Face processing impairments after amygdalotomy

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Summary
We report an investigation of face processing impairments in D.R., a 51-year-old woman with a partial bilateral amygdalotomy. D.R. was able to recognize pre-operatively familiar faces, but she showed generalized problems of name retrieval and a more circumscribed deficit affecting the recognition of faces learnt post-operatively. In contrast to her poor memory for new faces, D.R.'s ability to match simultaneously presented photographs of unfamiliar faces was unimpaired. However, D.R. also experienced deficits in expression processing which compromised the recognition of emotion from people's faces; she was poor both at matching and at identifying photographs of emotional facial expressions. In addition, her interpretation of eye gaze direction was defective, showing a more general problem in reading social signals from the face. The presence of impairments affecting the learning of new faces and the comprehension of gaze direction and facial expressions of emotion is consistent with the hypothesis of a role for the amygdala in learning and social behaviour.

Keywords: amygdala; face recognition; facial expression; gaze direction

Introduction
Selective damage to the human amygdala is unusual, and its consequences have not been definitively established (Aggleton, 1992, 1993). In most cases, there is no evidence of impairment on overall measures of intelligence, and no evidence of global memory impairment, but specific memory deficits have been noted to affect the recognition of nonverbal visual stimuli, and especially faces (Andersen, 1978; Jacobson, 1986; Tranel and Hyman, 1990; Aggleton, 1992).

This evidence of an impairment of memory for faces forms one of the few common features that has emerged from studies of the effects of amygdala damage, being noted in a number of cases with a variety of aetiologies (Aggleton, 1992).

Findings of face processing impairments after amygdalotomy are of particular interest because neurophysiological studies have identified cells which respond selectively to faces in the amygdala for primates (Rolls, 1984; Leonard et al., 1985; Nakamura et al., 1992) and humans (Seeck et al., 1993). In addition, studies of face processing impairments following damage to either human or primate cerebral cortex have shown that these can take dissociable forms, selectively affecting different aspects of face processing (Heywood and Cowey, 1992; Young, 1992; Young et al., 1993). A question which therefore arises concerns whether face processing impairments due to amygdalotomy will also show some degree of selectivity. To date, however, most investigators have only looked at recognition memory for faces, and there has only been one detailed case study of the consequences of amygdalotomy across a range of face processing tasks (Jacobson, 1986). Jacobson found that his patient showed poor learning of new faces, borderline abnormalities in the matching of unfamiliar faces, and impaired recognition of familiar faces, with particularly marked problems in naming them.

We report here a further amygdalotomy case showing face processing impairments, D.R. The presence and nature of the face processing impairments was established with some of the same tests as Jacobson (1986), allowing direct comparisons

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between the two cases. In addition, we included a number of further tests of face processing and of visual recognition and visual memory, to identify more precisely D.R.’s preserved and impaired abilities.

Case description
D.R. is a 51-year-old right-handed woman who first suffered from epilepsy during her second pregnancy at the age of 28 years. Prior to this, she had an uneventful medical history, with no evidence of behavioural or psychiatric disorder and no family history of epilepsy. Her first two seizures were generalized tonic clonic seizures and these continued at very infrequent intervals, but 2 weeks after the onset of epilepsy she began to suffer complex partial seizures which occurred two or three times each day. Since then, D.R. has continued to have three types of seizure. There are tonic clonic seizures about once each month. There are absences several times each day, sometimes associated with some movement of the head from side to side. Thirdly, there are complex partial attacks almost every day, lasting for ~2 min and followed by a period of confusion or automatic behaviour.

Over a period of 25 years, drug treatment seems to have had little effect on the number or type of attacks, although there has been some variation in frequency unrelated to treatment. Many different anti-convulsants have been tried at one time or another, but during the period when the tests to be reported here were begun, D.R. was taking Carbamazepine 700 mg daily and Phenytoin 300 mg daily, with Phenytoin serum level 11.1 mg/l and Carbamazepine level 5.9 mg/l. Later in the testing period, D.R. started taking Lamotrigine, but this was discontinued after 6 months and the dose of Phenytoin was increased to 350 mg a day and Carbamazepine to 800 mg a day, with Carbamazepine level 7.6 mg/l and Phenytoin 11.9 mg/l. However, during this time D.R.’s performance of the psychological tests to be reported was consistent across different testing sessions, and did not seem in any way affected by changes in medication.

Failure of anti-convulsants to control D.R.’s seizures led to a series of electroencephalogram investigations in the 1970s, including three with sphenoidal leads. These established a seizure source in the left anterior temporal lobe and, since 1974, there have been records with an autonomous discharge in the right temporal lobe. Electroencephalography at the time of proposed temporal lobe surgery in 1975 showed widespread discharges involving frontal, parietal and even occipital areas on the left side without evidence of clear derivation from the seizure source located by depth electrodes in the left temporal lobe. Pre-operative CT scans, a ventriculogram, an air encephalogram and a left carotid angiogram did not identify more precisely any pathology.

Between 1978 and 1981 D.R. underwent a series of stereotaxic procedures targeted initially at the left amygdala and, later, at the left and right amygdala. In all, D.R. had four cryoprobe lesions and one electrocoagulation lesion on the left side, and she had two cryoprobe lesions on the right, following one of which a CT scan showed a haematoma in the region of the right caudate nucleus.

These procedures may have had some success in reducing the frequency of seizures, but at present D.R. still has six or seven attacks per day in which she becomes absent and makes fidgeting movements. In some attacks she falls, and some start with shaking of the left arm and leg. Following the seizure she is sometimes confused and disinhibited, but usually she regains normal orientation in time and place quite quickly.

MRI scans were performed in 1991 and 1992. T2 axial sequence 2200/80 7 mm thick sections followed by T1 coronal sequence 600/15 7 mm sections were acquired. Later, T1 coronal sequence 500/15 2.2 mm thick sections were imaged, throughout the region of the basal ganglia and amygdala. Gradient echo 1.5 mm sections through the same region were also acquired.

These MRIs showed an extensive lesion of the left medial amygdala, which destroyed much of the basal nuclei but largely spared the lateral nucleus. The area of damage extended throughout the rostro-caudal limits of the left amygdala, just reaching the anterior horn of the left hippocampus. Associated damage extended dorsally beyond the amygdala to involve part of the anterior commissure, lateral putamen and external capsule. In the right hemisphere, there was a small posteriorly placed lesion at the caudal limit of the amygdala, and a second small lesion in the right anterior amygdaloid area. Planimetric measurements of the MRIs (using a Placom KP-90N planimeter) indicated that the amygdalar lesions involved at least 25% of the total volume of the left amygdala and more than 4% of the right amygdala. Figure 1 shows tracings of lesions in the region of the amygdala derived from six coronal MRI sections at 2.2 mm intervals.

There was also some additional extra-amygdalar subcortical damage in the right hemisphere, probably as a result of the bleeding noted after one surgery; this involved a discrete lesion in the pulpallid region at the level of the anterior commissure, extending more dorsally within the striatum at a level rostral to the anterior commissure, with possible damage to adjacent parts of the internal capsule and caudate nucleus. In addition, very small areas of cortical abnormality (high signal on T2 and low signal on T1) were noted in the left occipito-parietal region adjacent to the falx and in the anterior right frontal lobe; these were also considered to result from surgery.

D.R. no longer has any sense of smell. She readily engages in conversation in a lively manner, but she can have problems in finding the exact word needed and therefore resorts to circumlocutions fairly frequently. These word finding difficulties are the only obvious problem with language, and they do not present any hindrance to communication because D.R. uses effective circumlocutions. In all other respects, her conversation is usually appropriate and grammatical. With respect to emotion, D.R. can readily give examples of occasions when she says that she has experienced feelings
Face processing after amygdalotomy

Fig. 1 Tracings of lesions in the region of the amygdala derived from six coronal MRI sections at 2.2 mm intervals. The region of the amygdala is marked by dashed lines, and the regions of damage are marked in black. The sections are numbered in a caudal to rostral direction, with the left amygdala on the right side of each.

of happiness or sadness since her operations, and she can describe circumstances in which other people would be happy, sad, angry, afraid, etc. However, her usual mood is somewhat upbeat and she does not easily get upset or complain of pain, even when she falls and injures herself.

Pre-operative assessment with the Weschler Adult Intelligence Scale (WAIS) in 1976 gave a Full Scale IQ of 99 (VIQ 94, PIQ 105). Psychometric testing carried out more than 1 year after D.R.'s last surgery indicated a possible fall in WAIS scores (Full Scale IQ 90; VIQ 89, PIQ 92). The most recent IQ testing has been in 1990 using the revised version of the WAIS (WAIS-R) (Full Scale 87; VIQ 82, PIQ 96), which is known to yield lower values than the WAIS (Wechsler, 1981). D.R.'s predicted premorbid IQ is 111 using the revised version of the National Adult Reading Test (Nelson, 1991), but this figure is above both pre- and post-operative results with WAIS and WAIS-R.

D.R.'s score on the Wechsler Memory Scale prior to surgery was 105. Post-operative memory tests showed normal verbal memory (List learning, 25th–50th percentile; Story recall, immediate 10th–25th percentile, with 30 min delay 25th–50th percentile). On informal assessment she demonstrated reasonably good recall of recent public news events and autobiographical episodes. However, D.R. does complain of occasional lapses of everyday memory, often involving the recognition of people she knows quite well. It seems that this is most likely to occur when the person in question is encountered in an unusual context. For example, D.R. and her husband report that, although she has no difficulty recognizing neighbours in their home or garden she has often failed to recognize the same person outside the immediate neighbourhood. We (P.B. and M.J.) have noticed that D.R. has failed to recognize us outside the usual context of our office or clinic room, for example on meeting in a hospital corridor.

There was no evidence of impairment of basic visual functions, with normal spatial contrast sensitivity function on the Vistech VCTS6000 chart and full visual fields to confrontation testing. Repeated examinations over many years have not revealed any neurological abnormalities other than those already described.

Investigation of face processing abilities

D.R. and her husband gave their informed consent to an investigation of her face processing abilities, using non-invasive tests with photographs as stimuli. This project received ethical approval from Leeds Health Authority. The tasks we used examined performance in three general areas: (i) face processing; (ii) recognition of visual stimuli other than faces; (iii) recognition memory. We will consider each of these in turn. Except where otherwise stated, D.R.'s performance was compared with that of 20 control subjects (10 men, 10 women) aged 40–59 years. This control group was well matched to D.R. on age (D.R. = 51 years; control mean = 51.20 years, SD = 6.06), and on predicted IQ using the revised version of the National Adult Reading Test (Nelson, 1991) (D.R. = 111; control mean = 113.75, SD = 11.84).

Face processing

We assessed D.R.'s ability to recognize familiar faces, match unfamiliar faces, and to determine eye gaze direction and facial expression. The results are summarized in Table 1.
Identification of familiar faces

Three 'line-ups' of photographs of familiar and unfamiliar faces were used. The first of these (Lancaster Faces Line-Up) is one we have used in previous studies of face processing impairments (Young et al., 1990a; de Haan et al., 1991; Young, 1992), and it was also used by Jacobson (1986). In the version of the test used here, 20 highly familiar faces, 20 moderately familiar and 20 unfamiliar faces, were presented one at a time in random order. For each face, D.R. was asked whether or not it was a familiar person and, if so, his or her occupation and name. This is a slightly simplified variant of our previous method, in which familiarity was rated on a seven-point scale for each face. The reason for the change is that we have found that, in practice, it is sufficient for subjects to indicate whether each face is familiar or unfamiliar to them, and this is a much easier procedure to use. The data of interest concern D.R.'s ability to recognize as familiar and give correct occupations and names to the 20 highly familiar faces, and the rate at which the 20 unfamiliar faces were misidentified. Data for the moderately familiar faces are not included in Table 1, because the control subjects showed high variance in their responses to these items.

D.R. recognized all 20 of the highly familiar faces as familiar, and she correctly rejected 20 out of 20 of the unfamiliar faces as people she had not seen before. She was within the normal range at giving occupations for the familiar faces (16 out of 20 correct), but she was poor at naming them (8 out of 20 correct, $Z = 2.31$, $P < 0.05$).
The Lancaster Faces Line-Up was assembled in the early 1980s, and involves several faces whose familiarity had peaked some time before D.R. was tested in 1991. Whilst this is, in part, mitigated by the fact that the control data shown in Table 1 were also collected in 1991 and 1992, it was thought prudent to confirm the results with a further test using currently famous faces. Therefore, D.R. was also tested on a new Faces Line-Up consisting of 30 faces of people who were famous in 1991 and 10 unfamiliar faces. This produced the same pattern of performance, with unimpaired recognition of familiar faces (29 out of 30) and rejection of unfamiliar faces (nine out of 10 correct), good ability to give the occupations of familiar people (29 out of 30), and impaired ability to name them (13 out of 30, $Z = 2.76, \ P < 0.01$).

Although this line-up showed unimpaired recognition of faces of people who were famous in 1991, it did not control the time period when these people became famous, and in fact included many faces which would have been known to D.R. pre-operatively. A third faces line-up with Time-Banded Faces was therefore adapted from Hanley et al.'s (1990) investigation of a case of impaired visual memory. This used 26 faces of people who were famous before 1980 (James Callaghan, Frank Sinatra, Jimmy Connors, etc.), and were therefore likely to have been known by D.R. before her operations, 26 people who have only become famous since the mid-1980s (Mikhail Gorbachev, Sarah Ferguson, Madonna, etc.), who D.R. would have had to learn since her operations, and 26 faces of unfamiliar people. As in the other line-ups used in the present investigation, these faces were presented one at a time in random order. For each face D.R. was asked whether or not it was a familiar person and, if so, his or her occupation and name.

Table 1 shows D.R.'s performance with these time-banded familiar faces in comparison with 13 age-matched control subjects (mean age = 57.74 years, SD = 5.11). As with the other line-ups, D.R. was easily able to recognize the unfamiliarity of faces she had not seen before (25 out of 26 correct rejections). For the faces of people who were famous before 1980, D.R. was, if anything, slightly outperforming the controls in ability to recognize them as familiar (26 out of 26 correct, 0.88 SDs above control mean) and give their occupations (24 out of 26 correct, 0.68 SDs above control mean). She did not show a significant impairment in naming these pre-operatively familiar faces in comparison with the control subjects (12 out of 26 correct, $Z = 1.14, \ P > 0.05$), but her ability to name them showed a marked drop in comparison with her very good ability to give their occupations (difference between occupation and naming scores = 12 for D.R; mean difference = 3.08 for controls). For the faces of people who have become famous since the mid-1980s, D.R. was significantly impaired at giving familiarity (16 out of 26 correct, $Z = 2.21, \ P < 0.05$), occupation (11 out of 26 correct, $Z = 1.96, \ P < 0.05$), or name (four out of 26 correct, $Z = 1.97, \ P < 0.05$). When asked, she could usually say who each of these people was (i.e. what they were famous for, occupation, etc.) if given their name. Hence there was clear evidence of problems in learning the faces of people who had only been encountered post-operatively, rather than problems in learning new semantic information. However, although D.R.'s performance was poor, she could none the less recognize a proportion of these post-operatively familiar faces; the problem in new learning was by no means absolute.

Unfamiliar face matching
The Benton Test of Facial Recognition (Benton et al., 1983) was given. This was also used by Jacobson (1986). In this test, subjects have to choose which of six photographs of unfamiliar faces are pictures of the same person as a simultaneously presented target face photograph. The test includes items involving choice of identical photographs, as well as transformations of orientation or lighting, which are pooled to give an overall total. D.R.'s score (47 out of 54 correct) was unimpaired both in terms of the test's norms and our own control data.

A second unfamiliar face matching test examined ability to match disguised faces. Two separate test sheets were used, each showing a $4 \times 4$ matrix of faces in which each of the four faces in the top row appeared three times in disguised or undisguised forms elsewhere on the sheet (Young et al., 1990b). D.R.'s accuracy score was again unimpaired (20 out of 24 correct).

Gaze direction
A forced-choice task was used to assess D.R.'s ability to determine eye gaze direction. Pairs of photographs of the same person's face were presented alongside each other. For one-third of the pairs (six trials) both pictures were full-face photographs, for one-third (six trials) they were both facing 20° to the left, and for the remaining third of pairs (six trials) both faces were facing 20° to the right. In each pair, the eyes of the target face were oriented directly toward the viewer, and the non-target face was looking away to the left or right by 5°, 10° or 20°. The combination of six directions of gaze for the non-target faces (left and right direction of gaze at 5°, 10° and 20°), and three possible head orientations for both members of each pair (full-face, 20° left or 20° right) produced a total of 18 trials. On each of these, D.R. was asked to choose the photograph in which the face was looking directly toward her, and the non-target face was looking away to the left or right by 5°, 10° or 20°. The combination of six directions of gaze for the non-target faces (left and right direction of gaze at 5°, 10° and 20°), and three possible head orientations for both members of each pair (full-face, 20° left or 20° right) produced a total of 18 trials. On each of these, D.R. was asked to choose the photograph in which the face was looking directly toward her. Her performance (13 out of 18 correct, $Z = 4.44, \ P < 0.001$) was below that of 20 normal control subjects (10 men, 10 women) of comparable age (mean = 51.20 years, SD = 6.06). D.R. made no errors when the gaze direction of the non-target face deviated by 20° (six out of six correct), but she performed less well with 10° (three out of six correct) and 5° (four out of six) deviations. The control subjects only made errors with 5° deviations.
Facial expressions

Facial expression processing was examined using tests which required matching and recognition of emotional facial expressions.

In the expression matching task, a photograph of a target face displaying one of six possible emotions (anger, sadness, happiness, disgust, surprise, fear) had to be matched against four simultaneously presented alternatives (another view of the target emotion, and three distractors selected from the remaining possibilities). All five photographs (target + alternatives) were of faces of five different people of the same sex, taken from the Ekman and Friesen (1976) series. They were mounted in a vertical arrangement on a sheet of paper, with the target face slightly separated from the others at the top of the page, and the four alternative choices in line below it, as described by Gainotti (1989). D.R. was asked to point to the face which showed the same expression as the target face, and the task began with four practice trials, followed by 18 experimental trials (three using each of the six emotions as target). A score out of a possible maximum of 18 correct choices was recorded.

D.R. performed this task particularly poorly, being very impaired (six out of 18 correct, Z = 13.80, P < 0.001) in comparison with a group of 20 normal control subjects (10 men, 10 women) of comparable age (mean = 51.20 years, SD = 6.06). In fact, her performance was no different from chance level (Z = 0.54, P > 0.1), given that each trial involved a four-way forced-choice.

In the expression recognition task, D.R. was shown a photograph of a face from the Ekman and Friesen (1976) series, displaying one of the six possible emotional expressions (anger, sadness, happiness, disgust, surprise, fear). The names of the six emotions were printed below the photograph in a vertical alignment, with the order of these emotion names randomized across trials. D.R. was asked to identify each expression by deciding which of the emotion names best described the facial expression shown. There were six practice trials and 24 experimental trials (four for each of the six emotions), leading to an accuracy score out of a possible maximum of 24 correct choices. Again, D.R. performed poorly (16 out of 24 correct, Z = 2.96, P < 0.01).

The photographs of facial expressions used as targets in this task were chosen because they were all accurately recognized in the norms published by Ekman and Friesen (1976; mean accuracies for our chosen targets are anger = 98%, sadness = 96%, happiness = 100%, disgust = 96%, surprise = 96%, fear = 93%). None of the target photographs had been used as targets in the expression matching task.

Recognition of other visual stimuli

We also examined D.R.'s ability to recognize objects and buildings. Data from these tasks are summarized in Table 2.

Identification of familiar objects

D.R. correctly identified 14 out of 20 drawings of living objects and 11 out of 20 non-living objects from the sets used by Young and Ellis (1989). Both of these performances were severely impaired in comparison with the control subjects (Z > 3.10, P < 0.001 in each case), but this problem in tests of object identification reflected a naming deficit rather than a recognition impairment, because D.R. could give accurate information about objects whose name she didn't remember at the time (e.g. guitar: 'they play a lot of them on Top of the Pops'). To confirm the naming deficit, she was given the McKenna and Warrington (1983) Graded Naming Test. As predicted, her performance was very poor (two out of 30), but again she could give accurate semantic information about a further 22 items whose names she was unable to remember. This high frequency of dysphasic errors is well outside the range of McKenna and Warrington's (1983) normal sample (0% made more than 10 such errors).

Identification of familiar buildings

D.R. was shown 20 photographs of familiar buildings (the White House, Sydney Opera House, etc.) and 10 photographs of grand but largely unfamiliar buildings, in random order. She was asked whether each was familiar and, if so, what it was. D.R. had no problems in correctly recognizing the famous buildings as familiar (15 out of 20 correct, Z = 1.14, P > 0.1), and correctly rejected all of the unfamiliar buildings. However, her performance at identifying the familiar buildings was again compromised by problems of name retrieval (three out of 20, Z = 3.19, P < 0.001).

Recognition memory

D.R. was given a standard test involving recognition memory for faces and words (Warrington, 1984), and variants of this test which we produced to assess recognition memory for buildings and pronounceable nonwords. Data from these tasks are summarized in Table 3.

Warrington Recognition Memory Test (RMT)

In the RMT (Warrington, 1984), recognition memory is tested separately for faces and words. The RMT was also used by Jacobson (1986). In the Faces part of the RMT, 50 faces are shown at the rate of one every 3 s for a ‘pleasant or unpleasant’ decision, and recognition memory is then tested immediately by presenting each of the faces paired with a distractor, with the subject having to choose which has been seen before. A similar procedure is used with Words. D.R.’s score of 34 out of 50 correct for the Faces part of the RMT was impaired in terms of our own control data (shown in Table 3) and the test’s norms, and markedly different from her score of 47 out of 50 correct on recognition memory for Words (significant Faces discrepancy score on the test’s norms).

Although 34 out of 50 correct represents poor recognition memory for faces, it is above chance level (Z = 2.40, P < 0.01). This is consistent with our observation that,
Table 2 Performance of D.R. on visual recognition tasks, and means and SDs for control subjects of comparable age

<table>
<thead>
<tr>
<th>D.R.</th>
<th>Controls</th>
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<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
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</tbody>
</table>

**OBJECT RECOGNITION**

| Living          | 14/20*** | 19.10  | 0.97 |
| Non-living      | 11/20*** | 19.25  | 1.16 |
| Graded Naming Test | 2/30+    |        |      |

**IDENTIFICATION OF BUILDINGS**

<table>
<thead>
<tr>
<th>Famous buildings</th>
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<tbody>
<tr>
<td>Recognized as familiar</td>
<td>15/20</td>
<td>17.75</td>
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<tr>
<td>Correctly identified</td>
<td>3/20***</td>
<td>15.30</td>
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</tbody>
</table>

<table>
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<tr>
<th>Unfamiliar buildings</th>
<th></th>
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<tbody>
<tr>
<td>Correct rejections</td>
<td>10/10</td>
<td>9.50</td>
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</tbody>
</table>

Asterisked scores are significantly impaired in comparison to the performance of controls: ***Z > 3.10, \( P < 0.001 \); + indicates frequency of dysphasic errors outside the range of McKenna and Warrington’s (1983) normal sample.

Table 3 Performance of D.R. on recognition memory tasks, and means and SDs for control subjects of comparable age

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</table>

| RMT: Faces     | 34/50** | 44.60  | 3.89 |
| RMT: Words     | 47/50   | 46.95  | 3.14 |
| Nonwords       | 39/50   | 42.95  | 4.05 |
| Buildings      | 43/50   | 43.35  | 2.25 |

Asterisked scores are significantly impaired in comparison to the performance of controls: **Z > 2.33, \( P < 0.01 \).

 Discussion

Selective bilateral damage to the amygdala offers important insights into the functions of the amygdala, but it is rare. As in the present case, there is usually some extra-amygdalar pathology. It is therefore necessary to proceed cautiously, noting which impairments are found in each case, and placing the greatest confidence in those deficits that prove common across cases with differing aetiologies and extra-amygdalar damage.

A further complication in D.R.’s case is the existence of long-standing epilepsy, raising the issue of the extent to which results are affected by medication and by ongoing seizure activity, rather than the effects of surgery itself. To some extent, these questions can also only be fully resolved by noting similarities and differences from the effects of amygdala damage resulting from other aetiologies. However, we think it unlikely that the impairments we have noted derive from medication effects because they have been remarkably stable and specific throughout the testing period.

In addition, the tasks for which D.R. showed impaired performance were not simply those that controls found the most difficult; in other words, her pattern of performance

although D.R. was poor at recognizing the faces of people who have become famous since her operations (see Table 1: Time-banded faces), she was not completely unable to do this, and had learnt to recognize a proportion of them.

Recognition memory for nonwords and buildings

To assess further D.R.’s recognition memory, we developed equivalent tests using pronounceable nonwords and using photographs of unfamiliar buildings (houses), in which 50 nonwords or 50 buildings were shown at the rate of one every 3 s for a ‘pleasant or unpleasant’ decision, and then recognition memory was tested by presenting each of the nonwords or each of the buildings paired with a distractor, with the subject having to choose which had been seen before. The reasoning behind this was that we wanted to explore recognition memory for unfamiliar verbal stimuli by using pronounceable nonwords, and unfamiliar visual stimuli other than faces by using buildings. D.R.’s performance was unimpaired (39 out of 50 correct for pronounceable nonwords, 43 out of 50 correct for buildings, \( Z < 1, \ P > 0.1 \) in each case).
reflects specific disabilities, not a generalized impairment which is only apparent with the most difficult tasks. For example, the Benton Test of Facial Recognition is often failed by patients with brain injuries (Benton et al., 1983), yet D.R. passed this with ease. Similarly, tests of familiar face recognition can be failed by patients who remain able to recognize emotional expression from the face (Young et al., 1993), yet D.R. showed precisely the opposite pattern with pre-morbidly familiar faces.

In fact, D.R.’s pattern of normal recognition of pre-morbidly familiar faces both from the pre-1980 time-banded faces and in the Lancaster faces line-up, and poor recognition of faces of people who have become famous since the mid-1980s (Table 1), points strongly toward an effect of surgery. Consider, for example, the point that after 1978 the effect of the operation is hard to disentangle from the effects of continued seizure activity, but for faces famous before 1978 there is only seizure activity which could have interfered with D.R.’s ability to learn them. Yet D.R. recognized the pre-1980 time-banded faces and the faces from the Lancaster line-up as well as controls. These faces included those of people who had been famous before D.R. suffered any seizures at all and those of people she must have learnt whilst having several seizures per day; yet both types of face were readily recognized. The impairment with faces learnt post-operatively must therefore be a consequence of surgery, not continued seizure activity. Notice also that, consistent with her relatively spared ability to learn verbal information, D.R.’s problem lay in recognizing the faces of people who had become familiar since her operations, and not in learning semantic information about them.

Our investigation highlighted D.R.’s problems in learning new faces, name retrieval, and understanding gaze direction and facial expression. In contrast, recognition of pre-operatively familiar faces (other than name retrieval) and ability to match unfamiliar faces were well preserved across different tests. Hence, D.R.’s problems did not affect all face processing tasks, but were selective to certain aspects of face processing.

Problems in learning new faces were expected from the small existing literature on amygdalotomy; the cases reported by Jacobson (1986) and Tranel and Hyman (1990) had both shown discrepancies between intact performance with words and poor recognition memory for faces on the Warrington RMT. For D.R., as we have noted, we were able to demonstrate that this problem extended to the everyday learning of new faces, since she showed poor recognition of faces of people who have become famous since her operations. However, D.R.’s learning impairment did not involve verbal stimuli, whether these were pre-operatively familiar or unfamiliar (she showed unimpaired recognition memory performance with familiar words on the RMT, and unimpaired recognition memory for pronounceable nonwords which she would only have encountered for the first time in our test; in addition, her verbal learning and recall abilities were also found to be intact on other tests). Moreover, there was evidence of a degree of selectivity of the impairment in learning new faces, since it did not extend to other visual stimuli which are not readily named or described verbally (unimpaired recognition memory performance with buildings).

D.R.’s problems in new learning were therefore differentially severe for faces, though we cannot, at present, be certain that faces were the only class of stimuli affected; all we can say is that faces were the only stimuli for which D.R. showed poor learning among those we were able to test. The finding of poor learning of new faces is of particular interest since D.R. performed well on unfamiliar face matching tasks where the faces were in view simultaneously; hence it does not seem that her impaired learning of new faces was due to any defect of face perception.

Although D.R. showed a relatively circumscribed deficit in learning new faces, she had widespread problems in tasks that required name retrieval, including naming everyday objects, familiar buildings and familiar faces. A problem of name retrieval was also apparent in everyday life, because D.R. made fairly frequent circumlocutions in conversation. Jacobson’s (1986) patient, G.R., was also poor at naming faces from the Lancaster Faces Line-Up, which was the only naming task used in his study, so the naming deficit may be more than a coincidence, and worth investigating in other cases. This finding was unexpected, but of course not something that could be predicted from animal studies. However, the possible contributions of extra-amygdalar damage must always be considered, even though the clinical features of D.R.’s and G.R.’s cases and the reasons for the amygdalotomies were quite different. The issue can only be resolved with studies of further cases.

In addition to problems in naming familiar faces, Jacobson’s (1986) patient G.R. complained of problems in recognizing them in everyday life, and this was confirmed by her performance of the Lancaster Faces Line-Up, which showed a mild degree of impairment in recognizing faces as familiar and in giving their occupations. However, because G.R.’s operations were carried out in the early 1970s, this line-up would have included both faces that were well-known pre-operatively to G.R. and faces she would only have learnt more recently. When we separated pre- from post-operatively familiar faces for D.R., her performance at recognizing familiar faces as familiar and at giving their occupations was unimpaired for those who were known to her pre-operatively. For faces learnt post-operatively, D.R. did show impairments of recognition, but she could, none the less, identify a substantial proportion of these correctly; her impairment in learning new faces was therefore not so severe as to completely prevent her from learning them at all.

Subjectively, D.R. complained of problems in recognizing faces in incorrect or unusual contexts. This is a fairly common type of everyday error (Young et al., 1985), but clinical and anecdotal observations supported the view that it might be particularly frequently experienced by D.R. Despite this, D.R.’s ability to recognize pre-operatively familiar faces from
the faces line-ups showed that there was no gross defect in recognizing faces presented without any supporting context; if there was any measurable effect of context it seemed to be restricted to faces learnt post-operatively, for which D.R.’s performance was poor.

Our findings that D.R. was impaired in processing facial expressions and gaze direction are consistent with the neuropsychological literature. One of the most striking effects of amygdalotomy in primates is a loss of emotional responsiveness, which can include willingness to approach previously frightening stimuli (Aggleton, 1992; Halgren, 1992). Moreover, Leonard et al. (1985) found that face-selective neurons in the monkey amygdala were in some respects more selective in their responses to different faces than were cells in the cortex of the superior temporal sulcus (STS), which is richly interconnected with the amygdala (Aggleton et al., 1980; Amaral and Price, 1984). This led Leonard et al. (1985) to suggest that ‘the deficits in social and emotional behaviour produced by amygdala lesions could be due, in part, to damage to a neuronal system specialized in utilizing information from faces so that appropriate social and emotional responses can be made to different individuals.’ This speculation is consistent with findings indicating that temporal lobe cells selective for facial expression tend to be located within the STS, whereas cells selective for identity tend to be located on the inferior temporal gyrus (Hasselmo et al., 1989; Desimone, 1991). In addition, cells responsive to gaze direction have been found in monkey STS (Perrett et al., 1985), and impairments in interpreting gaze direction occur in humans and monkeys after temporal lobe lesions (Perrett et al., 1988; Campbell et al., 1990). Similarly, removing the STS does not impair monkeys’ ability to discriminate or recognize faces, whereas it does affect their ability to determine gaze direction (Heywood and Cowey, 1992).

On this basis, Heywood and Cowey (1992) have proposed that STS is also concerned with the perception of social signals communicated by the face. Since the amygdala is richly interconnected with the STS (Aggleton et al., 1980; Amaral and Price, 1984), it is likely to be implicated in the same processes. In addition, there is some evidence which suggests that the amygdala receives richer projections from the STS than the inferior temporal gyrus (Aggleton et al., 1980).

Whilst the effects of amygdalotomy on human emotional behaviour have been noted and studied, it is thus somewhat surprising that more attention has not been given to the possibility of changes in the perception of emotion through facial expressions. Although Jacobson (1986, p.441) reported that O.R. complained of ‘occasional difficulty in recognizing the emotional expression on other faces’, he did not find her performance to be impaired on a task of discriminating happy from sad faces.

For D.R., there were obvious deficits in expression processing, with problems in matching and identifying photographs of emotional facial expressions from the Ekman and Friesen (1976) series. Her interpretation of eye gaze direction was also defective, showing a more general problem in reading social signals from the face. These findings fit well alongside the neurophysiological literature we have outlined. From their single-cell recording study of the monkey amygdala, Nakamura et al. (1992, p. 1447) concluded that it ‘may be involved in the recognition and/or evaluation of complex stimuli, and it may play a role, though relatively minor, in the short-term storage of complex visual stimuli.’

Our findings are broadly consistent with this view, since we noted impairments of evaluation in the form of defective facial expression processing and gaze direction for D.R., and an additional impairment of ability to learn new faces. However, we did not note any impairment of ability to recognize the identities of pre-operatively familiar faces, other than a general problem of name retrieval. As Leonard et al. (1985) imply, the reason why single cells in the monkey’s amygdala have been found to be sensitive to identity, may lie in the importance of coding identity for appropriate social behaviours (i.e. the monkey must be able to behave differently to different monkeys, even if they are expressing the same emotion), rather than because these cells are involved in recognition per se.

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