# Disgust and fear recognition in paraneoplastic limbic encephalitis

Reiner Sprengelmeyer[1,2*], Anthony P. Atkinson[3], Anke Sprengelmeyer[1], Johanna Mair-Walther[2], Christian Jacobi[2], Brigitte Wildemann[2], Winand H. Dittrich[4], and Werner Hacke[2]

[1]School of Psychology, University of St. Andrews, Scotland, UK
[2]Department of Neurology, University of Heidelberg, Germany
[3]Department of Psychology, University of Durham, England, UK
[4]School of Psychology, University of Hertfordshire, England, UK

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**Correspondence to:** R. Sprengelmeyer
School of Psychology
University of St. Andrews
South Street
St. Andrews KY16 9JP
Scotland
E-mail: rhs3@st-andrews.ac.uk

***Abstract***

Paraneoplastic limbic encephalitis (PNLE) affects limbic portions of the brain associated with recognition of social signals of emotions. Yet it is not known whether this perceptual ability is impaired in individuals with PNLE. We therefore conducted a single case study to explore possible impairments in recognising facially, vocally, and bodily expressed emotions, using standardised emotion recognition tests. Facial expression recognition was tested with two forced-choice emotion-labelling tasks using static faces with either prototypical or morphed blends of basic emotions. Recognition of vocally and bodily expressed emotions was also tested with forced-choice labelling tasks, one based on prosodic cues, the other on whole-body movement cues. We found a deficit in fear and disgust recognition from both face and voice, while recognition of bodily expressed emotions was unaffected. These findings are consistent with data from previous studies demonstrating critical roles for certain brain regions – particularly the amygdala and insular cortex – in processing facially and vocally displayed basic emotions, and furthermore, suggest that recognition of bodily expressed emotions may not depend on neural structures involved in facial and vocal emotion recognition. Impaired facial and vocal emotion recognition may form a further neuropsychological marker of limbic encephalitis, in addition to the already well-described mnestic deficits.

## 1. INTRODUCTION

Paraneoplastic limbic encephalitis (PNLE) (Brierley et al., 1960) is a rare condition, in which antibodies produced to target tumor cells destroy the limbic portions of the central nervous system (Gultekin et al., 2000). In the majority of cases, mesiotemporal regions, but also the basal ganglia and insular cortex are affected (Vollmer et al., 1993). Clinical symptoms vary and may include psychiatric abnormalities (affective changes, hallucinations), personality changes, and cognitive deficits ranging from confusional states to more circumscribed deficits such as dyscalculia, apraxia and aphasia (Gultekin et al., 2000).

Neuropsychiatric descriptions have focussed mainly on memory deficits as the most salient neuropsychological marker of PNLE (Bak et al., 2001). However, neuropsychological research has shown that lesions to the amygdala can result in deficits in recognising facial and vocal expressions of fear, and that lesions to insular cortex and basal ganglia can result in deficits in recognising facial and vocal expressions of disgust (Calder et al., 2001). Since these regions are prominently affected in PNLE, deficits in emotion recognition should be evident in this disorder. Surprisingly, until now, there has been no study looking in more detail at emotion processing in PNLE. The current study therefore aimed to investigate the presence of recognition deficits for facially and vocally displayed basic emotions in limbic encephalitis using well-established and standardised neuropsychological procedures.

While lesions to the amygdala can impair recognition of facially and vocally expressed fear, there is some evidence that these lesions are not associated with impaired recognition of dynamic displays of bodily expressed fear (Atkinson et al., 2007a). It is not yet known whether an impaired ability to recognise facially and vocally displayed disgust is associated with impaired recognition of bodily expressions of disgust. A supplementary

aim of the current study was, therefore, to examine the ability of our PNLE patient to recognise bodily expressed emotions.

## 2. CASE REPORT

### *2.1. Clinical presentation and history*

Case H.N. is a 40-year-old university educated male who was admitted to hospital in 2002 after suffering from a grand mal seizure. An initial contrast enhanced MRI revealed abnormalities in the mesiotemporal region of the right hemisphere suggesting a possible tumour. However, stereotactic biopsy revealed inflammatory changes in this region. This finding was supported by CSF pleocytosis with 9 cells per *µl*. CSF analysis further showed positive oligoclonal bands as an indicator of intrathecally synthesised IgG antibodies. Following up this line of evidence, anti-MA2 antibodies were found, leading to the definite diagnosis of paraneoplastic limbic encephalitis. Congruent with this diagnosis, H.N. reported being suspicious since 2001 of having a testicular cancer, however, close examination showed no evidence of a neoplasm but a palpable concretion in one testicle, possibly indicating the site of a former tumour successfully targeted by MA2-antibodies. Glucocorticoid treatment started immediately after diagnosis of PNLE in 2002 (5 x 500 mg methylprednisolone every six weeks) for up to two years. After 2 years of treatment, steroids were discontinued in 2004 because of osteoporosis and replaced by repetitive high dose intravenous immunoglobulins (3 x 30 g every six weeks). In addition, H.N. continues to be administered varying doses of anti-convulsive medication, as he suffered from up to 30 simple partial seizures per day, characterised by aureatic experiences of anxiety, uneasiness, and sensations of smelling chemical substances.

MRI scans were performed between 2002 and the time of testing (2006), routinely at intervals of approximately 6 months. Follow-up MRI scans from 2002 to 2004 revealed progressive atrophic changes to the right mesiotemporal/amygdalar region and insula.

Since 2004, however, the condition was stable and unchanged. Figure 1 (taken at time of neuropsychological assessment) illustrates the affected regions.

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Figure 1 about here, please

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Structural alterations were accompanied by personality changes. During the course of the disease, mild obsessive-compulsive behaviour emerged. For example, H.N. fastidiously keeps notes on virtually all matters of his disease, which, at the time of testing, filled three lever arch files. When discussing matters with doctors, H.N. always has these files at hand and refers to them. New questions he intends to raise are kept in a separate loose-leaf folder.

### *2.2. Neuropsychology*

H.N. gave written informed consent for this investigation, which had been approved by the local ethics committee of the Medical Faculty of Heidelberg University, in accordance with the Declaration of Helsinki.

#### *2.2.1. Background Testing*

At time of testing in spring 2006, H.N. was well oriented to time and location. The German version of the HADS (Hospital Anxiety and Depression Scale) revealed scores in the normal range with 7 points for anxiety and 7 points for depression (cut-off is 11). A short neuropsychological battery was administered examining frontal lobe functioning (*Trail Making Test, Lexical and Semantic Word Fluency*), construction (*Rey-Osterrieth Figure, copying*), visuo-motor function *(Digit-Symbol Test),* visual memory (*Rey-Osterrieth Figure, delayed reproduction*), and verbal memory *(Digit Span forward and backward, German version of the CVLT)*. In the German version of the CVLT memory test, participants are

asked to remember a list of 15 words presented five times. This is followed by a distracter list. The first list then has to be reproduced. Thirty minutes later, the participants are again asked to reproduce the first list. The results of these neuropsychological tests are given in Table 1. Results show pronounced deficits in verbal memory functions.

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Table 1 about here, please

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*2.2.2. Recognition of facial expressions of emotion*

To assess the ability to recognise facial expressions of basic emotions, two separate tests taken from the *Facial Expressions of Emotion: Stimuli and Tests* (FEEST) were used (Young et al., 2002).

*Ekman 60 Faces test* - The Ekman 60 Faces test contains photographs of the faces of 10 people from the Ekman and Friesen series (Ekman and Friesen, 1976). For each face, there are poses corresponding to each of six basic emotions (happiness, surprise, fear, sadness, disgust, and anger), giving a total of 60 photographs (10 for each emotion), which are presented in random order. The maximum score is 10 for each of the 6 emotion categories.

*Emotion Hexagon* - The Emotion Hexagon test uses photographic-quality continua of morphed images of an individual's face from the Ekman and Friesen series (poser JJ), which were prepared by blending between prototype expressions. The test set consists in 30 stimuli, comprising 5 morphed images for each of 6 emotion continua: happiness – surprise, surprise – fear, fear – sadness, sadness – disgust, disgust – anger, and anger – happiness, in proportions 90/10 (e.g., 90% fear + 10% surprise), 70/30 (70% fear + 30%

surprise), 50/50 (50% fear + 50% surprise), 30/70 (30% fear + 70% surprise), and 10/90 (10% fear + 70% surprise). The test involves a practice block of 30 trials, followed by 5 test blocks. In each block of trials the 30 images are presented once each, in random order. For the purposes of scoring, the responses to the 50/50 morphed images (which are not usually identified consistently as one particular emotion) and the responses to the practice block trials are excluded, leaving a maximum score of 20 for each of the emotion categories (i.e., the 4 images most similar to each specific emotional expression, repeated across 5 blocks of test trials).

*Procedures* - For both the Ekman 60 and Emotion Hexagon tests, the faces are presented one at a time for 5 seconds each, and the participant is asked to decide which of the emotion names (happiness, sadness, surprise, disgust, anger, and fear) best describes the facial expression shown. The names of these six emotions are visible on the computer screen throughout the test, with the order in which the emotion names are shown on the screen randomised each time the test is given. Full details of the procedure for each test can be found in the manual accompanying the FEEST (Young et al., 2002).

*Results* - Performance of H.N. was compared with the cut-off scores derived from the tests' standardisation samples. Significant impairments for recognition of disgust and fear were found for both the Ekman 60 and the Emotion Hexagon tests. The results are summarised in Table 2. Table 3 provides the full matrix of H.N.'s responses for the Ekman 60 test. As can be seen from Table 3, H.N. misclassified 4 out of 5 disgust expressions in the Ekman 60 test as angry, and the fifth he labelled as surprised. Disgust and anger are normally fairly commonly confused facial expressions (Ekman & Friesen, 1976). He misclassified all 10 fearful expressions, 3 of which were labelled as surprised, 2 as sad, 2 as angry, 2 as disgusted, and 1 as happy. Normally, common misclassifications for fearful

expressions are surprised and sad, but rarely angry or happy (Ekman & Friesen, 1976). Interestingly, H.N. did not use the label 'fear' at all in the Ekman 60 test, although he did in the Emotion Hexagon test.

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Tables 2 and 3 about here, please

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Figure 2 about here, please

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Figure 2 shows responses of H.N. on the Emotion Hexagon test. The patient's performance is contrasted for illustration purposes with the performance of a subset of 96 participants forming part of the standardisation sample of the FEEST. H.N. misclassified 6 out of the 20 disgust expressions presented as angry, and 7 expressions as sad. Two expressions were misclassified as fear and 1 expression as surprise. Disgust is often confused in healthy participants with facial expression of anger and sadness (Ekman & Friesen, 1976). He misclassified 12 out of 20 fearful expressions, 4 of which were labelled as surprised, 5 as disgusted, and 3 as angry. Normally, common misclassifications for fearful expressions are surprised and sad, but rarely disgusted or angry (Ekman & Friesen, 1976).

*2.2.3. Recognition of vocal expressions of emotion*

*Test and procedures* - Recognition of vocally presented emotions was assessed using the Morgenstern test (Sprengelmeyer et al., 1996). Meaningless words were used to create a set of 10 different nonsense "sentences", each spoken by an actor with a happy, surprised, fearful, sad, disgusted, or angry vocal intonation. This gives a total of 60 stimuli with a possible maximum of 10 for each of the six emotions. Stimuli were presented in

pseudo-random order. As in the facial expression task, participants had to decide which of the 6 basic emotion labels best described the vocal intonation.

H.N.'s recognition rates were compared with the performance of an age-matched (mean age: 41.7 years, SD 7.2) and education-matched (mean years of education: 15.8 years, SD 2.9) control group (n = 30).

*Results* - As for the facial expression tests, significant deficits for recognition of fear and disgust were found, as summarised in Table 2. As can be seen from Table 4, common confusions for H.N. on this test were labelling fearful expressions as sad (4 out of 10 expressions) and disgusted expressions as angry (6 out of 10 expressions). Mistaking fearful for sad vocal expressions is a common confusion across cultures, including in Germany (Scherer et al., 2001); however, on this Morgenstern test it tends to be no more common than labelling fearful vocal expressions as disgusted, which H.N. did not do. Mistaking disgusted for angry expressions on this test is not as common as mistaking them for surprise, which again H.N. did not do.

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Tables 4 and 5 about here, please

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*2.2.4. Recognition of bodily expressions of emotion*

*Test and procedures* - Finally, we examined recognition of bodily expressed emotions. Ten actors (5 male) with thirteen 20mm-wide reflective strips attached to head and major joints of the body were asked to produce movements expressing 5 basic emotions: happiness, fear, sadness, disgust, or anger. This resulted in a total of fifty video clips with a length between 4.5 and 9 seconds and with 10 clips for each emotion. When presented, only the reflective strips are visible as moving patches against a black background (Atkinson et al., 2004). Similar to the other recognition tasks, participants had to decide

which emotion best described each display by choosing the appropriate emotion label from a list of 5 (anger, disgust, fear, happiness, sadness).

*Results* - When compared to an age- and education-matched control group, H.N. showed no impairments on this task, as summarised in Table 2. Furthermore, his classification errors (see Table 5) were the same as those typically made by neurologically healthy individuals, such as occasionally classifying fearful body movements as disgusted, disgusted movements as sad, and certain happy movements as angry (Atkinson et al., 2004; Atkinson et al., 2007b).

## 3. DISCUSSION

We investigated various aspects of emotion recognition in a person suffering from limbic encephalitis and found significant deficits in recognising facial and vocal expressions of disgust and fear. Given that case H.N. showed atrophic changes extending from mesiotemporal regions to the insular cortex, principally in the right hemisphere, these findings did not come as a surprise because previous neuropsychological research on people with damage to the amygdala has shown selective deficits in recognising fearful facial and vocal expressions, while dysfunction of the insular cortex has been shown to impair recognition of disgust from both face and voice (reviewed by Calder et al., 2001). The importance of these neural structures for emotion recognition has been further highlighted by numerous functional imaging studies showing activation to faces expressing fear and disgust (for reviews, see Phan et al., 2002; Calder et al., 2001; Murphy et al., 2003). In what follows, we discuss several aspects of H.N.'s emotion recognition performance in relation to these previous findings and the specific locations of his lesions. We finish with a comment about the possible clinical implications of emotion recognition deficits in PNLE.

The right lateralised damage to H.N.'s brain and his deficit in facial and vocal emotion recognition is partly consistent with previous lesion evidence for the right hemisphere's critical role in the perception and recognition of emotional prosody and facial expressions (e.g., Heilman et al., 1984; Blonder et al., 1991; Kucharska-Pietura et al., 2003; Adolphs et al., 2000; Borod et al., 1998), as well as with functional imaging evidence of right hemisphere dominance in processing emotional (relative to emotionally neutral) facial expressions (e.g., Lane et al., 1995) and prosody (e.g., Mitchell et al., 2003; Bach et al., 2008). Yet much of this evidence implicates right-hemisphere cortical regions that remain spared in H.N. and damage to which tends to result in a more global deficit in facial emotion recognition than that we observed with H.N. While damage to subcortical structures can impair the recognition of facially and vocally expressed emotions without evident lateralization (Yip et al., 2004), there is some evidence of lateralization from cases of more focal lesions to those (subcortical and cortical) structures which are affected in H.N. Unilateral or asymmetric amygdala damage tends to result in milder and more variable impairments in facial and vocal emotion recognition than bilateral damage (Adolphs et al., 2001; Anderson et al., 2000; Fowler et al., 2006); nonetheless, some of this evidence indicates a more critical role for the right than the left amygdala and surrounding medial temporal cortex in the recognition of facial expressions of fear (Adolphs et al., 2001) or of withdrawal-related emotions more generally (Anderson et al., 2000).

Two case studies have shown clear evidence of insula and basal ganglia damage selectively impairing the recognition of facial and vocal expressions of disgust; in one, the patient's lesion was in the left hemisphere (Calder et al., 2000), while in the other the lesion was bilateral with extensive temporal lobe damage (Adolphs et al., 2003). Neuroimaging evidence implicates right as well as left insula and basal ganglia involvement in the perception of facial and vocal expressions of disgust (e.g.,

Sprengelmeyer et al., 1998; Phillips et al., 1998; Phillips et al., 1997). Moreover, there is lesion evidence for the critical involvement of right insula – in addition to right somatosensory cortex, the latter spared in H.N. – in the explicit recognition of facial (Adolphs et al., 2000) and vocal expressions (Adolphs et al., 2002) of emotions in general, rather than disgust specifically.

In addition to facial and vocal expressions, we used dynamic point-light displays of bodily expressions (Atkinson et al., 2004) to assess recognition of basic emotions. Interestingly, we found no difference in performance between H.N. and the control group on this rather difficult task. Why might this be? It is instructive to compare and contrast our results with previously published findings of individuals with damage either to the amygdala or to basal ganglia and insula.

The results of the present study are consistent with the recent finding of one person with selective bilateral amygdala lesions, who is known to be severely impaired at recognising fear from faces, but who was not impaired in recognising fear from either body movements or static postures (Atkinson et al., 2007a). It should be noted that the body movement stimuli in that study were drawn from the same set as that used in the present study.

Contradicting results, however, come from the only other single case study to have examined the effect of amygdala lesions on emotion recognition in which static body expressions have been used (Sprengelmeyer et al., 1999). For this male patient with a bilateral amygdala lesion, a selective impairment in identifying fear from static body postures, as well as from faces and voices, was reported. However, this subject's lesion included some damage to the left thalamus, and thus it is possible that the impaired recognition of fear from static body postures in this subject was a consequence of damage to the thalamus or both the thalamus and amygdala. In this regard it is pertinent to note evidence indicating a causal role for the pulvinar (especially its medial aspect) in the

perception and recognition of fear, at least from faces. Most relevantly, a patient with complete unilateral loss of the pulvinar was incapable of recognising briefly presented fearful facial expressions in his contralateral field, yet three other patients, with damage limited to anterior and lateral pulvinar, showed no deficits in facial fear recognition (Ward et al., 2007). It is yet to be established whether pulvinar damage similarly impairs fear recognition from vocal expressions or from static or dynamic bodily expressions. Furthermore, it is as yet unclear why damage to the amygdala that spares the thalamus/pulvinar tends to impair the recognition of emotions, especially fear, from faces (and in some cases voices) but not bodies, whereas damage to both the amygdala and the thalamus/pulvinar might impair the recognition of emotions, especially fear, from all three stimulus types. Further research is necessary to investigate these dissociations.

As already mentioned, 2 single cases have been described with selective impairment in the recognition of facial and vocal expressions of disgust following insula and basal ganglia damage. In one of these cases, the damage was confined to the left insula and basal ganglia (Calder et al., 2000), whereas in the other case the damage was bilateral and extended to the temporal lobes (Adolphs et al., 2003); interestingly, in this latter case, the selectivity of the disgust recognition deficit was evident for dynamic but not static facial expressions (the patient was impaired in recognising all basic emotions other than happiness from static faces). Pre-symptomatic individuals with Huntington's disease, in whom atrophic changes to the insular cortex are reported (Thieben et al., 2002), also display a disproportionate deficit in recognition of facial expressions of disgust (Sprengelmeyer et al., 2006). With progression of the disease and the involvement of other neural substrates, recognition of other basic emotions from faces and voices becomes increasingly affected (e.g., Sprengelmeyer et al., 1996; Sprengelmeyer et al., 1997). Despite some questions over the specificity of the impairment for the recognition of disgust (Milders et al., 2003; Henley et al., 2008), there is evidence that individuals with

Huntington's disease are impaired not only in recognising facially and vocally expressed disgust, but also in classifying disgusting pictures, in responding to disgusting odorants, and in providing declarative knowledge about the situational determinants of disgust (Hayes et al., 2007). Another pathological condition, in which recognition of facial expressions of disgust has been reported, is Obsessive Compulsive Disorder (Sprengelmeyer et al., 1997). It is worth mentioning that H.N. also developed a mild form of obsessive-compulsive behaviour as a consequence of his limbic encephalitis. The relationship between symptoms of OCD and impaired disgust recognition merits further investigation.

To date, no study examining the recognition of bodily expressed disgust has been conducted in people with lesions to the insular cortex, and there is only one published study having examined the recognition of emotions from bodily expressions in individuals with Huntington's disease; however, even in this study the recognition of disgusted postures was not tested. De Gelder et al. (2008) reported impaired recognition of anger from static body postures in a Huntington's disease group, as well as impaired recognition of emotionally neutral instrumental actions from static images of whole body postures, but not of sad or fearful postures. Given the widespread deficits in disgust processing in people with pathological changes to the insula and basal ganglia, we would not have been surprised if it had turned out that H.N. was impaired in recognising disgust in body expressions. There are several possible reasons why this prediction was not borne out, all of which deserve investigation.

The first reason why H.N. was not impaired on our bodily emotion recognition task, despite being impaired at recognising disgust and fear in faces and voices, might be to do with differences in the nature of the emotion recognition tasks between studies. In particular, whereas H.N. performed a forced-choice emotion-labelling task, the Huntington's disease individuals in de Gelder et al.'s (2008) study engaged in a task

requiring them to match one of two body postures with a simultaneously presented target posture. However, in the light of H.N.'s neuropsychological profile, it would be reasonable to assume that H.N. would be more likely to be impaired on a forced-choice labelling task than on a task requiring matching of simultaneously presented images of postures. A second reason might be to do with differences in stimuli between our tasks and between studies. In the current study, bodily emotion recognition was tested with moving stimuli, whereas the facial emotion recognition task involved static stimuli. Moreover, whereas H.N. classified emotions in point-light body movement stimuli, in which static body form cues are minimal but motion cues preserved, the Huntington's disease individuals in de Gelder et al.'s (2008) study were presented with static body postures. It is unlikely that a general advantage for dynamic over static stimuli would adequately account for H.N.'s spared performance on the bodily expression task despite impaired performance on the facial expression task, for the emotions expressed in the vocal stimuli also arguably evolve over time and yet he was impaired in recognising disgust and fear on this task as well. Nonetheless, it is possible that the specifically visual motion cues aided H.N. on the bodily expression task.

Finally, we turn to a brief consideration of the patterns of errors in H.N.'s emotion recognition performance. These patterns of errors were similar to those from neurologically healthy individuals except for facial and vocal expression of fear and disgust.

For fear, H.N. labelled in the Ekman 60 test 20% of fearful expressions as angry, 20% as disgusted, and 10% as happy; in the Emotion Hexagon test he labelled 25% of fearful expressions as disgusted and 15% as angry. This pattern of errors is qualitatively and quantitatively distinct from healthy participants. Only quantitatively distinct from the performance of healthy participants is H.N.'s pattern of errors for facial expressions of disgust, which is most often confused with anger and sadness. The reason for this distinction is yet unclear and has to be explored. However, a possible explanation is the

extent of neurological damage, which is more extensive to the amygdala than to the insular cortex. In the vocal expression test he labelled 60% of disgusted stimuli as angry. Such errors are very rarely normally seen, underlining the severity of H.N.'s impairment in recognising fear in faces and disgust in voices.

In conclusion, the deficits in emotion recognition in case H.N. make it worthwhile to look more closely at this kind of impairment in a larger group of people suffering from antibody associated paraneoplastic limbic encephalitis. It may well be that impaired emotion processing forms a core symptom of this disorder in addition to the well described memory deficits (Vollmer et al., 1993). However, additional studies are necessary to support this claim. Our findings therefore could have some clinical implications. If deficits in emotion recognition turn out to be symptomatic for PNLE, we suggest that possible deficits in emotion recognition should be assessed routinely for optimal social adjustment of these patients.

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*Table 1:* Results of neuropsychological background tests.

*Neuropsychological Background Testing*

| | Score | Percentile |
|---|---|---|
| *Frontal lobe functioning* | | |
| Trails A (performance in sec.) | 36 sec | 30-40 |
| Trails B (performance in sec.) | 71 sec | 30-40 |
| Word Fluency (No. of Letter starting with S; 1 min) | 13 | 15-20 |
| Word Fluency (No. of Animals; 1 min) | 29 | 5-10 |
| *Construction* | | |
| Rey-Osterrieth Figure (copying, max. 36 points) | 34 | 70-75 |
| *Visuo-motor function* | | |
| Digit-Symbol Test | 33 | 5-10 |
| *Visual Memory* | | |
| Rey-Osterrieth Figure (delayed reproduction, max. 36 points) | 6 | 5-10 |
| *Verbal Memory* | | |
| Digit Span | | |
| Forward | 4 | 0-5 |
| Backwards | 3 | 0-5 |
| CVLT | | |
| Total no. of remembered words (immediately) | 52/75 | 45-55 |
| Reproduction after interference | 5/15 | 0-5 |
| Delayed recall | 5/15 | 0-5 |
| Delayed Recognition | 13/15 | 15-30 |

*Table 2:* Results of tests for assessing emotion recognition.

*Recognition of facial, vocal and postural expressions of emotion*

| | Ekman 60 Faces H.N. | | Emotion Hexagon H.N. | |
|---|---|---|---|---|
| Surprise | 7 | | 15 | |
| Happiness | 10 | | 17 | |
| Fear | 0 | * | 8 | * |
| Sadness | 7 | | 13 | |
| Disgust | 5 | * | 6 | * |
| Anger | 10 | | 16 | |

(* = performance below the test's cut-off score)

| | Morgenstern test | | | | Emotional Postures | | | |
|---|---|---|---|---|---|---|---|---|
| | H.N. | Controls Mean | SD | z-score | H.N. | Controls Mean | SD | z-score |
| Surprise | 9 | 8.27 | 1.17 | -0.62 | | | | |
| Happiness | 5 | 6.40 | 1.69 | 0.82 | 6 | 7.73 | 1.57 | 1.11 |
| Fear | 3 | 7.57 | 1.65 | 2.77 ** | 6 | 7.57 | 1.45 | 1.08 |
| Sadness | 6 | 8.57 | 1.50 | 1.71 | 6 | 7.97 | 1.25 | 1.58 |
| Disgust | 0 | 6.87 | 1.91 | 3.60 *** | 6 | 6.37 | 1.97 | 0.19 |
| Anger | 8 | 9.17 | 1.05 | 1.11 | 5 | 7.57 | 1.79 | 1.44 |

Scores marked with asterisks are significantly lower than those of the control group:
* $p < .05$, ** $p < .01$, *** $p < .001$.

*Table 3.* The full response matrix for patient H.N. on the Ekman 60 facial emotion recognition test. The figures represent the number of times a particular response label (columns) was chosen for each of the represented facial emotion categories (rows). Figures in bold are for correct responses.

| **Stimulus** | **Seen as** | | | | | |
|---|---|---|---|---|---|---|
| | happiness | surprise | fear | sadness | disgust | anger |
| happiness | **10** | 0 | 0 | 0 | 0 | 0 |
| surprise | 1 | **7** | 0 | 0 | 0 | 2 |
| fear | 1 | 3 | **0** | 2 | 2 | 2 |
| sadness | 0 | 0 | 0 | **7** | 2 | 1 |
| disgust | 0 | 1 | 0 | 0 | **5** | 4 |
| anger | 0 | 0 | 0 | 0 | 0 | **10** |

*Table 4.* The full response matrix for patient H.N. on the Morgenstern vocal emotion recognition task. The figures represent the number of times a particular response label (columns) was chosen for each of the represented vocal emotion categories (rows). Figures in bold are for correct responses. We included a column labeled 'nothing', since for three stimuli H.N. refused to label the emotional expression, stating that he did not hear any emotion in the voice.

| **Stimulus** | **Heard as** | | | | | | |
|---|---|---|---|---|---|---|---|
| | happiness | surprise | fear | sadness | disgust | anger | nothing |
| happiness | **5** | 3 | 0 | 1 | 0 | 1 | 0 |
| surprise | 0 | **9** | 0 | 1 | 0 | 0 | 0 |
| fear | 0 | 2 | **3** | 4 | 0 | 1 | 0 |
| sadness | 0 | 2 | 2 | **6** | 0 | 0 | 1 |
| disgust | 1 | 0 | 0 | 0 | **0** | 6 | 3 |
| anger | 0 | 2 | 0 | 0 | 0 | **8** | 0 |

*Table 5.* The full response matrix for patient H.N. for the body movement emotion recognition test. The figures represent the number of times a particular response label (columns) was chosen for each of the represented facial emotion categories (rows). Figures in bold are for correct responses. We included a column labeled 'nothing', since for four stimuli H.N. refused to label the emotional expression, stating that he did not see any emotion in the given displays.

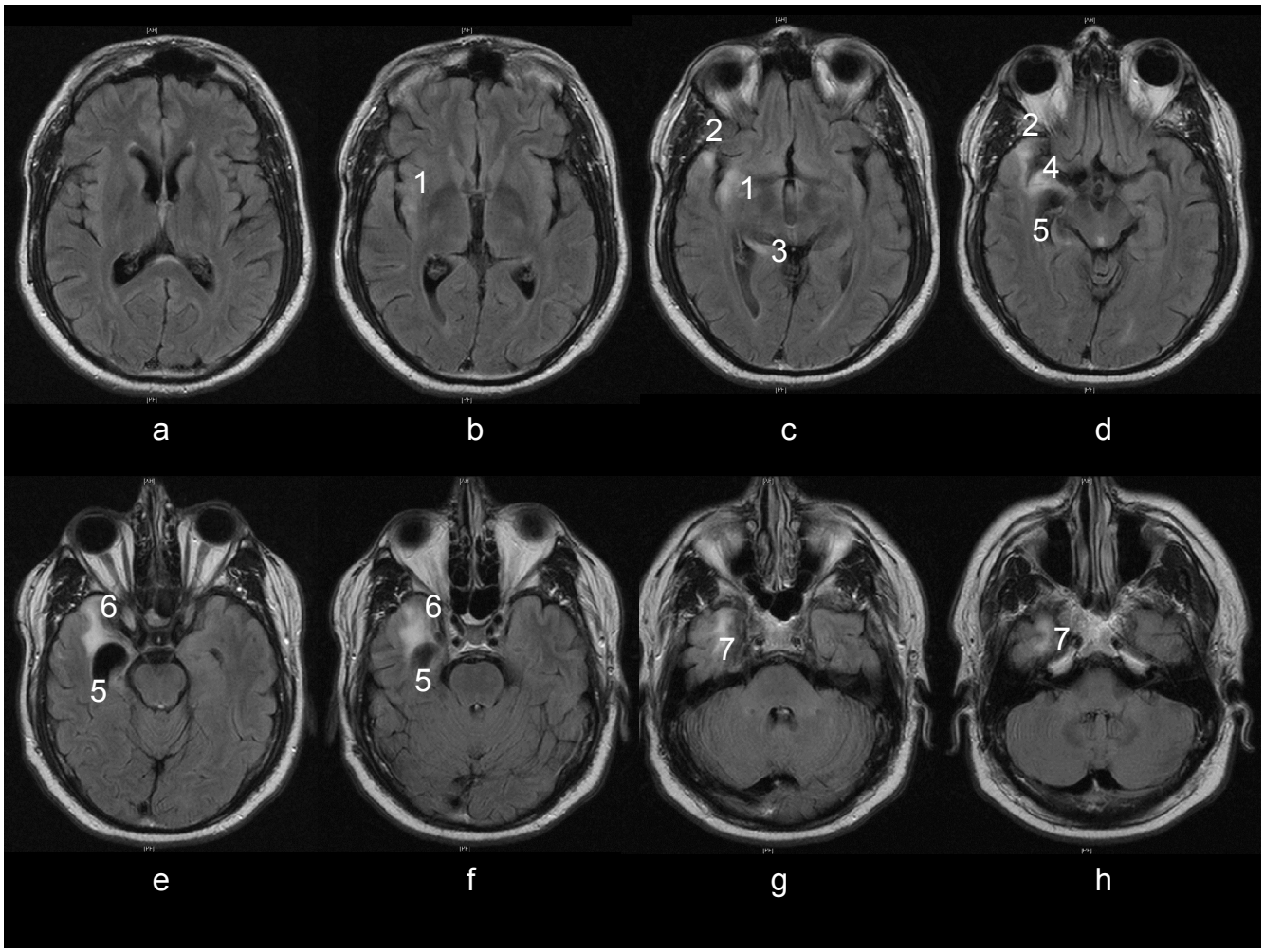
| **Stimulus** | **Seen as** | | | | | |
|---|---|---|---|---|---|---|
| | happiness | fear | sadness | disgust | anger | nothing |
| happiness | **6** | 0 | 0 | 0 | 3 | 1 |
| fear | 0 | **6** | 1 | 2 | 1 | 0 |
| sadness | 0 | 3 | **6** | 0 | 0 | 0 |
| disgust | 0 | 1 | 2 | **5** | 1 | 1 |
| anger | 1 | 0 | 0 | 1 | **6** | 2 |

**Figure Legends**

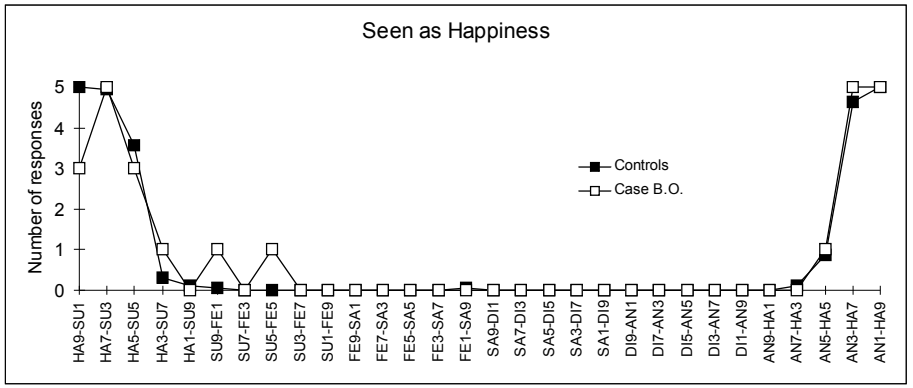
*Figure 1:* Horizontal MRI scans (FLAIR sequence) showing pathological signal enhancements in the right insular cortex (1), the right temporal operculum (2), and the posterior part of the parahippocampal region (3). There are further signal enhancements in the temporal uncus (4), the temporal pole (6), and the more ventral regions of the right temporal lobe (7). MRI scans d to f show severe atrophic changes to the right amygdala (5).

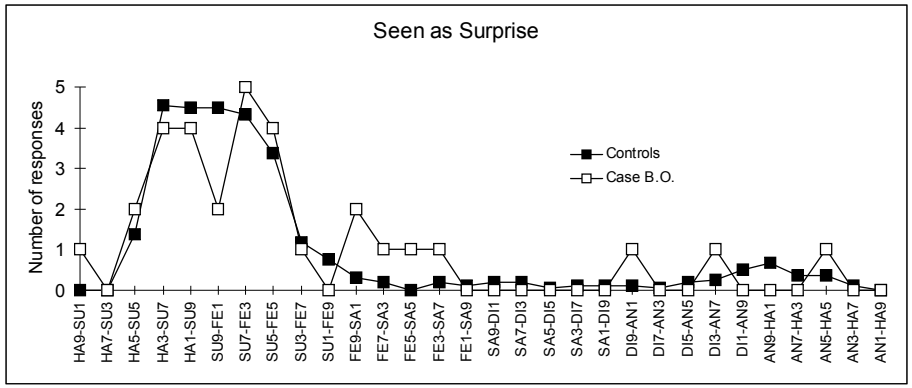
*Figure 2:* Identification of the morphed facial emotion images of the Emotion Hexagon test by H.N. and control subjects. Along the horizontal axis HA, SU, FE, SA, DI and AN represent happiness, surprise, fear, sadness, disgust and anger respectively and 1, 3, 5, 7 and 9 represent 10, 30, 50, 70, and 90% respectively. Thus HA9-SU1 is a morphed image of 90% happiness and 10% surprise.

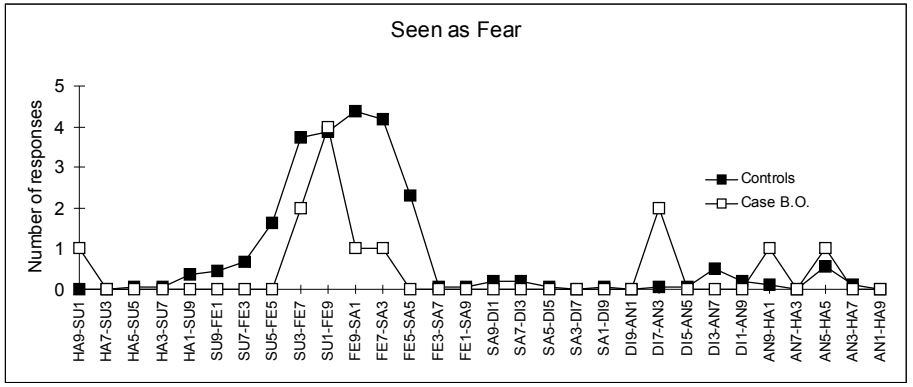
# Figure 1

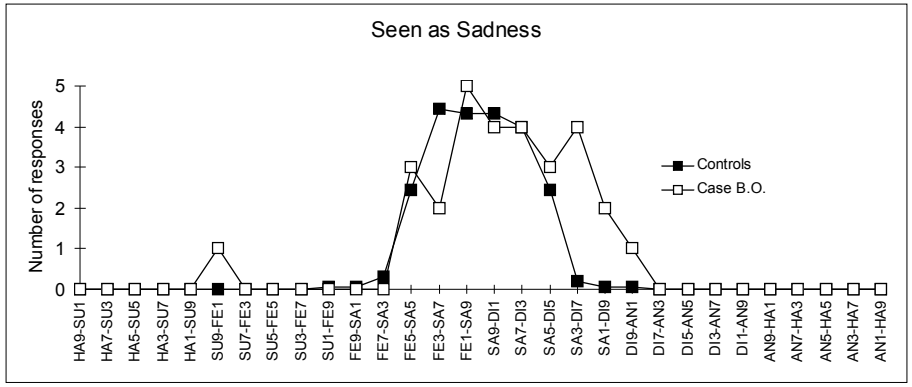


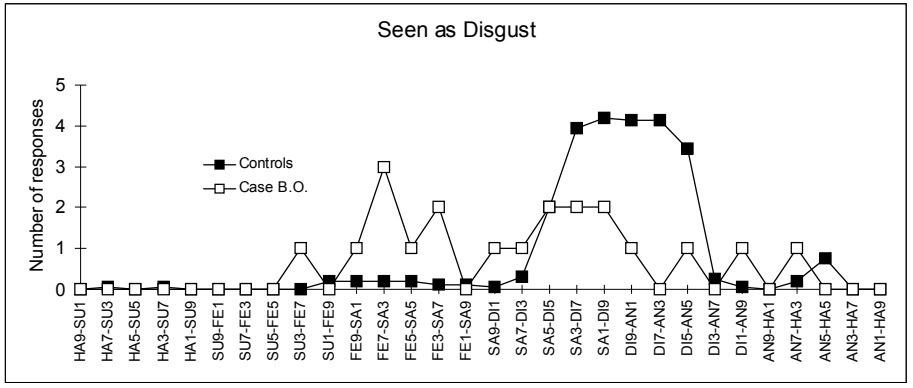
# Figure 2

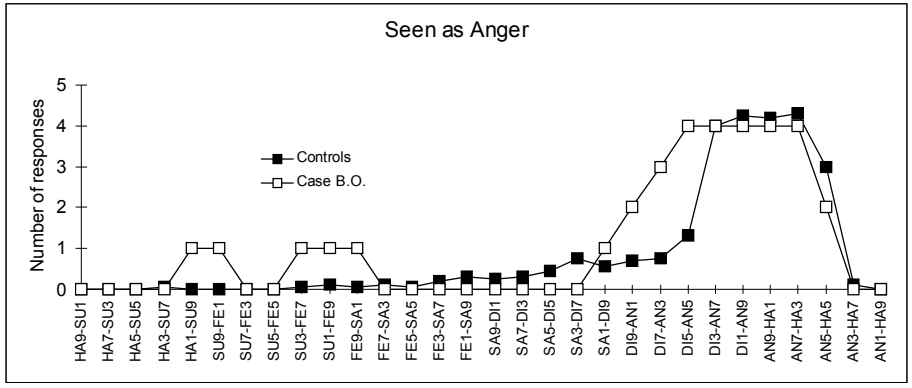

Seen as Happiness
Number of responses
Controls
Case B.O.
HA9-SU1 HA7-SU3 HA5-SU5 HA3-SU7 HA1-SU9 SU9-FE1 SU7-FE3 SU5-FE5 SU3-FE7 SU1-FE9 FE9-SA1 FE7-SA3 FE5-SA5 FE3-SA7 FE1-SA9 SA9-DI1 SA7-DI3 SA5-DI5 SA3-DI7 SA1-DI9 DI9-AN1 DI7-AN3 DI5-AN5 DI3-AN7 DI1-AN9 AN9-HA1 AN7-HA3 AN5-HA5 AN3-HA7 AN1-HA9


Seen as Surprise
Number of responses
Controls
Case B.O.
HA9-SU1 HA7-SU3 HA5-SU5 HA3-SU7 HA1-SU9 SU9-FE1 SU7-FE3 SU5-FE5 SU3-FE7 SU1-FE9 FE9-SA1 FE7-SA3 FE5-SA5 FE3-SA7 FE1-SA9 SA9-DI1 SA7-DI3 SA5-DI5 SA3-DI7 SA1-DI9 DI9-AN1 DI7-AN3 DI5-AN5 DI3-AN7 DI1-AN9 AN9-HA1 AN7-HA3 AN5-HA5 AN3-HA7 AN1-HA9


Seen as Fear
Number of responses
Controls
Case B.O.
HA9-SU1 HA7-SU3 HA5-SU5 HA3-SU7 HA1-SU9 SU9-FE1 SU7-FE3 SU5-FE5 SU3-FE7 SU1-FE9 FE9-SA1 FE7-SA3 FE5-SA5 FE3-SA7 FE1-SA9 SA9-DI1 SA7-DI3 SA5-DI5 SA3-DI7 SA1-DI9 DI9-AN1 DI7-AN3 DI5-AN5 DI3-AN7 DI1-AN9 AN9-HA1 AN7-HA3 AN5-HA5 AN3-HA7 AN1-HA9


Seen as Sadness
Number of responses
Controls
Case B.O.
HA9-SU1 HA7-SU3 HA5-SU5 HA3-SU7 HA1-SU9 SU9-FE1 SU7-FE3 SU5-FE5 SU3-FE7 SU1-FE9 FE9-SA1 FE7-SA3 FE5-SA5 FE3-SA7 FE1-SA9 SA9-DI1 SA7-DI3 SA5-DI5 SA3-DI7 SA1-DI9 DI9-AN1 DI7-AN3 DI5-AN5 DI3-AN7 DI1-AN9 AN9-HA1 AN7-HA3 AN5-HA5 AN3-HA7 AN1-HA9


Seen as Disgust
Number of responses
Controls
Case B.O.
HA9-SU1 HA7-SU3 HA5-SU5 HA3-SU7 HA1-SU9 SU9-FE1 SU7-FE3 SU5-FE5 SU3-FE7 SU1-FE9 FE9-SA1 FE7-SA3 FE5-SA5 FE3-SA7 FE1-SA9 SA9-DI1 SA7-DI3 SA5-DI5 SA3-DI7 SA1-DI9 DI9-AN1 DI7-AN3 DI5-AN5 DI3-AN7 DI1-AN9 AN9-HA1 AN7-HA3 AN5-HA5 AN3-HA7 AN1-HA9


Seen as Anger
Number of responses
Controls
Case B.O.
HA9-SU1 HA7-SU3 HA5-SU5 HA3-SU7 HA1-SU9 SU9-FE1 SU7-FE3 SU5-FE5 SU3-FE7 SU1-FE9 FE9-SA1 FE7-SA3 FE5-SA5 FE3-SA7 FE1-SA9 SA9-DI1 SA7-DI3 SA5-DI5 SA3-DI7 SA1-DI9 DI9-AN1 DI7-AN3 DI5-AN5 DI3-AN7 DI1-AN9 AN9-HA1 AN7-HA3 AN5-HA5 AN3-HA7 AN1-HA9