Emotion recognition impairment and apathy after subthalamic nucleus stimulation in Parkinson’s disease have separate neural substrates

D. Drapier, J. Périn, E. Leray, P. Sauleau, I. Biseul, S. Drapier, F. Le Jeune, D. Travers, A. Bourguignon, C. Haegelen, B. Millet, M. Vérin

Department of Psychiatry, Centre Hospitalier Guillaume Régnier, 108 avenue du Général Leclerc, 35703 Rennes, France
Department of Neurology, Centre Hospitalier Pontchaillou, rue Henri le Guillaum, 35033 Rennes, France
Department of Epidemiology and Public Health, Centre Hospitalier Pontchaillou, rue Henri le Guillaum, 35033 Rennes, France
Department of Nuclear Medicine, Centre Eugène Marquis, av Bataille Flandre Dunkerque, 35000 Rennes, France
Department of Neurosurgery, Centre Hospitalier Pontchaillou, rue Henri le Guillaum, 35033 Rennes, France
Unité de Recherche Universitaire “Comportements et noyaux gris centraux” Université de Rennes 1, Avenue Pr Léon Bernard, Rennes, France

Objective: To test the hypothesis that emotion recognition and apathy share the same functional circuit involving the subthalamic nucleus (STN).

Methods: A consecutive series of 17 patients with advanced Parkinson’s disease (PD) was assessed 3 months before (M – 3) and 3 months (M + 3) after STN deep brain stimulation (DBS). Mean (±S.D.) age at surgery was 56.9 (8.7) years. Mean disease duration at surgery was 11.8 (2.6) years. Apathy was measured using the Apathy Evaluation Scale (AES) at both M – 3 and M3. Patients were also assessed using a computerised paradigm of facial emotion recognition [Ekman, P., & Friesen, W. V. (1976). Pictures of facial affect. Palo Alto: Consulting Psychologist Press] before and after STN DBS. Prior to this, the Benton Facial Recognition Test was used to check that the ability to perceive faces was intact.

Results: Apathy had significantly worsened at M3 (42.5 ± 8.9, p = 0.006) after STN-DBS, in relation to the preoperative assessment (37.2 ± 5.5). There was also a significant reduction in recognition percentages for facial expressions of fear (43.1% ± 22.9 vs. 61.6% ± 21.4, p = 0.022) and sadness (52.7% ± 19.1 vs. 67.6% ± 22.8, p = 0.031) after STN DBS. However, the postoperative worsening of apathy and emotion recognition impairment were not correlated.

Conclusions: Our results confirm that the STN is involved in both the apathy and emotion recognition networks. However, the absence of any correlation between apathy and emotion recognition impairment suggests that the worsening of apathy following surgery could not be explained by a lack of facial emotion recognition and that its behavioural and cognitive components should therefore also be taken into consideration.

0028-3932/ – see front matter © 2008 Elsevier Ltd. All rights reserved.

doi:10.1016/j.neuropsychologia.2008.05.006
control group of Parkinsonian patients who met the surgical criteria but were still on the waiting list for surgery.

Apathy is clinically defined as a decrease in or lack of motivation, interest or emotions, which cannot be ascribed to any impairment of consciousness or any emotional or cognitive disorder (Marin, 1991). This led Marin (1990) to define three main domains for characterising apathy: behaviour, emotion and cognition, as reflected in the Apathy Evaluation Scale. According to the multicomponential view, emotions are defined as “episodes of massive, synchronized recruitment of mental and somatic resources allowing to adapt the Apathy Evaluation Scale. According to the multicomponential view, emotions are defined as “episodes of massive, synchronized recruitment of mental and somatic resources allowing to adapt to or cope with a stimulus event subjectively appraised as being highly pertinent to the needs, goals, and values of the individuals” (Scherer, Schorr, & Johnstone, 2001). Our group has demonstrated that, when it comes to facial expressions of emotions, fear recognition is impaired by STN DBS in PD (Biseul et al., 2005; Le Jeune et al., 2008), implying that the STN could be involved in the fear recognition circuit, either via computation within the STN or by virtue of its impact on other limbic territories.

The STN’s involvement in emotional processing has been suggested by other prospective studies, which have reported a selective reduction in the recognition of negative emotion following STN DBS in PD (Dujardin et al., 2006; Schroeder et al., 2004) but also by perioperative studies, such as that conducted by Künn et al. (2005), which showed a differential and dynamic modulation of STN potential in response to the presentation of affective pictures. However, Künn et al.’s result has to be viewed with caution, as some parameters, such as the visual stimulus features, were not properly controlled in the study and could therefore account for this result.

Apathy is an important psychiatric component of PD (Aarsland et al., 1999; Cummings et al., 1994) which can be defined clinically as a lack of reaction to emotional stimuli. Thus, apathy appears to take the form of a complex emotional withdrawal with emotional, behavioural and cognitive dimensions (Marin, 1991), which may be aggravated by STN DBS. Emotion recognition is also impaired after STN DBS. In the light of our previous findings (Biseul et al., 2005; Drapier et al., 2006; Le Jeune et al., 2008) the aim of this study was to examine whether apathy/emotional withdrawal can be explained by a facial emotion recognition impairment. This would imply that apathy emotional withdrawal and facial expression recognition networks at least share some common circuits passing through the STN. Furthermore, we wanted to test whether the emotional dimension is actually the major disorder in apathy and whether it influences the other – cognitive and behavioural – dimensions of apathy.

2. Patients and methods

2.1. Patients

We studied a series of 17 consecutive patients with medically refractory PD who underwent bilateral STN DBS at Rennes University Hospital (France). Standard selection and exclusion criteria for surgery were applied to all patients (Weiter et al., 2002). There were 11 men and 6 women. Mean (±S.D.) age at surgery was 56.9 (8.7) years. Mean (±S.D.) disease duration at surgery was 11.8 (2.6) years. The Ethical Committee of Rennes University Hospital approved the study and written informed consent was obtained for each participant. The study was conducted in accordance with the Declaration of Helsinki.

2.2. Methods

All the patients were assessed 3 months before and 3 months after surgery, using motor, psychiatric and neuropsychological tests. All patients were on-stimulation and on-dopa when the psychiatric and neuropsychological assessments were performed.

2.3. Surgical procedure

Quadripolar deep brain stimulation electrodes (Medtronic, Minneapolis, Minnesota, USA) were implanted bilaterally in the STN during two operating sessions separated by an interval of 8 days. The overall methodology was similar to that previously described by Benabid et al. (2000). The location of the unipolar chronic electrode contacts at M3 was determined using the technique we have previously reported (Sauleau et al., 2005). The focus of each stimulation contact was located in relation to the middle of the bicommissural line (AC-PC), by superimposing the electrode positioning picture on the corresponding ventriculogram. Distances were measured on a squared transparent sheet, and then readjusted using a computerised spreadsheet.

2.4. Motor assessments

All patients were evaluated according the Core Assessment Program for Intracerebral Transplantation (Langston et al., 1992), and were scored on the Unified Parkinson’s Disease Rating Scale I–IV (Fahn & Elton, 1987), the Hoehn and Yahr score (Hoehn & Yahr, 1967), and the Schwab and England score (S&ES; Schwab & England, 1960). 3 months before surgery and 3 months after. Patients were assessed both on- and off-dopa before and after surgery. Stimulation was on-dopa after surgery.

2.5. Psychiatric assessment

The Mini International Neuropsychiatric Inventory (MINI 500, French version) (Sheehan et al., 1998) was used for all patients. Apathy was scored 3 months before and 3 months after surgery using the Apathy Evaluation Scale (Clinician version, C-AES) divided into 4 subscores (C = Cognitive, B = Behaviour, E = Emotion, O = Other) (Marin, Biedrzycki, & Firincougiliari, 1991).

2.6. Neuropsychological assessment

2.6.1. Neuropsychological background

A short neuropsychological battery was administered before the facial affect recognition session 3 months before surgery and 3 months after. This battery included the Mattis scale (Mattis, 1988) and a series of tests assessing frontal executive functions: Nelson’s modified version of the Wisconsin Card Sorting Test (Nelson, 1976) the Trail Making Test (Reitan, 1958) categorical and literal fluency (Cardebat, Doyon, Puel, Goulet, & Joanette, 1990) and the Stroop Test (Stroop, 1935).

2.6.2. Benton Facial Recognition Test

To check that the early processing stages of face perception were intact, the Benton Facial Recognition Test (Benton, Hamsher, Varney, & Spreen, 1983) was administered to all patients 3 months before surgery and 3 months after. Patients were excluded from the study if facial recognition as measured by the Benton Recognition Test was impaired. None of the patients included in this study presented any apperceptive prosopagnosia as measured by the Benton Recognition Test.

2.6.3. Facial affect recognition

After they had been familiarised with the task and the list of emotions, each patient was presented with a randomised sequence of 55 computerised photographic slides of 7 facial expressions (happiness, sadness, fear, surprise, disgust, anger and no emotion) on a screen (Ekman & Friesen, 1976). In order to avoid a list effect between the pre- and postoperative conditions, two versions of the facial affect recognition task were used and counterbalanced. In the preoperative condition, half the patients were assessed with version “a” of the task and half with version “b”. In the postoperative condition, the first half were assessed with version “b” and the second half with version “a”. In line with the procedure described by Marinovic, Trebon, Chaivel, & Halgren, (2000), Biseul et al. (2005) and Le Jeune et al. (2008), each version contained between 7 and 10 pictures for each facial expression category (for version “a”: 10 for happiness, 9 for sadness, 7 for fear, 7 for surprise, 7 for disgust, 8 for anger, and 7 for neutral; for version “b”: 8 for happiness, 8 for sadness, 8 for fear, 7 for surprise, 8 for disgust, 9 for anger and 7 for neutral). After observing the picture for 3 s, the patients were prompted to give an answer by choosing the most suitable response among the 7 expressions. Responses were made verbally and the experimenter recorded the responses on a scoresheet. This task was administered 3 months before surgery and 3 months after.

2.7. Statistical analysis

Given the small number of patients included in the study, only nonparametric analyses were used. Pre- and postoperative values of the clinical, neuropsychological and psychiatric scales were compared using the Wilcoxon test for paired samples. Correlations between (1) apathy and emotion recognition, (2) neuropsychological background and apathy, and (3) neuropsychological background and emotion recognition were assessed using Spearman’s rank correlation coefficient. Coefficients were computed with preoperative scores, then with postoperative scores and finally with differences between post- and preoperative scores (ΔNP = postoperative score – preoperative score). p-Values <0.05 were considered to be statistically significant. All these calculations were performed using SPSS 15.0 software for Windows.
2.8.3.2. Facial affect recognition.
The facial affect recognition data of the PD patient group are presented in Table 4.

2.8.3.1. Neuropsychological background and Benton Facial Recognition Test.

2.8.3. Neuropsychological results

2.8.2. Psychiatric results

2.8.1. Motor results

Table 1 shows the effect of surgery on motor symptoms.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Off-dopa period score</th>
<th>On-dopa period score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preoperative (Baseline)</td>
<td>Postoperative (M + 3)</td>
</tr>
<tr>
<td></td>
<td>Mean ± S.D.</td>
<td>Mean ± S.D.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDRS III</td>
<td>35.7 ± 11.5</td>
<td>19.7 ± 12.5</td>
</tr>
<tr>
<td>Schwab &amp; England (%)</td>
<td>58.5 ± 19.3</td>
<td>73.5 ± 20.3</td>
</tr>
<tr>
<td>Hoehn &amp; Yahr</td>
<td>2.7 ± 1.0</td>
<td>2.2 ± 1.2</td>
</tr>
<tr>
<td>Dopa eq. dose (mg)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1448 ± 400</td>
</tr>
</tbody>
</table>

No significant difference was found between the pre- and postoperative conditions. UPDRS: Unified PD Rating Scale; Dopa eq. dose: L-dopa equivalent dose; S.D.: standard deviation.

### Table 2

Overall and subscores for apathy before and after surgery (comparison using the Wilcoxon test for paired samples)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative condition (Baseline)</th>
<th>Postoperative condition (M + 3)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± S.D.</td>
<td>Mean ± S.D.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AES</td>
<td>37.2 ± 5.5</td>
<td>42.5 ± 8.9</td>
<td>0.006</td>
</tr>
<tr>
<td>Cognition</td>
<td>16.8 ± 3.2</td>
<td>18.9 ± 3.8</td>
<td>0.004</td>
</tr>
<tr>
<td>Behaviour</td>
<td>9.9 ± 2.7</td>
<td>11.1 ± 3.1</td>
<td>0.145</td>
</tr>
<tr>
<td>Emotion</td>
<td>5.4 ± 1.1</td>
<td>5.8 ± 1.2</td>
<td>0.052</td>
</tr>
<tr>
<td>Other</td>
<td>6.3 ± 1.2</td>
<td>6.8 ± 1.7</td>
<td>0.006</td>
</tr>
</tbody>
</table>

AES: Apathy Evaluation Scale; S.D.: standard deviation.

There was a significant reduction in recognition percentages for facial expressions of fear (43.1% ± 22.9 vs. 61.6% ± 21.4, p = 0.022) and sadness (52.7% ± 19.1 vs. 67.6% ± 22.8, p = 0.001) after STN DBS.

### Table 3

Neuropsychological background data (mean ± S.D.) before (baseline preoperative condition, M = 3) and after (postoperative condition, M + 3) STN DBS in PD patients (comparison using the Wilcoxon test for paired samples), p < 0.05; Data are reported for both the off- and on-dopa conditions

<table>
<thead>
<tr>
<th></th>
<th>Preoperative condition (Baseline)</th>
<th>Postoperative condition (M + 3)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± S.D.</td>
<td>Mean ± S.D.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.M.S.E:</td>
<td>Mini Mental State Examination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMT: Trail Making Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.C.S.T: Modified Wisconsin Card Sorting Test</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.8.4. Correlations

2.8.4.1. Apathy–Ekman correlations. There was no significant correlation between the apathy score and either fear recognition (r = -0.127, p = 0.63) or sadness recognition (r = 0.175, p = 0.50) before surgery.

There was no significant correlation between the apathy score and either fear recognition (r = 0.394, p = 0.12) or sadness recognition (r = 0.266, p = 0.30) at M3.

Lastly, there was no significant correlation between variations in apathy and emotion recognition scores before and after surgery for either fear (r = 0.353, p = 0.17) or sadness (r = 0.276, p = 0.28).

2.8.4.2. Apathy-neuropsychological background correlations. At M3, there was no correlation between the apathy score and the categorical verbal fluency score (r = 0.042, p = 0.873), although there was a significant correlation between the postoperative apathy score and the phonemic verbal fluency score (r = 0.624, p = 0.007).

No significant correlation was found between the variations in these two scores before and after surgery (r = 0.223, p = 0.39 and r = 0.054, p = 0.84, respectively). Furthermore, there was no significant correlation between the apathy scores and the other neuropsychological scores.

### Table 4

Facial affect recognition. The facial affect recognition data of the PD patient group are presented in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Preoperative condition (Baseline)</th>
<th>Postoperative condition (M + 3)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± S.D.</td>
<td>Mean ± S.D.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMT (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>58.1 ± 19.6</td>
<td>55.9 ± 19.9</td>
<td>0.962</td>
</tr>
<tr>
<td>B</td>
<td>139.1 ± 69.9</td>
<td>157.5 ± 92.6</td>
<td>0.394</td>
</tr>
<tr>
<td>B – A</td>
<td>81.1 ± 57.7</td>
<td>101.6 ± 83.7</td>
<td>0.435</td>
</tr>
<tr>
<td>Verbal fluency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Categorical</td>
<td>20.2 ± 6.5</td>
<td>15.3 ± 4.6</td>
<td>0.015</td>
</tr>
<tr>
<td>Phonemic</td>
<td>20.8 ± 7.4</td>
<td>16.9 ± 5.5</td>
<td>0.049</td>
</tr>
<tr>
<td>M.C.S.T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of categories</td>
<td>5.6 ± 0.7</td>
<td>5.3 ± 1.4</td>
<td>0.346</td>
</tr>
<tr>
<td>Number of errors</td>
<td>8.3 ± 5.2</td>
<td>6.4 ± 5.9</td>
<td>0.139</td>
</tr>
<tr>
<td>Number of perseverations</td>
<td>3.0 ± 2.8</td>
<td>2.8 ± 3.3</td>
<td>0.524</td>
</tr>
</tbody>
</table>

M.M.S.E: Mini Mental State Examination; TMT: Trail Making Test; M.C.S.T: Modified Wisconsin Card Sorting Test; S.D.: standard deviation.
2.8.4.3. Ekman-neuropsychological background correlations. There was no significant correlation between impaired fear recognition and either categorical verbal fluency ($r = 0.150$, $p = 0.566$) or phonemic verbal fluency ($r = -0.451$, $p = 0.060$) at M3, although the latter was close to significance. There was no significant correlation between impaired sadness recognition and either categorical verbal fluency ($r = -0.197$, $p = 0.45$) or phonemic verbal fluency ($r = -0.062$, $p = 0.81$) at M3. With the difference scores, no correlation was found between these two scores and either fear recognition ($r = 0.326$, $p = 0.20$ and $r = 0.115$, $p = 0.66$, respectively) or sadness recognition ($r = 0.313$, $p = 0.22$ and $r = 0.300$, $p = 0.24$, respectively).

### Table 4
Facial affect recognition data (mean ± S.D.) before (baseline preoperative condition, M − 3) and after (postoperative condition, M + 3) STN DBS in PD patients (comparison using the Wilcoxon test for paired samples). *$p < 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>Preoperative condition (Baseline)</th>
<th>Postoperative condition (M + 3)</th>
<th>Group effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (%) ± S.D.</td>
<td>Mean (%) ± S.D.</td>
<td></td>
</tr>
<tr>
<td>Happiness</td>
<td>95.8 ± 6.1</td>
<td>98.5 ± 4.1</td>
<td>0.377</td>
</tr>
<tr>
<td>Sadness</td>
<td>67.6 ± 22.8</td>
<td>52.7 ± 19.1</td>
<td>0.031*</td>
</tr>
<tr>
<td>Fear</td>
<td>61.6 ± 21.4</td>
<td>43.1 ± 22.9</td>
<td>0.022*</td>
</tr>
<tr>
<td>Surprise</td>
<td>89.9 ± 14.3</td>
<td>94.1 ± 11.3</td>
<td>0.848</td>
</tr>
<tr>
<td>Disgust</td>
<td>91.6 ± 14.3</td>
<td>93.4 ± 12.3</td>
<td>0.737</td>
</tr>
<tr>
<td>Anger</td>
<td>67.0 ± 16.6</td>
<td>67.9 ± 21.6</td>
<td>0.943</td>
</tr>
<tr>
<td>No emotion</td>
<td>87.3 ± 16.6</td>
<td>91.5 ± 10.1</td>
<td>0.379</td>
</tr>
<tr>
<td>Total score</td>
<td>80.1 ± 7.9</td>
<td>76.9 ± 7.0</td>
<td>0.076</td>
</tr>
</tbody>
</table>

Data are reported for both the off- and on-dopa conditions. S.D.: standard deviation.

3. Discussion

In this prospective study, we replicated the findings of two earlier studies (Biseul et al., 2005; Drapier et al., 2006) with a different group of patients, demonstrating that significant apathy and emotion recognition impairment can be observed following STN-DBS. However, in the present study, we failed to find any significant correlation between apathy and emotion recognition either before or after STN DBS in PD. Although this negative result has to be interpreted with caution, it may suggest that each of these phenomena—apathy and basic emotion recognition—responds to a separate functional network, even if both circuits pass through the subthalamic nucleus. Furthermore, it may suggest that the emotional dimension of apathy in PD is not linked to emotion recognition impairment.

Some limitations have to be taken into account when interpreting our results. We need to bear in mind that the facial affect recognition task has several methodological limitations. First, the use of categorization and forced choice could be a limitation, because it does not allow users to explore the correlations between the different scales. Second, the use of static facial expressions could also be a limitation, because it does not offer any opportunity to modulate the facial actions in terms of the smallest visible unit of muscular activity (action units) (Ekman & Friesen, 1978).

Another limitation of our study is that we studied Parkinsonian brains, which limited the speculations we could make about the role of the STN in emotion processing in normal brains. However, it is important to note that our patients had a normal neuropsychological status and that there were no significant correlations between either emotion recognition or apathy and most of the neuropsychological data, suggesting that these impairments were not linked to nonspecific cognitive impairments.

Lastly, our results were based on a negative finding (no correlation between apathy and emotion recognition scores) which may be difficult to interpret. Even though the study’s power calculation based upon the main criterion, i.e. the worsening of apathy scores, produced good results, it is still possible that the small number of observations was responsible for the lack of correlation. However, the Apathy–Ekman correlation graphs showed a wide dispersion of observations: among patients with the same apathy difference score, we can observe opposite variations in the Ekman scores for fear or sadness. This point reinforces our notion of a lack of correlation between apathy and the emotion recognition scores, as measured by the coefficient calculations and assessed by the statistical tests.

In one of our previous studies (Drapier et al., 2006) we examined whether STN-DBS induced apathy in PD patients. We showed that STN-DBS does indeed contribute to the development of postoperative apathy, which was significantly identified in the patient group when it was compared with a control group.

Clinically, apathy can be defined as a lack of reaction to emotional stimuli. Extensively described by Marin (1991) apathy appears to take the form of complex emotional withdrawal with emotional, behavioural and cognitive dimensions, as reflected by the different subscores of Marin’s scale (Marin et al., 1991). However, our results show that there is no correlation between apathy and emotion recognition in PD before surgery, indicating that emotional disorders in apathy before surgery cannot be ascribed to a recognition impairment. Furthermore, we failed to find any significant correlation between variations in the apathy and emotion recognition scores before and after surgery. The emotional and cognitive subscores of the apathy scale were significantly lower following surgery. Taken together, these results show that, despite the fact that DBS was responsible for the worsening of apathy and the emotion recognition impairment, these two phenomena could not be closely linked, even though both of them could be modulated by STN stimulation.

Due to the lack of data for most diseases, the neuroanatomy of apathy has mainly been explored in functional brain imaging studies of patients with dementia—a group of patients where apathy is detected at its onset (Robert et al., 2002). Results have revealed the involvement of the anterior and inferior frontal regions (Benoit et al., 2002). The anterior cortical circuit, one of the five cortical-subcortical circuits described by Alexander, Delong, & Strick (1986), is associated with the mediation of motivation-based behaviour (Chow, Cummings, Miller, & Cummings, 1999). It enables motivation to be turned into action (Groenewegen, Wright, & Beijer, 1986; Mogenson, Jones, & Yim, 1980) and has afferent connections with the orbitofrontal cortex, limbic regions and basal ganglia (Mega & Cummings, 1997).

In the second of our two previous studies (Biseul et al., 2005), our team investigated facial expression recognition in PD patients following STN-DBS. The results showed a specific impairment of fearful facial expression recognition in the postoperative group in comparison with both the preoperative and control groups. The functional emotion recognition network has been extensively described and involves many cortical and subcortical structures. Amygdala stimulation commonly evokes fear in humans (Phillips, Drewets, Rauch, & Lane, 2003a). Several studies have emphasized the importance of the amygdala in identifying emotional expressions displayed by others, particularly threat-related emotions such as fear (Calder, Lawrence, & Young, 2001; Davis & Whalen,
The existence of a functional network linking the amygdala and both the orbitofrontal and anterior cingular cortex was recently demonstrated, using fMRI during the perceptual processing of fearful facial expressions (Hariri, Mattay, Tessitore, Fera, & Weinberger, 2003), with activation of the inferior prefrontal cortex (Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998). Both the ventromedial prefrontal cortex and the orbitofrontal cortex, which have direct connections with the amygdala, would appear to be particularly important in animals and humans for representing the reward value of a stimulus and the way in which this representation then guides goal-directed and normal social behaviour (Damasio, 1994) merging emotion, motivation and behaviour. Our results suggest that the STN may modify amygdala activity, although the existence of direct interconnections between these two structures has never been proven, either in animals or in humans.

Phillips, Drevets, Rauch, & Lane (2003a, 2003b) have suggested that emotion perception and expression are organised at a neuronal level. This type of organisation would involve two complementary neuronal systems. The first of these, a ventral system, would include the amygdala, the insula, the ventral striatum and the ventral region of the anterior cingular gyrus. This system would identify the emotion’s meaning and produce a suitable emotional state. The second, dorsal system, would include the hippocampus and the dorsal region of the anterior cingular cortex and prefrontal cortex—regions more deeply involved in the cognitive aspect of emotions. Reciprocal interactions probably exist between these two systems.

The STN is described as being situated in a central position in all five corticobasal ganglia-thalamocortical circuits, which each have specific motor, oculomotor, associative and limbic functions (Alexander & Crutcher, 1990). Neuroanatomical and physiological studies in animals have demonstrated that the STN can be functionally divided into sensorimotor (dorsolateral), limbic (medial) and cognitive (ventromedial) regions (Parent & Hazrati, 1995). Our results suggest that both apathy and emotion recognition can be impaired after STN DBS. Because of the small size of the STN and current diffusion within the structure, STN DBS may act on different functional circuits, either activating or inhibiting different neuronal networks, including emotional and associative circuits.

Apathy is a complex neuropsychiatric disorder with behavioural, cognitive and emotional dimensions. Our results suggest that the facial emotion recognition disorder cannot explain apathy, which has to be considered as a whole, including its behavioural and cognitive aspects. Apathy following STN DBS could be related to the stimulation of the STN’s associative circuit, rather than its limbic region, which could account for the facial recognition impairment. Moreover, verbal fluency is classically linked to the associative part of STN (Dujardin, Defebvre, Krystkowiak, Blond, & Destee, 2001; Trepanier et al., 2000). Our finding of a negative correlation between the apathy score and verbal fluency after STN DBS suggests that these two phenomena may vary to the same degree (scores moving in opposite directions) and confirms the influence of the STN’s associative circuit on the occurrence of apathy following DBS. Further imaging studies should help to confirm this dual functional hypothesis.

Acknowledgement

The authors would like to thank Ms. Wiles Portier for preparing the manuscript.

References


