Nevertheless, according to a strong version of lateralisation, where reading is a left hemispheric function only and face recognition is a right hemispheric function only, it seems reasonable to expect a large effect size; that is, no or very few reading impairments following right hemisphere infarcts and no or very few face recognition impairments following left hemisphere infarcts. If, by contrast, we took a more modest stance, as advocated by Behrmann and Plaut (2013), we would only expect a small or medium effect size; that is relatively more instances of reading impairments following left than right hemisphere injury but with some instances of reading impairment following right hemisphere injury also. The same would go for face recognition impairments which should be relatively more frequent following right than left hemisphere injury but with some instances following from left hemisphere injury also. Setting the α-level to .05 and the β-level to .95 the present data-set had enough statistical power to detect a medium to large effect size (>.65) in terms of differences in frequency of impairments (Faul, Erdfelder, Lang, & Buchner, 2007). Based on these considerations we can with some confidence reject a strong version of lateralisation in the case of reading and face recognition.

In conclusion, we find evidence of impaired face recognition and word reading following unilateral infarcts in the PCA territory of *both* the left and the right hemispheres. In this respect the approach adopted in the present study seems fruitful: Selecting patients based on lesion site and testing these patients with the same tests may overcome a potential weakness associated with investigations based on symptoms. Such studies are likely to yield a biased impression of lateralisation because they usually represent cases with rather pure deficits in one modality (e.g., word reading) leaving (more subtle) deficits in other modalities (e.g., face recognition) unexplored. We do acknowledge, however, that the present study has limitations of its own. The small sample size prevents us from reaching any firm conclusions regarding the frequency of face recognition and word reading deficits following left and right hemisphere injuries, and the measures performed in terms of both lesion analysis and neuropsychological examination prevent us from identifying the locus of deficit in individual patients. Also, we acknowledge that the use of only CT in verifying lesions does not preclude the existence of cases of bilateral damage. However, although randomly located "silent" small infarcts may be fairly common, bilateral symmetrical or nearly symmetrical strokes are not, and it would be even more uncommon if one was both invisible on CT and of sufficient size to cause significant impairment. Although these limitations should clearly be addressed in future studies, the present data are sufficient for addressing the issue concerning laterality of reading and face recognition deficits, where we find no strong evidence for lateralisation. This concurs with Behrmann and Plaut's (2013) suggestion that face recognition and word reading may be mediated by more bilaterally distributed neural systems than previously thought.

Supplementary material

Supplementary Table is available via the "Supplementary" tab on the article's online page (http://dx.doi.org/10.1080/20445911.2014.928713).

Original manuscript received April 2014
Revised manuscript received May 2014
Revised manuscript accepted May 2014
First published online June 2014

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