

## Prevalence and correlates of face recognition impairments after acquired brain injury

Tim Valentine<sup>1</sup>, Jane Powell<sup>1,2</sup>, Jules Davidoff<sup>1</sup>, Susan Letson<sup>1</sup>,  
and Richard Greenwood<sup>2</sup>

<sup>1</sup>*Department of Psychology, Goldsmiths College, London, UK;* <sup>2</sup>*Regional Neurological Rehabilitation Unit, Homerton Hospital, London, UK*

Impairments of face recognition after acquired brain injury (ABI) are not restricted to prosopagnosia but commonly arise in association with other cognitive deficits and can be psychosocially debilitating. Despite this, the prevalence and cognitive concomitants of such impairments after ABI have not been systematically investigated. We tested 91 adults with ABI on a range of cognitive measures including several indices of face recognition and learning. The proportion of patients who show impaired performance varied across face learning/recognition tests between 21% and 80%. Principal components analyses indicated orthogonality between impairments of “directed facial processing”, associated with memory and visuo perceptual deficits and manifest in slow learning and matching of previously unfamiliar faces, and of “face identification”, associated with deficits on verbal tests and manifest in difficulty in naming famous faces. Theoretical and rehabilitative implications are considered.

### BACKGROUND

An individual’s ability to interact appropriately with a succession of people who cross his or her path in the course of normal social commerce, and to

---

Correspondence should be sent to Professor Tim Valentine, Department of Psychology, Goldsmiths College, Lewisham Way, New Cross, London SE14 6NW, Tel: +44 (0) 20 7919 7871, Fax: +44 (0) 20 7919 7873. Email: t.valentine@gold.ac.uk

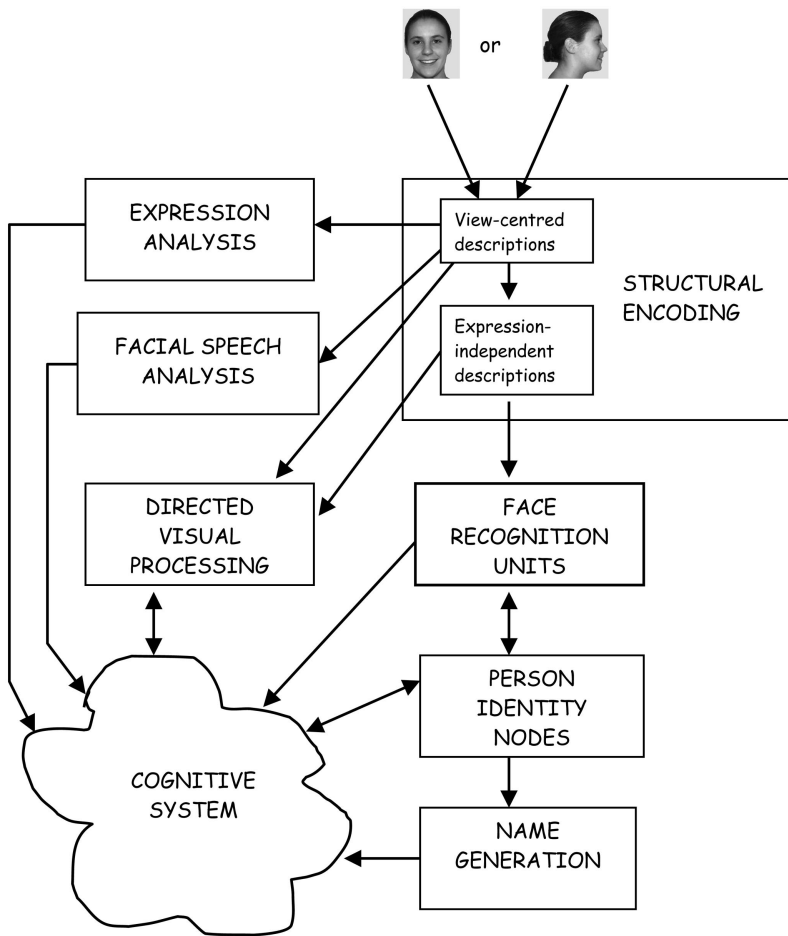
This research was supported by a grant from the James S. McDonnell Foundation to whom we are most grateful. We also thank the medical and nursing staff on the units from which patients were recruited.

develop personal relationships over repeated interactions, is dependent to a degree on accurate and speedy processing of faces. If the abilities to recognise familiar faces, understand facial expressions, or learn to recognise new faces are compromised, s/he is likely to feel somewhat disorientated and unable to “place” the other person. This may result in possible offence to that person, and, by reducing the predictability of the interaction, will decrease the probability of achieving shared goals. As a consequence of these uncertainties, someone who has face recognition difficulties may well lose confidence and retreat from situations such as social events or work environments in which s/he is likely to encounter many individuals in different contexts.

Familiar face recognition has provided fertile ground for the development of information-processing and other cognitive models. For example, the model proposed by Bruce and Young (1986) drew on evidence from experimental studies with both healthy and neurologically impaired populations to identify the key stages in recognition of familiar faces (see Figure 1). According to this model, identification relies upon the following hierarchy of processes: (1) encoding of visual information, allowing invariant structural properties of the face to be perceived independently of variations in orientation, expression, and context; (2) comparison of this perceptual information with memory representations of previously-seen faces, termed face recognition units (FRUs); (3) associating these representations with identity-specific semantic information about known individuals (represented by Person Identity Nodes, PINs), and (4) recall of their name. Since the Bruce and Young model was published, much research has refined or elaborated the mechanisms of face recognition, but the basic sequence of access to representations has been supported by many empirical studies.

Bruce and Young’s (1986) model identified processing pathways for several other aspects of face processing. The route for identification of familiar faces is independent of pathways for analysis of facial expression, analysis of facial speech (lipreading), and also a pathway dedicated to “directed visual processing”. This last pathway supports deliberative analysis of the visual appearance of a face that might be used to judge its age, race or sex, or to decide if two pictures were of the same unfamiliar individual. Support for this framework is drawn from double dissociations reported between the ability to recognise familiar faces, and process facial expression (Etcoff, 1985), analyse facial speech (Campbell, Landis, & Regard, 1986), and the ability to match unfamiliar faces (Malone, Morris, Kay, & Levin, 1982).

Most of the clinical literature concerning impairments of face recognition has focused on “prosopagnosia”—the inability to recognise familiar faces. The literature is based largely on case studies of a relatively small number of prosopagnosic patients, whose deficits are relatively “pure” and thus indicative of damage to a cognitive module concerned specifically with the



**Figure 1.** An information processing model of face processing (adapted from Bruce & Young, 1986).

processing of face-related information. However, face processing is dependent on more general cognitive processes (e.g., attention, storage and retrieval of semantic information, visuo-perceptual analysis, naming) which influence performance on a wide range of cognitive tasks. It is easy to dismiss a problem with face recognition as uninteresting if it is “just” part of a generalised memory impairment, or “secondary” to poor attention and concentration. Nevertheless, face perception may be a primary problem to the patient and one for which a theoretically driven analysis might yield effective intervention strategies. Furthermore, over-reliance on “pure” cases

of prosopagnosia may give a misleading clinical impression. For example, notwithstanding the double dissociation between familiar face recognition and recognition of facial expression noted above, many prosopagnosics also show impairment to recognition of facial expression (Davidoff & Landis, 1990). The literature would also lead one to assume that prosopagnosia is not a common clinical condition. Although pure cases may be relatively rare, there are no data available on the prevalence of impairments to face processing which occur in the context of other neuropsychological impairments.

The present study was designed to ascertain the prevalence of difficulties in face recognition within a sample of patients with acquired brain injury, and to investigate the relationship of such difficulties to other cognitive impairments. We subsequently developed three theoretically-derived procedures aiming to enhance face memorability in a subgroup of patients with face recognition impairments selected from this sample; those findings are the subject of a separate report.

### Indices of face recognition impairments

Any attempt to measure the prevalence of a problem entails firstly defining it in operational terms. In the case of face recognition, impairments can manifest in a number of different functions. These include the ability to recognise well-known faces as familiar (associated in the Bruce & Young, 1986, model with activation of an FRU); the ability to access semantic information about such faces (requiring access to information accessed at the PIN); the ability to match unfamiliar faces seen from different angles or with different expressions (based on directed visual processing); and the ability to learn new faces, which for long-term learning, would require new FRUs to become established.

There already exist tests of recognition of “famous” faces—i.e., photographs of people with a high level of media exposure because of their involvement in public life—and of faces which have been seen only once (i.e., where photographs of previously unseen faces are presented once and then tested immediately for recognition from the same photograph). In everyday life, however, the most common practical difficulties are likely to arise with the recognition of less familiar or new people who appear occasionally but infrequently in the person’s social network. Difficulty is less likely to be encountered in recognising the few people who are at the centre of the injured person’s domestic life (immediate family, close friends) and whose appearance is likely to be massively overlearned, or with those who are met once or twice as fleeting contacts but have no recurrent role in the person’s social network.

The question arises, therefore, of how learning of unfamiliar faces or consolidation of low familiarity faces is achieved. The learning history associated

with a new person will be an important factor. Usually the face of a new person whom one wishes to recognise subsequently would be looked at over several short periods, perhaps during a conversation or on a number of separate occasions. Their facial appearance will also change with speech, facial expression and gesture. Therefore, genuine recognition of the face rather than simply of its pictorial representation is required (Bruce, 1982). It does not follow that those who perform poorly on tests of recognition of a brief single exposure of a photograph will necessarily have a similar difficulty in recognising people once they have encountered them several times or over an extended interaction; slow learning does not mean no learning. However, as far as we are aware, there is currently no test of face recognition after repeated presentation that requires a different picture of an individual to be recognised. We have therefore developed such a test for the purposes of the present study in order to be able to explore how impairments of face learning relate to performance on other, established, tests of other aspects of face recognition.

## METHODS

### Design of study

Ninety-one patients with acquired brain injury (ABI) were assessed at least six months following their injury on a battery of cognitive assessment measures. These measures were chosen to index a range of cognitive functions and included various indices of face recognition.

### Participants

All participants were aged between 18 and 64 years ( $mean = 41.3$ ,  $SD = 12.8$ ), and had been admitted to either the stroke or regional neurological rehabilitation units at the Homerton Hospital following acquired brain injury. Forty-one had sustained traumatic brain injury, 39 had suffered cerebrovascular accidents (CVAs) of various types, and the remainder had other aetiologies including anoxia or cerebral infections. Some were assessed while admitted as in-patients; others were assessed, following their discharge, either at the hospital or at their home. Duration since injury varied between 6 and 68 months ( $mean = 20$ ,  $SD = 16.7$ ).

Patients were excluded from the study if they had not been educated in the UK, on the basis that this might be associated with limited familiarity with celebrity faces used in the tests of famous face recognition under investigation. Although the sample was predominantly white European ( $n = 70$ ), the remaining 21 participants came from a diverse range of ethnic backgrounds. It was essential that all participants were able to

understand all test requirements and to be able to give reliable verbal responses, and so patients were also excluded if they had gross receptive or expressive language impairments or if they were unable to concentrate for at least 20 minutes of testing. Testing took between 90 minutes and 2 hours to complete. Some participants completed the tests over two sessions. All participants were given a 15 minute break during each session. Seven participants had some degree of visual field loss, but all passed screening tests of visual perception (Efron Squares, Efron, 1968; identifying photographs of “usual views” of objects, Warrington & James, 1988; Fragmented Letters and Shape Detection subtests from the Visual and Object Space Perception battery, Warrington & James, 1991).

### Assessment measures

A fairly extensive set of measures was used to give brief indices of general reasoning ability, executive function, attention span, confrontation naming, visuospatial perception, and visual and verbal memory, in order that the relationship of these variables to face recognition could be explored statistically. None of the preceding tests utilised faces as stimuli; however, a test of the ability to label facial emotional expression was included in this set of general cognitive measures as an index of participants’ ability to process facial information independently of any recognition requirements.

Face recognition ability was assessed using a number of different tests with varying response requirements and using different types of face stimuli. Some are well-known and widely used, with established norms; others have been designed here to assess specific aspects of face recognition which are not adequately tested using existing measures.

#### General intelligence and abstract reasoning ability

*Raven’s Coloured Progressive Matrices* (Raven, 1965). A test of non-verbal reasoning in which the respondent has to examine a patterned display with a part missing and to identify from a set of several alternatives the one which will complete the display. The score used here is the number of items correct (maximum = 36). This test is typically scored at or close to ceiling by healthy adults and it was included to index impairment rather than to provide a sensitive measure of visuo-spatial reasoning across the spectrum of ability.

*Similarities sub-test from the Wechsler Adult Intelligence Scale–Revised* (WAIS-R; Wechsler, 1987). Here the participant has to identify conceptual links between two words. Scores on this test correlate very highly both with verbal IQ and with full-scale IQ assessed using all subtests of the WAIS-R ( $r = .75$  and  $.73$ ). Raw scores range from 0 to 28.

### 'Frontal Lobe' or 'Executive' Functions

Two indices of strategic information-processing, often considered to be measures of frontal lobe or higher order "executive" functions, were administered. These are likely to be correlated with measures of general IQ, at least in the lower ranges represented in this brain-injured sample, but can show impairment even when IQ remains intact.

*Cognitive Estimates* (adapted from Shallice & Evans, 1978). This 10-item test requires respondents to generate estimates of real-world values which they are unlikely to know with precision. Error scores can range between 0 and 30, and high scores are indicative of problems in either the organisation or implementation of an effective problem-solving strategy.

*Verbal Fluency: The Controlled Oral Word Association Test* (COWAT; Benton & Hamsher, 1989). Participants are asked to generate as many words as possible beginning with the letters F, A, and S in one minute for each letter. The score used is the total of all legitimate responses.

### Attention span/working memory

*Digit Span* (Wechsler, 1987). Digit span was used as a brief measure of attention span and working memory. Forwards and backwards spans were scored separately as the number of sequences correct, with discontinuation after failure of both sequences at one length. Since the correlation between forward and backwards scores here was extremely high ( $r = .88$ ), a single combined score is reported in the analyses below.

### Confrontation naming

*Oldfield Naming Test* (Oldfield & Wingfield, 1965). This test comprises 30 line drawings which have to be named correctly as quickly as possible.

### Visuo-spatial perception

*Position Discrimination Test from the Visual Object and Space Perception Battery* (VOSP; Warrington & James, 1991). Two adjacent squares are shown, one with a black dot exactly in the centre and one with a black dot slightly "off-centre". The respondent has to identify which of the two has the central dot. There are 20 items, and most healthy adults make no errors.

*Unusual Views* (Warrington & James, 1988). 24 objects are photographed in black and white from an unusual angle. The participant has to identify the object in each case. This is a fairly difficult test: On a 20-item

version, the 5% cut-off point for healthy control participants is 13/20 correct (Warrington & James, 1988).

*Letter Cancellation* (from the Behavioural Inattention Test; Wilson, Cockburn, & Halligan, 1987). Here the respondent has to cross out all the Es and Rs from a four line array of letters comprising 40 targets and 130 non-targets. There is no time limit. The score used is the total number of correctly crossed targets.

#### Verbal memory

*Story Recall (immediate)* from the Rivermead Behavioural Memory Test (RBMT; Wilson, Cockburn, & Baddeley, 1991). The participant is required to recall as much as s/he can from a short story immediately after it has been read aloud to him/her. One point is awarded for each of 21 "ideas" from the story.

*Recognition Memory Test (Words)* (Warrington, 1984). Participants are presented sequentially with 50 single words for 3 seconds each. To focus attention and increase depth of processing, they are required to indicate whether each one is pleasant or unpleasant. Following the study phase, they are presented with 50 pairs of words, each comprising one of the previously seen ("target") stimuli and a distractor. Participants are required to choose (or guess) which of the two they have seen before. Score is number correct. The mean score for healthy adults aged 40–54 is 45.3 ( $SD = 3.4$ ).

#### Visual memory

*Picture Recognition from the RBMT* (Wilson, Cockburn & Halligan, 1987). Line drawings of 10 common objects are shown, in sequence, for 5 seconds each. The participant is required to name each picture, and after a short filled delay (during which the story described above is presented) has to select the original 10 from a set of 20 pictures presented one at a time. The score is the number of targets correctly identified (maximum 10). Most healthy adults perform this task perfectly; 8 or fewer is considered abnormal.

#### Processing of facial information

*Labelling of Emotional Facial Expression.*<sup>1</sup> The test comprised 24 photographs showing four different individuals each displaying six facial expressions (anger, disgust, fear, happiness, sadness, and surprise), extracted from a set developed by Ekman and Friesen (1975); the selected faces

<sup>1</sup> We thank Andrew Young for supplying this test.

included those which were best-recognised in their original study. Each face was presented one at a time above a list of the names for the six possible expressions, and the participant was required to indicate which label best described the depicted expression. The score was the number of faces for which the correct response was given (maximum = 24).

### Face recognition

*Unfamiliar Face Matching.* The short version of the Test of Facial Recognition (Benton, Hamsher, Varney, & Spreen, 1983; Benton, Van Allen, Hamsher & Levin, 1975) was used. This requires participants to match views of similar unfamiliar faces across views that differ in orientation or lighting. There are 27 items, but the total correct is doubled in order to convert scores to those obtained from the long version of the test. Scores of 37 or 38 are considered “moderately impaired” and scores below 37 “severely impaired”.

*The NHNN Face Matching Test* was an abbreviated (12 item) version of a 20-item test originally described by Warrington and James (1988) at the National Hospital for Neurology and Neurosurgery (NHNN) in London. Participants are shown pairs of black-and-white photographs of the faces of female nursing staff. Half of the pairs comprise two different faces of the same person, and half comprise two pictures of different but similar-looking people. In every case the two faces are photographed from slightly different angles. All non-facial cues for matching (e.g., hairstyle) are kept to a minimum. There are no external paraphernalia (e.g., uniform differences, jewellery) to aid matching. Participants are required to identify in each case whether the two faces are of the same or different people. Warrington and James (1988) found a sample of normal controls to score 75% correct.

*Warrington Recognition Memory Test—Faces* (Warrington, 1984). In this widely used clinical test, participants are presented sequentially with 50 previously unseen faces of men, varying in age, for 3 seconds each. As with the Words version of this test, described above, they are required to indicate whether each one is pleasant or unpleasant. Following the study phase, they are presented with pairs of faces, each comprising one of the previously seen (“target”) stimuli and a distractor. They are required to select (guessing if necessary) the one they have previously seen. The score is the total number correct. The mean score for healthy adults aged 40–54 is 44.3 ( $SD = 3.5$ ).

*Face Recognition from the RBMT* (Wilson et al., 1991). The participant is shown five faces, one at a time, for five seconds each. After a filled delay, s/he is presented with these five target faces interposed with five

distractors and has to identify whether or not s/he has seen each before. The test is scored by subtracting the number of false positives from the number correct; maximum score is 5. Most healthy adults perform this task perfectly; a score below 5 is abnormal.

*NHNN Famous Faces.* This unpublished instrument was based on a clinical test developed at the NHNN by Elizabeth Warrington. Patients are shown a set of 13 black-and-white photographs of well-known people, including two television celebrities, two members of the British royal family, four senior members of the ruling UK political party, the previous prime minister, the leaders of the two main UK opposition political parties, and the present and previous US presidents; the precise faces are changed periodically so that they are always contemporary. The patient is asked to identify each face, and their response is scored correct if it provides either the name or sufficient biographical detail to demonstrate that there has been accurate identification. Maximum score is 13.

*Famous Face identification* (Valentine, unpublished). Participants were shown 24 black-and-white photographs of celebrities, primarily film-stars, singers, actors and TV personalities but including also a small number of high-profile politicians and were asked to name them. This test consists mainly of celebrities from popular culture, and therefore includes a different and more diverse range of individuals than those included in the NHNN Famous Face Test. For this reason scores on the two tests of famous face recognition may tend to diverge for some patients who are more familiar with one or other of the sample of famous faces tested. The score was the number correctly named.

*Face Learning Test (FLT).* This was designed specifically for the present study as a test with greater ecological validity than some of those described above in that it assesses recognition of formerly unknown faces after repeated presentations, and uses recognition stimuli which differ in facial expression from those presented during the learning phase.

The stimuli comprised 10 black-and-white photographs of the faces of young Caucasian women, all wearing near-identical blouses and with their hair pulled back off their faces. In all cases the pose was directly facing the camera, and the expression was non-smiling. Each presentation was for approximately 3 seconds. After the 10 faces had been presented in sequence once, the whole sequence was re-presented four more times in immediate succession so that ultimately each face had been studied five times and for a total of approximately 15 seconds. Participants were instructed to study them carefully as they would be tested for recognition after the study phase.

In the test phase, the same 10 faces were presented one at a time, randomly intermixed with a set of 10 distractor faces with the same general physical characteristics as those of the target faces. The pictures presented during the test phase differed from those used for the learning phase in respect to facial expression, which (for all faces) was now smiling. This difference was intended to approximate the reality of face recognition, where the visual stimulus is not invariant and so cannot be recognised simply on the basis of exact pattern matching. The respondent was required to indicate (yes/no) whether or not s/he had previously seen each face as it was presented in turn. Total number of correct responses (out of 20) was recorded.

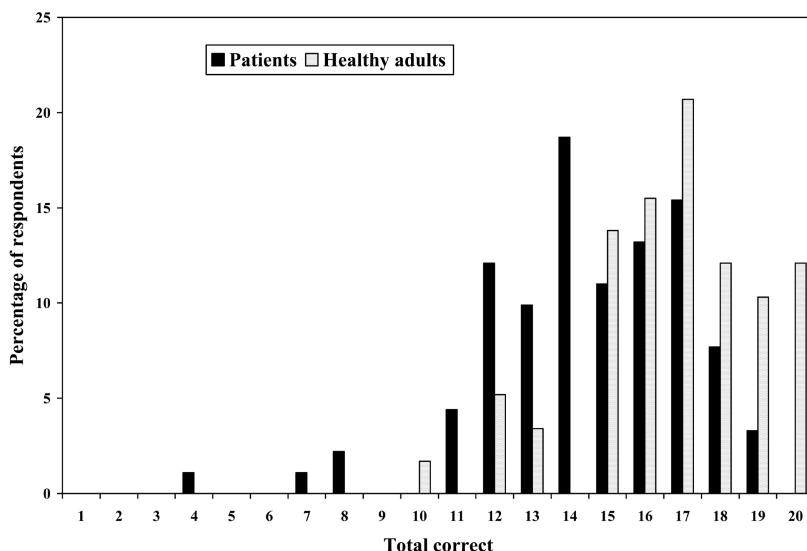
Two alternate forms of the FLT were developed, comprising non-overlapping sets of target and distractor faces. The two forms provided equivalent tests for pre- and post-treatment testing in our subsequent treatment trial (described in a separate paper), allowing no face to be repeated during testing before and after treatment. This procedure avoids familiarity with individual faces becoming confounded with the pre- to post-treatment comparison. Within the present sample, 65 participants received Form 1 and 26 received Form 2; mean scores on the two forms were 14.7 ( $SD = 2.8$ ) and 14.0 ( $SD = 2.5$ ), and did not differ significantly ( $t_{89} = 1.1$ , *ns*). The combined mean was 14.5 ( $SD = 2.7$ , range 4–19). When one outlier with a below chance score of 4 was excluded, the combined mean was 14.6 ( $SD = 2.5$ ).

In a control sample of 55 healthy volunteers, aged between 19 and 73 years ( $mean = 37.3$ ,  $SD = 15.5$ ), of whom 42 received Form 1 (16.6, 2.5) and 13 received Form 2 (17.0, 1.4), the means for the two forms were likewise very similar (16.6,  $SD = 2.5$ , and 17.0,  $SD = 1.4$ , respectively;  $t_{53} < 1$ , *ns*). The combined mean for the healthy volunteers was 16.7 ( $SD = 2.3$ , range 10–20).

Figure 2 shows the distributions of scores for brain-injured and healthy participants' first assessment.

It is clear from inspection of Figure 2 that while scores in both groups follow an approximately normal distribution, the curve is shifted to the right for the healthy participants with a slight skew to the top end and 13% scoring at ceiling. By contrast, none of the brain-injured patients scored at ceiling and about 20% scored within or below chance level (12 or below). *T*-test confirmed that the scores for the two groups differed highly significantly ( $t_{143} = 5.1$ ,  $p < .001$ ).

*Rating of difficulties with face recognition in daily life.* Participants were asked to rate their ability to recognise (1) family members, (2) longstanding friends, (3) acquaintances, and (4) famous people, using a 5 point scale (0 = would definitely not be able to; 5 = definitely be able to) for each. The maximum possible score of 20 would therefore indicate no problems.



**Figure 2.** Face Learning Test—Distribution of scores for patients and healthy volunteers.

Where a carer or relative was available, they were also asked to rate the patients' recognition of these classes of face, using the same rating scale.

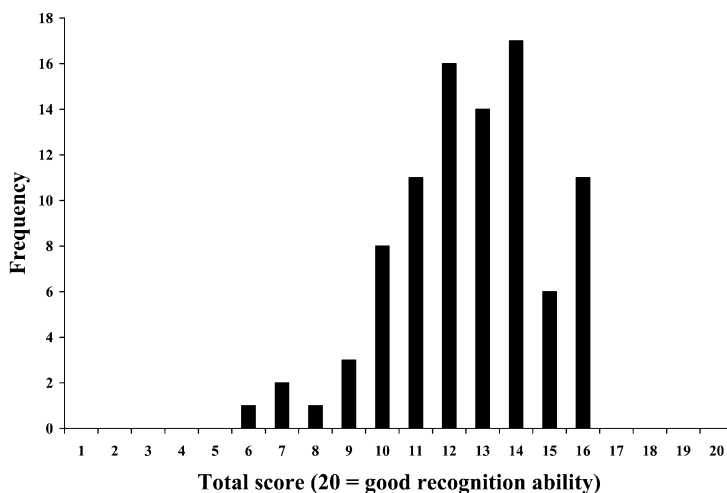
Mean score in the 91 brain-injured participants was 12.6 ( $SD = 2.3$ , range 6–16), and scores followed an approximately normal distribution although with a slight skew to the right (Figure 3). For the 82 participants for whom carer ratings were available, the carer ratings of their recognition abilities were very similar to those given by the patients ( $x = 12.1$ ,  $SD = 2.6$ ;  $t_{81} = 1.7$ ,  $ns$ ;  $r = .44$ ,  $p < .001$ ).

No data have yet been collected on this measure in healthy volunteers; however, the main purpose of including this index was to explore relationships between performance on objective tests and perceived difficulties.

## RESULTS

### Descriptive statistics

Table 1 gives means, standard deviations, and minimum and maximum scores, for all of the cognitive assessment variables with the exception of the tests used for exclusion purposes (Shape Detection, Object Decision and Fragmented Letters from the VOSP; Efron Squares; Usual Views). Where available the means, standard deviations, and minimum and maximum scores of a healthy adult sample is included.



**Figure 3.** Distribution of subjective self-ratings by patients of their face recognition difficulties in daily life. A score of 20 denotes no difficulties.

Scores on most tests were approximately normally distributed, with the exception of letter cancellation, position discrimination, and RBMT picture recognition on which there were pronounced ceiling effects (i.e., the majority of participants showed no impairment).

### Prevalence of face recognition impairments

For each of the face recognition/learning tests on which normative data were available, the proportions of the brain-injured sample scoring more than 1 and 2 SD below the population norm are shown in Table 2 below.

It is apparent from inspection of Table 2 that the tests are differentially sensitive to impairment in the brain-injured group, with the Warrington Recognition Memory Test for Faces being the most sensitive and the RBMT Faces test the least. However, even the least sensitive test is detecting impairment in no less than one in five brain-injured patients. Reasons for the discrepancies between tests, and the implications of the present data, are considered in the discussion section.

With respect to patients' ratings of their own difficulties in recognising people in daily life, while most felt they would "very likely" or "definitely" recognise family members ( $n = 88$ ; 98%), longstanding friends ( $n = 81$ ; 90%), and someone famous people ( $n = 79$ ; 77%), only about half felt this degree of confidence about recognising someone they had met only a few times ( $n = 47$ ; 52%). Twenty-one (23%) felt they would be unlikely, or

TABLE 1  
Scores of sample on cognitive tests

|  | <i>Patient sample</i> |                  |              | <i>Healthy adult performance</i>          |
|--|-----------------------|------------------|--------------|---|
|  | <i>n</i>              | <i>Mean (SD)</i> | <i>Range</i> |   |
| General cognitive functioning                        |                       |                  |              |   |
| Ravens CPM   | 91                    | 28.0 (6.8)       | 10–36        | Close to ceiling (max = 36)               |
| Similarities   | 91                    | 17.1 (6.5)       | 0–27         | Average range: <sup>a</sup> 19–28         |
| Cognitive Estimates                                  | 91                    | 7.9 (4.2)        | 1–28         | $\bar{x} = 3.6, SD = 1.2$                 |
| Verbal Fluency                                       | 91                    | 20.9 (10.1)      | 5–53         | Average range: <sup>a</sup> 31–44         |
| Digit Span   | 91                    | 13.2 (4.3)       | 3–25         | Average range: <sup>a</sup> 14–20         |
| Oldfield Naming                                      | 91                    | 25.1 (4.8)       | 2–30         |   |
| Position discrimination                              | 91                    | 18.6 (2.2)       | 8–20         | Most score max. 20                        |
| Unusual Views  | 91                    | 19.3 (4.2)       | 5–24         | 13 = min of 95% c.i.                      |
| Letter cancellation (RBIT)                           | 91                    | 36.7 (5.8)       | 8–40         |   |
| Story Recall (immediate; RBMT)                       | 91                    | 5.5 (2.9)        | 0–13         |   |
| Warrington RMT–Words                                 | 91                    | 39.5 (7.7)       | 20–50        | $\bar{x} = 45.3, SD = 3.4$                |
| Picture recognition (RBMT)                           | 91                    | 8.9 (2.3)        | 0–10         | Most score max. 10                        |
| Labelling of Emotional Expression                    | 91                    | 18.1 (3.2)       | 9–23         |   |
| Face recognition/learning                            |                       |                  |              |   |
| Benton Unfamiliar Face Matching                      | 91                    | 41.0 (6.0)       | 27–52        | 39 or above                               |
| NHNN Unfamiliar Faces                                | 91                    | 9.7 (1.8)        | 5–12         | 9   |
| RBMT faces subtest                                   | 91                    | 4.6 (1.9)        | 0–5          | Most score max. 5                         |
| Warrington RMT–Faces                                 | 91                    | 33.5 (5.4)       | 20–45        | $\bar{x} = 44.3, SD = 3.5$                |
| NHNN Famous Faces test                               | 91                    | 7.9 (3.2)        | 0–13         |   |
| Valentine Famous Faces test                          | 91                    | 14.0 (5.9)       | 0–24         |   |
| Face Learning Test                                   | 91                    | 14.5 (2.7)       | 4–19         | $\bar{x} = 16.7, SD = 2.3$<br>Range 10–20 |
| Patients' ratings of face recognition in daily life  | 90                    | 12.6 (2.3)       | 6–16         | –   |
| Relatives' ratings of face recognition in daily life | 75                    | 12.1 (2.5)       | 5–16         | –   |

<sup>a</sup> These average ranges refer to 25th and 75th percentiles for raw scores achieved by healthy adults; for Similarities and Digit Span these refer to the 35–44 age band (mean age of present sample = 41 years)

TABLE 2  
Prevalence of abnormal performance on three tests of face recognition

| <i>Measure</i>                                 | <i>% of patients scoring 1 SD or more below mean for healthy adults,</i> | <i>% of patients scoring 2 or more SD below mean for healthy adults, or below cut-off in test manual</i> |
|--|--|--|
| Recognition Memory Test for Faces (Warrington) | 93.4   | 76.9   |
| Learning New Faces Test                        | 49.5   | 20.9   |
| Faces test from the RBMT                       |  | 19.8   |

definitely unable, to recognise such people. The frequencies which carers estimated patients would have difficulties with each category of person were very similar to their own ratings.

### Inter-relationships between different indices of face recognition impairment

Table 3 shows the correlations between the various face recognition/learning indices.

The highest correlation is between the most similar pair of tests—those of famous face recognition—notwithstanding differences in the sample of famous faces included. However, there are moderate correlations between most of the cognitive tests, and it is noteworthy that the tests of face perception (Benton et al.'s, 1983, Test of Facial Recognition and the Emotional Expression test) predict between 20% and 25% of the variance in the Face Learning Test. Interestingly, patients' ratings of their recognition problems in daily life are more strongly correlated with the tests of face recognition than are their carers' ratings.

In order to explore the inter-relationships between face recognition problems and other aspects of cognitive functioning as economically as possible, scores on these two sets of indices were subjected, separately, to principal components analysis. This yielded a smaller number of broad dimensions of function within each area, and the extent to which face recognition ability was predicted by more general cognitive abilities was then explored using a combination of simple correlational and multiple regression analyses.

#### Principal components analysis of face recognition/learning indices

Inspection of the scree plot suggested a three component solution (eigenvalues 3.4, 1.3, and 1.1). Following varimax rotation,<sup>2</sup> the components accounted for 25.6%, 22% and 17.7% of the variance; Table 4 shows all of the measures with loadings of 0.40 or higher on each component.

Component 1 is most strongly defined by the two tests of famous face identification (both with loadings in excess of 0.8), but also by two tests requiring recognition of previously unfamiliar faces in which the training and test stimuli are identical to one another (i.e., no alterations of expression, orientation, or other aspects of appearance). By contrast, all of the measures with loadings in excess of 0.50 on Component 2 entail matching or recognising faces when the stimuli to be compared differ in expression or angle of view. We suggest that this may be the critical distinction between the two components: the measures in the first component reflect face identification, that is, the ability to identify the face of a specific individual; while those

<sup>2</sup> N.B. oblique rotations produced nearly identical factor structures.

TABLE 3  
Correlations between different indices of facial perception, learning, and recognition

|   | (1)                  | (2)                | (3)                            | (4)            | (5)              | (6)                | (7)               | (8)                    | (9)               | (10)               |
|---|----------------------|--------------------|--------------------------------|----------------|------------------|--------------------|-------------------|------------------------|-------------------|--------------------|
|   | Benton face Matching | NHNN Face matching | Labelling emotional expression | RBMT Faces     | Warrington Faces | Face Learning Test | NHNN Famous Faces | Valentine Famous Faces | Patients' ratings | Relatives' ratings |
| Face perception   |                      |                    |                                |                |                  |                    |                   |                        |                   |                    |
| Benton Unfamiliar Face Matching                             | –                    | <b>0.35***</b>     | <b>0.51***</b>                 | <b>0.37***</b> | <b>0.34***</b>   | <b>0.49***</b>     | <b>0.21*</b>      | <b>0.30**</b>          | <b>0.35***</b>    | <b>0.27*</b>       |
| NHNN Unfamiliar Face Matching                               |                      | –                  | <b>0.43***</b>                 | <b>0.27**</b>  | <b>0.41***</b>   | <b>0.41***</b>     | <b>0.26*</b>      | <b>0.21*</b>           | <b>0.23*</b>      | 0.09               |
| Labelling emotional expression                              |                      |                    | –                              | <b>0.22*</b>   | <b>0.49***</b>   | <b>0.47***</b>     | <b>0.32**</b>     | <b>0.29**</b>          | 0.06              | 0.05               |
| Face recognition/learning                                   |                      |                    |                                |                |                  |                    |                   |                        |                   |                    |
| RBMT faces subtest  |                      |                    |                                | –              | <b>0.34***</b>   | <b>0.27**</b>      | <b>0.42***</b>    | <b>0.43***</b>         | <b>0.28**</b>     | <b>0.24**</b>      |
| Warrington RMT – Faces                                      |                      |                    |                                |                | –                | <b>0.42***</b>     | <b>0.42***</b>    | <b>0.32**</b>          | <b>0.25*</b>      | 0.06               |
| Face Learning Test  |                      |                    |                                |                |                  | –                  | 0.15              | <b>0.23*</b>           | <b>0.32***</b>    | 0.16               |
| Famous face identification                                  |                      |                    |                                |                |                  |                    |                   |                        |                   |                    |
| NHNN Famous Faces test                                      |                      |                    |                                |                |                  |                    |                   | <b>0.65***</b>         | 0.15              | 0.14               |
| Famous Faces test (Valentine)                               |                      |                    |                                |                |                  |                    |                   | –                      | 0.05              | 0.16               |
| Subjective difficulties with face recognition in daily life |                      |                    |                                |                |                  |                    |                   |                        |                   |                    |
| Patients' ratings   |                      |                    |                                |                |                  |                    |                   |                        | –                 | <b>0.44***</b>     |
| Relatives' ratings  |                      |                    |                                |                |                  |                    |                   |                        |                   | –                  |

\* $p < .05$ ; \*\* $p < .005$ ; \*\*\* $p < .001$  (2-tailed significance)

TABLE 4  
Principal components analysis of measures of face matching/recognition: Items with loadings >0.40 on each component

| <i>Component 1 Face Identification</i> |      | <i>Component 2 Directed Facial Processing</i> |      | <i>Component 3 Subjective Face Recognition</i>    |      |
|--|------|---|------|---|------|
| Famous Faces (NHNN)                    | 0.87 | Learning New Faces                            | 0.84 | Carer ratings of patient's problems in daily life | 0.84 |
| Famous Faces (Valentine)               | 0.82 | NHNN Unfamiliar Face Matching                 | 0.71 | Patient ratings of own problems in daily life     | 0.77 |
| RBMT Face Recognition                  | 0.65 | Benton Unfamiliar Face Matching               | 0.65 |   |      |
| Warrington Face Recognition            | 0.57 | Warrington Face Recognition                   | 0.47 |   |      |

in the second component test the ability to learn, by directed visual processing, structural commonalties between different views of the same face. This second factor is more associated with learning and differentiating between previously unfamiliar faces. We have therefore tentatively labelled the two components "*Face Identification*" and "*Directed Facial Processing*", respectively. We use the term "Directed Facial Processing" to denote the similarity of Component 2 with "Directed Visual Processing" identified by Bruce and Young (1986), but emphasise that the component reflects facial processing rather than more generic visual processes (as Bruce and Young intended). Despite the orthogonality of the components, however, it is notable that the Warrington Face Recognition test cross-loads to a moderate degree on both components. Carers' and patients' own ratings of the difficulties that patients have in recognising faces in daily life were the only two variables to load strongly on Component 3, and this has therefore been labelled "*Subjective Face Recognition*".

For purposes of subsequent correlational analysis, scores on these three components were calculated using the regression method. This has the consequence that scores (on all three components) are available for only 75 of the participants, since carer ratings were not available for 16 participants.

#### Principal components analysis of other cognitive functions

The scree plot suggested a four component solution, the components having eigenvalues of 5.3, 1.5, 1.1, and 1.0; following varimax rotation they accounted for 23.6%, 22.9%, 12.1%, and 10.4% of the variance, respectively. Table 5 shows all of the items loading at 0.40 or higher on each component.

The first component is defined by the Labelling of Emotional Expression, Raven's CPM, Position Discrimination, Letter Cancellation, and Unusual

TABLE 5  
Principal components analysis of cognitive tests *not* involving face matching/recognition: Items with loadings > 0.40 on each component

| <i>Component 1:<br/>Visual Processes</i> | <i>Component 2:<br/>Verbal Processes</i> | <i>Component 3:<br/>Recognition Memory</i> | <i>Component 4:<br/>Cognitive Estimates</i> |
|--|--|--|---|
| Labelling of Emotional Expression        | 0.79                                     | 0.77                                       | 0.89  |
| Ravens Coloured Progressive Matrices     | 0.78                                     | 0.74                                       | 0.66  |
| Position Discrimination (VOSP)           | 0.77                                     |  |   |
| Letter Cancellation (RBIT)               | 0.72                                     |  |   |
| Unusual Views                            | 0.55                                     |  |   |
|  |  | Picture recognition (RBMT)                 | Cognitive Estimates                         |
|  |  | Word recognition (Warrington)              |   |
|  |  |  | -0.87                                       |

Views tests; their most obvious common characteristic is the involvement of visuospatial processing, and the component has therefore been labelled “*Visual Processes*”. Component 2 comprises four tests of verbal reasoning and recall (Similarities, Oldfield Naming, Verbal Fluency, and Story Recall from the RBMT) and is consequently designated “*Verbal Processes*”; Component 3, labelled “*Recognition Memory*”, is defined by the picture recognition subtest from the RBMT and the Warrington test of recognition memory for words. Only one item loads strongly on Component 4, and it is therefore referred to by the name of that item—“*Cognitive Estimates*”. Factor scores were again computed using the regression method.

#### Relationships between face recognition and other cognitive indices

Table 6 shows the correlations of the three face recognition component scores (for the 75 participants with complete data), and also the scores on individual face recognition/learning measures (for all 91 participants), with the four cognitive component scores. Bonferroni corrections were applied to correct for multiple comparisons within families of statistical tests. The first family comprised the 12 correlations between the three face recognition component scores and the four cognitive component scores. The next family of tests comprised the 36 correlations of the nine individual face recognition/learning scores with the four cognitive component scores.

Scrutiny of Table 6 shows clearly different patterns of association between the different face recognition components and the cognitive measures. Thus, Directed Facial Processing is strongly predicted by both Visual Processes and

TABLE 6  
Correlations between indices of face matching/learning and “other” cognitive functions

|  | <i>Visual Processes</i> | <i>Verbal Processes</i> | <i>Recognition Memory</i> | <i>Estimation</i> |
|--|-------------------------|-------------------------|---------------------------|-------------------|
| Directed Facial Processing ( $n = 75$ )      | <b>0.59**</b>           | 0.20 <i>ns</i>          | <b>0.43**</b>             | -0.14 <i>ns</i>   |
| Benton Unfamiliar Face Matching ( $n = 91$ ) | <b>0.54**</b>           | 0.24 <i>ns</i>          | 0.20 <i>ns</i>            | 0.08 <i>ns</i>    |
| Face Learning Test ( $n = 91$ )              | <b>0.36*</b>            | 0.15 <i>ns</i>          | <b>0.36*</b>              | -0.14 <i>ns</i>   |
| NHNN Unfamiliar Face Matching ( $n = 91$ )   | <b>0.47**</b>           | 0.15 <i>ns</i>          | 0.27 <i>ns</i>            | 0.13 <i>ns</i>    |
| Face Identification ( $n = 75$ )             | 0.22 <i>ns</i>          | <b>0.31*</b>            | -0.02 <i>ns</i>           | 0.16 <i>ns</i>    |
| NHNN Famous Faces test ( $n = 91$ )          | 0.19 <i>ns</i>          | <b>0.43**</b>           | 0.03 <i>ns</i>            | 0.11 <i>ns</i>    |
| Valentine Famous Faces test ( $n = 91$ )     | 0.24 <i>ns</i>          | 0.29 <i>ns</i>          | 0.17 <i>ns</i>            | -0.06 <i>ns</i>   |
| RBMT faces subtest ( $n = 91$ )              | 0.23 <i>ns</i>          | 0.27 <i>ns</i>          | 0.05 <i>ns</i>            | 0.04 <i>ns</i>    |
| Warrington RMT – Faces ( $n = 91$ )          | <b>0.38*</b>            | 0.13 <i>ns</i>          | 0.26 <i>ns</i>            | 0.08 <i>ns</i>    |
| Subjective Face Recognition ( $n = 75$ )     | 0.00 <i>ns</i>          | 0.24 <i>ns</i>          | 0.06 <i>ns</i>            | 0.01 <i>ns</i>    |
| Patients’ ratings ( $n = 90$ )               | 0.05 <i>ns</i>          | 0.24 <i>ns</i>          | 0.18 <i>ns</i>            | 0.07 <i>ns</i>    |
| Relatives’ ratings ( $n = 75$ )              | 0.09 <i>ns</i>          | 0.28 <i>ns</i>          | 0.12 <i>ns</i>            | -0.03 <i>ns</i>   |

\* $p < .05$ ; \*\* $p < .01$  (One-tailed, Bonferroni corrected)

Recognition Memory, but not by Verbal Processes; by contrast, this pattern is almost exactly reversed for Face Identification, which is significantly related only to Verbal Processes. Subjective Face Recognition, interestingly, is uncorrelated with any of the cognitive components.

The patterns of relationships shown by the three face recognition components are generally closely reflected in those shown by their most highly loading items, although some of the individual item correlations fall short of significance. The exception is the Warrington Face Recognition Test, whose pattern of correlations more closely resembles that of the Directed Facial Processing than the Face Identification measures. To some extent this reflects differences in the samples on which individual test scores and the component scores were available ( $N_s = 91$  and  $75$ , respectively); thus, Warrington scores for the smaller group of  $75$  participants correlated significantly with Verbal Processes as well as Visual Processes and Recognition Memory ( $r = 0.37, 0.24,$  and  $0.30$ ; all significant at  $p < .05$ ).

Given the orthogonality of the derived principal component scores, it was anticipated that any variance in each of the three "domains" of face recognition explained by the four cognitive domains would be additive. This was confirmed using forced entry multiple regression which included as predictors any of the cognitive domains which had shown a significant or nearly significant simple correlation with the face recognition variable. Thus over half of the variance in Directed Facial Processing was predicted by the combination of Visual Processes, Verbal Processes and Recognition Memory, adjusted  $R^2 = 0.52, F(3,71) = 27.6; p < .001$ .

## DISCUSSION

It is clear from these data that it is very common for people with brain injury severe enough to necessitate admission to a rehabilitation unit to have some difficulty with face recognition. Indeed,  $50\%$  of patients and their carers considered that although the patients would not have difficulty with well-known people (family, longstanding friends or famous people) they would be unlikely to recognise people they had met just a few times. While the base rate of such self-reported difficulties is unknown, so that these self-reports must be considered tentatively, more importantly a number of formal tests on which normative data are available likewise detected a high prevalence of impairment.

The sensitivity of the formal tests varied, presumably reflecting either the involvement of different component processes in different tests or a general "difficulty" factor, with the deficits of brain-injured patients being more influential when the demands of the test are greater. Thus, on Warrington's (1984) Recognition Memory Test, in which a large number of "new" faces are shown

only once prior to testing, 77% scored two or more standard deviations below the population mean, while on tests involving either far fewer faces (RBMT, Wilson et al., 1991) or fewer faces and multiple presentations (the Face Learning Test) only about 20% showed such marked impairment.

Statistical exploration of the inter-relationships between scores on the nine face recognition measures used here, and of their relationships with a range of other cognitive tests, supported the view that the cognitive processes tapped by different tests of face recognition are at least partially separate. Principal components analysis of the face recognition tests suggested that they could be characterised along three orthogonal dimensions. Thus two of the components, Face Identification and Directed Facial Processing, are associated with separable processes involved in recognising and identifying faces. The third component (Subjective Face Recognition) is loaded on by patient and carer ratings of the patients' difficulty with recognising faces in daily life.

The Face Identification component is most closely associated with the two tests of famous face identification. Both tests require familiar faces to be named. This component appears to reflect the identity-processing route of the Bruce and Young (1986) model (Figure 1), which proceeds via Face Recognition Units and Person Identity Nodes to Name Generation. However, the Face Identification component also receives loadings from two tests of recognition of previously unfamiliar faces, albeit with smaller coefficients than the tests of famous face recognition. We return to this issue later.

Of the four cognitive domains emerging from a separate principal components analysis of tests other than those of facial recognition, the strongest predictor of Face Identification, accounting for 9% of the variance, was the Verbal Processes component (defined by scores on tests of similarities, naming, fluency, story recall, and digit span). This relationship could reflect the involvement of linguistic factors in both the non-face cognitive tests and the two tests of famous face recognition, where faces had to be explicitly named. However, somewhat contradicting this explanation, the RBMT Face Recognition Test—which does not require naming—also showed a near-significant correlation with Verbal Processes. The lack of any hint of a relationship between Face Identification and the Recognition Memory component, which comprises non-facial recognition tests (pictures and words), is consistent with the view that identification and recognition memory are separable processes. Identification is the ability to understand the meaning of a word or recall identifying information about a celebrity, whereas recognition memory is a judgement that an item has occurred before in a specific test (cf. the distinction between semantic memory and episodic memory).

The second component, which we have called Directed Facial Processing, is associated with recognition memory for previously unfamiliar faces from a new picture (i.e., the Learning New Faces test) and with matching unfamiliar

faces across different views. We suggest that good performance on these face recognition tests reflects utilisation of a more effortful strategy where selective attention is used to examine specific aspects and parts of faces to attempt to discriminate between similar faces. This strategy will be especially important in matching faces across different views (as in the Benton and NHNN Face Matching tasks), or when faces to be remembered are presented several times during the learning phase.

Scores on the Directed Facial Processing component were strongly predicted by cognitive tests tapping Visual Processes and Recognition Memory: These two cognitive domains jointly accounted for over 50% of its variance, while there was no correlation with the Verbal Processes component. This pattern is the converse of that seen for Face Identification. We suggest that the association with Visual Processes reflects the visuospatial analysis involved in both sets of tasks, but we note that the association with Recognition Memory reflects a significant correlation with the Learning New Faces Test and not with the two face matching tests (see Table 6). This is unsurprising, given that the other two tasks loading onto Directed Facial Processing are both simultaneous face matching tasks which do not require memory.

Bruce and Young (1986) did not articulate clearly how representations of new faces (FRUs) are formed, but suggested that directed visual processing may be used in the early stages of learning new faces. As faces are learnt, the external features (e.g., hairline) become less salient and the internal features become more salient (Ellis, Shepherd, & Davies, 1979). This change in processing may reflect a shift from use of the Directed Facial Processing component to greater reliance on the Face Identification component. It is interesting to note that this trend is seen in naming tasks but not in tasks that require two different views of familiar faces to be matched (Young et al., 1985). The two components of face processing that we have identified may also reflect task differences: Predominantly naming tasks load on to Face Identification while predominantly matching tasks load onto Directed Facial Processing. The distinctions between familiar/unfamiliar face processing and naming/matching are difficult to tease apart. It is not possible to name unfamiliar faces, and we did not include any tests of matching famous faces across different views.

We now return to the question of why the Warrington Face Recognition Test loads on to both components. The Warrington is a difficult test with a large number of items (25 targets, 25 distractors) presented briefly, only once, and for just a few seconds each. Recognition is tested with an identical picture of the targets at test. Performance in the Warrington Faces Test may load onto both components because recognition may be achieved by use of an identification strategy based on holistic processing for some items, which would be facilitated by use of the identical picture at test, and directed facial processing to identify a characteristic feature for other items.

The independence of the Facial Identification and Directed Facial Processing components can account for the observation that prosopagnosic patients may perform within the normal range on the Benton face matching task, although they often take a long time and a great deal of effort to make their decisions (Newcombe, 1979; Nunn, Posta, & Pearson, 2001; Shuttlesworth, Syring, & Van Allen, 1982). Furthermore, the orthogonality between the two components is consistent with the observation that the ability to identify familiar (famous) faces is not associated with, and can dissociate from, the ability to distinguish between never-seen faces and previously unfamiliar faces which have been studied only in the context of a recognition memory experiment (Benton, 1980; Malone et al., 1982; Warrington & James, 1967).

Evidence suggests that holistic processing is characteristic of skilled performance in recognising faces (Tanaka & Farah, 2003). Furthermore, there is evidence that the ability to process faces holistically is impaired in prosopagnosic patients (Farah, Wilson, Drain, & Tanaka, 1995). This holistic style of processing may be associated with the Face Identification component identified in the present study. If the ability to process holistic information is impaired, as it appears to be in prosopagnosic patients and possibly in some of the patients in our sample, then patients may have to rely on different, but less effective strategies to attempt to recognise faces. This reasoning is consistent with self-report of some prosopagnosic patients who report that they resort to a part-based strategy to recognise faces (Davidoff, Matthews & Newcombe, 1986; Ellis & Florence, 1990). Such a part-based face recognition strategy may be the result of relying on Directed Facial Processing to recognise familiar faces due to impaired Face Identification.

It is interesting to note that, despite the double dissociation between familiar face recognition and recognition of facial expression reported in the prosopagnosia literature (e.g., Etcoff, 1985), performance in labelling facial expression correlates strongly with test of unfamiliar face matching and recognition. This result is consistent with the observation that many prosopagnosic patients also show impairment to recognition of facial expression (Davidoff & Landis, 1990).

The third component, Subjective Recognition, reflected patients' and their carers' ratings of patients' perceived difficulty in recognising faces in daily life. This failed to correlate significantly with any of the cognitive components, although there was a weak (non-significant) trend towards an association with verbal processes, perhaps suggesting that everyday difficulties are subjectively more strongly associated with problems in putting names to faces rather than with impairments of recognition per se. However, this failure to find any substantive relationship between subjective and objective indices replicates similar observations made over the last decade in relation to other aspects of cognitive and memory functions after brain injury. There are

many such reports of dissociation or very weak association (e.g., Lannoo et al., 1998; Maor, Olmer, & Mozes, 2001), and there is some empirical indication that low mood and stress may be stronger influences than objective impairment on perceptions of difficulty (e.g., Elixhauser et al., 1999; Mahoney, Dalby, & King, 1998; Maor et al., 2001). Alternatively, of course, lack of insight or impaired reasoning may render self-appraisals inaccurate (Sunderland, Stewart, & Sluman, 1996).

Finally, there are some implications for clinical practice and rehabilitation. The generally modest correlations between individual tests of face recognition (see Table 3) and the finding that tests show differential sensitivity to impairment in a population of patients with brain injury of mixed and often diffuse aetiology must reflect marked variations in their underlying cognitive operations. The likelihood of detecting a face recognition impairment in someone with brain injury therefore clearly depends on the particular test which is used. From a functional perspective we suggest that the most useful instruments for determining whether an individual is likely to have difficulty with recognition in real life are likely to be those, such as the Face Learning Test developed here, which utilise stimuli and training conditions that more closely approximate conditions in the patients' daily life which they find difficult. That is, learning new faces from a few exposures, which need to be recognised in varying poses. More sensitive tests, such as the Warrington, may be of limited relevance to functional abilities if someone is slow to learn to recognise a face and thus fails to do so after a single presentation but nevertheless may succeed in doing so within a few exposures. For rehabilitation, the abilities both to recognise faces as familiar, and to put names to these faces, are important to an individual's effective social functioning. If functionally significant impairments can be identified through an appropriate combination of face recognition/naming tests, rehabilitation strategies could focus on directing the individual patient to the most appropriate cognitive strategy. For example, verbally encoding particular facial features (Davidoff, 1988), or using caricatures to accentuate structural properties of to-be-learned faces (Rhodes, Brennan, & Carey, 1987; Valentine, 1991) may be selectively chosen to help overcome or compensate for a patient's specific impairment.

## REFERENCES

- Benton, A. L. (1980). The neuropsychology of face recognition. *American Psychologist*, *35*, 176–186.
- Benton, A. L., & Hamsher, K. DeS. (1989). *Multilingual Aphasia Examination*. Iowa City, Iowa: AJA Associates.
- Benton, A. L., Hamsher, K. de S., Varney N. R., & Spreen, O. (1983). *Contributions to neuropsychological assessment*. New York: Oxford University Press.

- Benton, A. L., Van Allen, M. W., Hamsher, K. de S., & Levin, H. S. (1975). *Test of Facial Recognition*. Department of Neurology: University of Iowa Hospitals.
- Bruce, V. (1982). Changing faces. Visual and nonvisual coding processes in face recognition. *British Journal of Psychology*, *73*, 105–116.
- Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology*, *77*, 305–327.
- Campbell, R., Landis, T., & Regard, M. (1986). Face recognition and lipreading: A neurological dissociation. *Brain*, *109*, 509–521.
- Davidoff, J. (1988). Prosopagnosia: A disorder of rapid spatial integration. In G. Denes, C. Semenza, & P. Bisiacchi (Eds.), *Perspectives on cognitive neuropsychology*. Hillsdale, NJ: Lawrence, Erlbaum Associates.
- Davidoff, J., & Landis, T. (1990). Recognition of unfamiliar faces in prosopagnosia. *Neuropsychologia*, *28*, 1143–1161.
- Davidoff, J., Matthews, W. B., & Newcombe, F. (1986). Observations on a case of prosopagnosia. In H. Ellis, M. Jeeves, F. Newcombe, & A. Young (Eds.), *Aspects of face processing*. Dordrecht: Martinus Nijhoff.
- Efron, R. (1968). What is perception? In R. Cohen & M. Wartofsky (Eds.), *Boston studies in the philosophy of science* (Vol 4). New York: Humanities Press.
- Ekman, P., & Friesen, W. V. (1975). *Pictures of facial affect*. Palo Alto, CA: Consulting Psychologists Press.
- Elixhauser, A., Leidy, N. K., Meador, K., Means, E., & Willian, M. K. (1999). The relationship between memory performance, perceived cognitive function, and mood in patients with epilepsy. *Epilepsy Research*, *37*, 13–24.
- Ellis, H. D., & Florence, M. (1990). Bodamer's (1947) paper on prosopagnosia. *Cognitive Neuropsychology*, *7*, 81–105.
- Ellis, H. D., Shepherd, J. W., & Davies, G. M. (1979). Identification of familiar and unfamiliar faces from the internal and external features: Some implications for theories of face recognition. *Perception*, *8*, 431–439.
- Etcoff, N. L. (1985). The neuropsychology of facial expression. In G. Goldstein & R. E. Tarter (Eds.), *Advances in clinical neuropsychology* (Vol 3). New York: Plenum.
- Farah, M. J., Wilson, K. D., Drain, H. M., & Tanaka, J. W. (1995). The inverted face inversion effect in prosopagnosia: Evidence for mandatory face-specific perceptual mechanisms. *Vision Research*, *35*, 2089–2093.
- Lannoo, E., Colardyn, F., Vandekerckhove, T., De Deyne, C., De Soete, G., & Jannes, C. (1998). Subjective complaints versus neuropsychological test performance after moderate to severe head injury. *Acta Neurochirurgica*, *140*, 245–253.
- Mahoney, A. M., Dalby, J. T., & King, M. C. (1998). Cognitive failures and stress. *Psychological Reports*, *82*, 1432–1434.
- Malone, D. R., Morris, H. H., Kay, M. C., & Levin, H. S. (1982). Prosopagnosia: A double dissociation between the recognition of familiar and unfamiliar faces. *Journal of Neurology, Neurosurgery and Psychiatry*, *45*, 820–822.
- Maor, Y., Olmer, L., & Mozes, B. (2001). The relation between objective and subjective in cognitive function among multiple sclerosis patients—the role of depression. *Multiple Sclerosis*, *7*, 131–135.
- Newcombe, F. (1979). The processing of visual information in prosopagnosia and acquired dyslexia: Functional versus physiological interpretation. In D. J. Osborne, M. M. Gruneberg, & J. R. Eiser (Eds.), *Research in psychology and medicine* (Vol 1). London: Academic Press.
- Nunn, J. A., Postma, P., & Pearson, R. (2001). Developmental prosopagnosia: Should it be taken at face value? *Neurocase*, *7*, 15–27.
- Oldfield, R. C., & Wingfield, A. (1965). Response latencies in naming objects. *Quarterly Journal of Experimental Psychology*, *17*, 273–281.

- Raven, J. C. (1965). *Guide to using the Coloured Progressive Matrices*. London: H.K. Lewis.
- Rhodes, G., Brennan, S., & Carey, S. (1987). Identification and ratings of caricatures: Implications for mental representations of faces. *Cognitive Psychology*, *19*, 473–497.
- Shallice, T., & Evans, M. E. (1978). The involvement of the frontal lobes in cognitive estimation. *Cortex*, *14*, 294–303.
- Shuttleworth, J. C., Syring, J., & Van Allen, N. (1982). Further observations on the nature of prosopagnosia. *Brain & Cognition*, *1*, 307–322.
- Sunderland, A., Stewart, F. M., & Sluman, S. M. (1996). Adaptation to cognitive deficit? An exploration of apparent dissociations between everyday memory and test performance late after stroke. *British Journal of Clinical Psychology*, *35*, 463–476.
- Tanaka, J. W., & Farah, M. J. (2003). The holistic representation of faces. In M. A. Peterson & G. Rhodes (Eds.), *Perception of faces, objects and scenes* (pp. 53–74). Oxford: Oxford University Press.
- Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion and race in face recognition. *Quarterly Journal of Experimental Psychology*, *43A*, 161–204.
- Warrington, E. K. (1984). *Recognition Memory Test*. Windsor, UK: NFER-Nelson.
- Warrington, E. K., & James, M. (1967). An experimental investigation of facial recognition in patients with unilateral cerebral lesions. *Cortex*, *3*, 317–326.
- Warrington, E. K., & James, M. (1988). Visual apperceptive agnosia: A clinico-anatomical study of three cases. *Cortex*, *24*, 13–32.
- Warrington, E. K., & James, M. (1991). *Visual object and space perception battery*. Bury St. Edmunds, UK: Thames Valley Test Co.
- Wechsler, D. (1987). *WAIS-R Manual*. New York: The Psychological Corporation.
- Wilson, B. A., Cockburn, J., & Baddeley, A. (1991). *The Rivermead Behavioural Memory Test*. Reading, UK: Thames Valley Test Co.
- Wilson, B. A., Cockburn, J., & Halligan, P. (1987). *Behavioural Inattention Test*. Titchfield, UK: Thames Valley Test Co.
- Young, A. W., Hay, D. C., McWeeny, K. H., Flude, B. M., & Ellis, A. W. (1985). Matching familiar and unfamiliar faces on internal and external features. *Perception*, *14*, 737–746.

Manuscript received July 2004

Revised manuscript received September 2004