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Neuropsychological effects of deep brain stimulation for Parkinson's disease

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Abstract

Background: Putative changes of cognition after deep brain stimulation (DBS) in patients with Parkinson's disease (PD) are a matter of debate. The aim of this study was to assess cognitive abilities before and following bilateral subthalamic nucleus (STN) DBS and to review the available literature.

Methods: Twenty patients underwent bilateral DBS of the STN. Cognitive skills were assessed in a standardized fashion before and at least at 12 months after the surgical intervention.

Results: There was a significant decline of both semantic and phonematic verbal fluency and a mild trend for a deterioration of verbal memory after DBS. Mood, general cognitive screening, and visospatial abilities remained unchanged.

Conclusion: STN DBS in the treatment of PD has resulted in a significant reduction of motor symptoms and improved independence and quality of life in appropriately selected patients. However, it may have isolatable effects on verbal fluency and related function. Case series in the literature reported similar findings. Potential candidates for DBS should be counseled about the risk of mild cognitive declines.

Key Words: Cognitive decline, deep brain stimulation, memory, Parkinson's disease, subthalamic nucleus, verbal fluency

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INTRODUCTION

Parkinson's disease (PD) is a common neurodegenerative motor disorder, clinically characterized by the progressive impairment of motor function and associated cognitive decline.[21] Deep brain stimulation (DBS) of the bilateral subthalamic nuclei (STN) treatment was proven to be surgically safe in well-selected candidates. DBS improves dopamine sensitive symptoms and dyskinesia and allows for reduced drug doses.[5,8,12,18,30] However, short- and long-term investigations of STN DBS in PD patients yielded variable findings regarding the nature and extent of cognitive changes after surgery. Therefore cognitive changes and the predictors for such changes are still a matter of debate.[3,6,8-10,12,14,17,19,28,32,37,38,42-44,48,49,51,52] We had already demonstrated an improved performance of executive functions, complex motion sequences, and complex reaction time shortly after DBS.[13] The aim of our present study was to assess cognitive outcome in PD patients by a standardized performance of a neuropsychological test battery following STN DBS after an interval of at least several months lasting interval.

PATIENTS AND METHODS

Patients

20 PD patients (13 men) participated in this trial. They received bilateral DBS of the STN. The selection criteria were clinically diagnosed PD, severe levodopa-related motor complications despite prior optimal adjustment of antiparkinsonian medication, no surgical contraindications, no dementia or major ongoing psychiatric illness and no other neurological disorders. The characteristics of the patients are summarized in Table 1.

Surgical techniques

The procedures were staged in all patients with implantation of bilateral STN electrodes in one session and implantation of the pulse generators in a second session 3-5 days later. A Leksell stereotactic head frame (Elekta Instruments, Stockholm, Sweden) was placed. The dorsolateral (sensorimotor) portion of the STN was localized using a proportional geometric scheme based on the distance between the anterior commissure and the posterior commissure, as well as the location of the midcommisural point. The electrodes were implanted under local anesthesia during a single operative session, using a combined approach of intraoperative recording and stimulation. The electrode position was controlled either by postoperative computed tomography (CT) or magnet resonance imaging (MRI). The definitive quadripolar electrodes (model 3389; Medtronic) were connected to a subcutaneous programmable pulse generator (Kinetra; Medtronic) in the subclavicular area in a second operative session. Electrical parameters (pulse width, frequency, and voltage) were adjusted progressively using an electromagnetic programmer (7532 neurological programmer; Medtronic).

Cognitive and behavioral assessment

Cognitive assessment was carried out with an extensive neuropsychological test battery. It included:

1. Cognitive screening by the Mini Mental State Examination (MMSE)[16] and the Parkinson Neuropsychometric Dementia Assessment (PANDA)[23]
2. Verbal memory with a German version of the Rey Auditory Verbal Learning Test (verbal memory test [VLMT])[33] and the verbal digit span forward and backward (German version of Wechsler memory scale-Revised [WMS-R])
3. Determination of amnestic disorders (Berlin amnesia test [BAT])[31]
4. Investigation of visospatial abilities by the Clock drawing test[41] and the Leistungsprüfsystem (LPS) subtests 3 and 7[20]
5. Performance of language phonological and semantic verbal fluency ("Regensburg verbal fluency test" [RWT])[2]
6. Execution of the Becks Depression Inventory (BDI).[4]

The raw scores were assessed for each patient. The raw scores for WMS-R, VLMT, RWT, BAT, and LPS were then adjusted for age-matched percentile-ranges.

Table 1: Patient characteristics

	Mean±Standard deviation
Age (years)	62.8±8.5
Duration of disease (years)	15±4,8
UPDRS I mental behavior	2.6±1.7
UPDRS II activities of daily living	11±5.0
UPDRS III on	15.3±9.3
UPDRS III off	37.6±16.7
Amplitude left (V)	2.77±0.7
Amplitude right (V)	2.70±0.7
Premorbid intelligence[a] (IQ)	112.6±17.9

[a]Assessment of premorbid intelligence as revealed by the German version of the Multiple Choice Vocabulary Test (MWT-B)[27], UPDRS: Unified Parkinson's disease rating scale

Table 2: Neuropsychological assessment results

	Preoperative	Postoperative	*P* value
General cognitive screening			
Mini mental state examination[a]	26.3	26.8	n.s.
The parkinson neuropsychometric dementia assessment[a]	17.7	19.0	n.s.
Memory			
Verbal digit span forward[b]	53.5	37.9	**
Verbal digit span backward[b]	31.1	24.1	*
Episodic verbal memory (VLMT)			
Trial 1-attention[b]	48.5	35.3	n.s.
Trial 5-attention[b]	46.3	35.3	**
Interference[b]	51.0	35.0	**
Trial 6[b]	41.5	33.8	n.s.
Immediate recall[b]	31.8	28.8	n.s.
Delayed recall[b]	29.0	24.6	n.s.
Berliner amnesia test[b]	25.0	25.7	n.s.
Language			
Phonematic Verbal fluency[b] (RWT)	53.9	32.1	***
Semantic Verbal fluency[b] (RWT)	43.1	31.2	*
Visospatial abilities			
Clock drawing[a]	2.1	2.2	n.s.
Logical thinking[b] (LPS subtest 3)	33.3	37.5	n.s.
Geometric figures[b] (LPS subtest 7)	37.4	33.5	n.s.
Mood			
Becks depression inventory[a]	10.0	9.8	n.s.

[a]Raw-scores, [b]Percentile, n.s.: Not significant, *P<0.05, **P<0.01, ***P<0.001

Design

Cognitive assessment and a clinical interview, aimed at detecting the presence of behavioral abnormalities or psychiatric disorders, were performed preoperatively (during the week preceding electrode implantation) and postoperatively between 12 and 18 months after implantation. All cognitive and behavioral assessments before and after surgery were performed while the patients were on an antiparkinsonian medication. Postoperative cognitive and behavioral assessments were performed with stimulators turned on.

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS version 13.0). The Wilcoxon rank sum test was applied for comparison between the mean scores preoperatively and at the postoperative assessment. A level of $P < 0.05$ was considered significant.

Ethics

Written informed consent was obtained from each subject. The local ethics committee of the university approved this study.

RESULTS

There was a worsening of verbal fluency and verbal digit span after DBS. Verbal memory declined compared with preoperative scores and deteriorated in two out of six items. The general cognitive screening and visospatial abilities remained unchanged. Mood was not altered [Table 2]. No serious adverse events (e.g., hemorrhage, infection, or infarction) occurred during surgery. Postoperative imaging revealed no dislocation of the electrodes.

DISCUSSION

Our results and the most consistent findings from the literature [Table 3] revealed declines in verbal fluency. Additionally, our results also confirmed previous results, which demonstrated more decline of verbal memory relative to nonverbal memory.[19] Otherwise, executive functions and visospatial abilities were less affected following STN DBS.

The variable frequencies of cognitive decline after STN DBS in the literature were caused by different ascertainment methods, patient selection criteria,

Table 3: Review of case series regarding cognitive decline after STN DBS for PD

Series	No. of patients	Follow-up in months	Improvements	Unchanged	Declines
Ardouin *et al*.[1]	24	12	EF	GCS	L
Pillon *et al*.[37]	63	6-12	EF	M	L
Perozzo *et al*.[36]	20	6	-	L, M, EF	-
Daniele *et al*.[10]	20	12-18	GCS, EF	M	L
Krack *et al*.[26]	49	60	-	GCS	EF
Funkiewiez *et al*.[18]	50	12-36	-	EF, GCS	L
Castelli *et al*.[7]	72	15	EF	M	L
De Gaspari *et al*.[11]	26	15	-	GCS	L
Deuschl *et al*.[12]	78	6	-	GCS	-
Erola *et al*.[14]	29	12	-	EF	L
Smeding *et al*.[42]	103	6	-	-	L, EF, M
Aybek *et al*.[3]	57	34	-	L, VS	M, EF
Ory-Magne *et al*.[35]	45	24	-	EF, L, M	-
Heo *et al*.[19]	46	12	-	GCS, EF, M (nonverbal)	L, M (verbal)
Ellrichmann *et al*.[13]	19	12	EF	-	-
York *et al*.[51]	23	6	-	GCS, EF, VS	L, M
Witt *et al*.[48]	60	6	-	GCS, M, VS	L, EF
Okun *et al*.[34]	26	7	-	L (phonematic VF)	L (semantic VF)
Zangaglia *et al*.[54]	32	36	-	GCS, M	L, EF
Fasano *et al*.[15]	20	96	-	GCS	L, M, EF
Kishore *et al*.[25]	45	60	-	GCS, EF, L, M, VS	-
Smeding *et al*.[43]	105	12	-	-	L, M, EF, GCS
Merola *et al*.[29]	19	95	-	-	L, M, EF
Saez-Zea *et al*.[39]	21	6	-	GCS, EF, M	L
Kim *et al*.[24]	36	6-36	-	-	GCS
Current series	20	6-12	-	GCS, EF, VS	L, M (verbal)

EF: Executive function, GCS: General cognitive screening, L: Language, M: Memory, VS: Visospatial abilities, STN: Subthalamic nucleus, DBS: Deep brain stimulation, PD: Parkinson's disease

operative techniques, and pre- and postoperative patient management strategies. Studies using formal and substantial neuropsychological evaluation were more likely to find changes than studies using undefined methods or simple cognitive screening instruments such as the MMSE.

Despite use of different assessment tools, STN DBS in most series was associated with decline of verbal fluency. Performance on verbal fluency might be disrupted in PD and consecutively predict incipient dementia.[21,50] Otherwise, the finding that STN DBS patients declined in verbal fluency and related functions more than in other cognitive tasks might reflect a different mechanism underlying cognitive deterioration following surgery. Declines in verbal fluency were usually associated with left-sided DBS.[53,54] In a positron emission tomography (PET) study STN stimulation resulted in decreased activation of the inferior frontal and temporal cortex in the left cerebral hemisphere, resulting in decreased verbal fluency.[40] The effects of STN DBS might be attributable to the electrical stimulation of specific structures or inhibition of over activity in the thalamic region. However, since the decline in verbal fluency was mostly detected shortly after surgery, it might be due to surgical micro lesions affecting cortical-basal circuits involved in word retrieval processes.[45-47] Several studies assessed language function in PD patients following STN DBS on and off stimulation. With the exception of two, all studies failed to observe a significant improvement or decline in verbal fluency in the on-stimulation compared with the off-stimulation condition.[22,37]

In conclusion, STN DBS independently affects verbal and nonverbal cognitive function.

STN DBS in the treatment of PD has resulted in a significant reduction of motor symptoms and improved independence and quality of life for most carefully selected patients. This procedure is associated with some risk for cognitive side effects beyond the expected rate of usual surgical complications such as hemorrhage or infection. The neuropsychological assessment must be considered essential to minimize such risks and to further our understanding of the underlying neurobiology and neuropsychological impact of these treatments.

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REFERENCES

1. Ardouin C, Pillon B, Peiffer E, Bejjani P, Limousin P, Damier P, *et al*. Bilateral subthalamic or pallidal stimulation for Parkinson's disease affects neither memory nor executive functions: A consecutive series of 62 patients. Ann Neurol 1999;46:217-23.
2. Aschenbrenner S, Tucha O, Lange KW, Regensburger Wortflüssigkeitstest- RWT. Göttingen: Hogrefe Publishing; 2000.
3. Aybek S, Gronchi-Perrin A, Berney A, Chiuvé SC, Villemure JG, Burkhard PR, *et al*. Long-term cognitive profile and incidence of dementia after STN-DBS in Parkinson's disease. Mov Disord 2007;22:974-81.
4. Beck AT, Ward D, Mendelson M, Mock J, Erbaugh J. An inventory for measuring depression. Arch Gen Psychiatry 1961;4:561-71.
5. Bronstein JM, Tagliati M, Alterman RL, Lozano AM, Volkmann J, Stefani A, *et al*. Deep brain stimulation for Parkinson disease: An expert consensus and review of key issues. Arch Neurol 2011;68:165.
6. Castelli L, Lanotte M, Zibetti M, Caglio M, Rizzi L, Ducati A, *et al*. Apathy and verbal fluency in STN-stimulated PD patients. An observational follow-up study. J Neurol 2007;254:1238-43.
7. Castelli L, Perozzo P, Zibetti M, Crivelli B, Morabito U, Lanotte M, *et al*. Chronic deep brain stimulation of the subthalamic nucleus for Parkinson's disease: Effects on cognition, mood, anxiety and personality traits. Eur Neurol 2006;55:136-44.
8. Contarino MF, Daniele A, Sibilia AH, Romito LM, Bentivoglio AR, Gainotti G, *et al*. Cognitive outcome 5 years after bilateral chronic stimulation of subthalamic nucleus in patients with Parkinson's disease. J Neurol Neurosurg Psychiatr 2007;78:248-52.
9. Coulthard EJ, Bogacz R, Javed S, Mooney LK, Murphy G, Keeley S, *et al*. Distinct roles of dopamine and subthalamic nucleus in learning and probabilistic decision making. Brain 2012;135:3721-34.
10. Daniele A, Albanese A, Contarino MF, Zinzi P, Barbier A, Gasparini F, *et al*. Cognitive and behavioural effects of chronic stimulation of the subthalamic nucleus in patients with Parkinson's disease. J Neurol Neurosurg Psychiatr 2003;74:175-82.
11. De Gaspari D, Siri C, Di Gioia M, Antonini A, Isella V, Pizzolato A, *et al*. Clinical correlates and cognitive underpinnings of verbal fluency impairment after chronic subthalamic stimulation in Parkinson's disease. Parkinsonism Relat Disord 2006;12:289-95.
12. Deuschl G, Schade-Brittinger C, Krack P, Volkmann J, Schäfer H, Bötzel K, *et al*. A randomized trial of deep-brain stimulation for Parkinson's disease. N Engl J Med 2006;355:896-908.
13. Ellrichmann G, Harati A, Müller T. Deep brain stimulation improves performance of complex instrumental paradigms. Eur Neurol 2008;60:32-6.
14. Erola T, Heikkinen ER, Haapaniemi T, Tuominen J, Juolasmaa A, Myllylä VV. Efficacy of bilateral subthalamic nucleus (STN) stimulation in Parkinson›s disease. Acta Neurochir (Wien) 2006;148:389-94.
15. Fasano A, Romito LM, Daniele A, Piano C, Zinno M, Bentivoglio AR, *et al*. Motor and cognitive outcome in patients with Parkinson's disease 8 years after subthalamic implants. Brain 2010;133:2664-76.
16. Folstein MF, Robins LN, Helzer JE. The mini-mental state examination. Arch. Gen. Psychiatry 1983;40:812.
17. Freund H-J, Kuhn J, Lenartz D, Mai JK, Schnell T, Klosterkoetter J, *et al*. Cognitive functions in a patient with Parkinson-dementia syndrome undergoing deep brain stimulation. Arch Neurol 2009;66:781-5.
18. Funkiewiez A, Ardouin C, Caputo E, Krack P, Fraix V, Klinger H, *et al*. Long term effects of bilateral subthalamic nucleus stimulation on cognitive function, mood, and behaviour in Parkinson's disease. J Neurol Neurosurg Psychiatr 2004;75:834-9.
19. Heo JH, Lee KM, Paek SH, Kim MJ, Lee JY, Kim JY, *et al*. The effects of bilateral subthalamic nucleus deep brain stimulation (STN DBS) on cognition in Parkinson disease. J Neurol Sci 2008;273:19-24.
20. Horn W. Leistungsprüfsystem, L-P-S: Handanweisung für die Durchführung, Auswertung und Interpretation. Göttingen: Hofgraefe Publishing; 1962.
21. Jacobs DM, Marder K, Côté LJ, Sano M, Stern Y, Mayeux R. Neuropsychological characteristics of preclinical dementia in Parkinson's disease. Neurology 1995;45:1691-6.
22. Jahanshahi M, Ardouin CM, Brown RG, Rothwell JC, Obeso J, Albanese A, *et al*. The impact of deep brain stimulation on executive function in Parkinson's disease. Brain 2000;123:1142-54.
23. Kalbe E, Calabrese P, Kohn N, Hilker R, Riedel O, Wittchen HU, *et al*. Screening for cognitive deficits in Parkinson's disease with the Parkinson neuropsychometric dementia assessment (PANDA) instrument. Parkinsonism Relat Disord 2008;14:93-101.
24. Kim HJ, Jeon BS, Yun JY, Kim YE, Yang HJ, Paek SH. Initial cognitive dip after subthalamic deep brain stimulation in Parkinson disease. J Neurol 2013;260:2130-3.

25. Kishore A, Rao R, Krishnan S, Panikar D, Sarma G, Sivasanakaran MP, *et al*. Long-term stability of effects of subthalamic stimulation in Parkinson's disease: Indian Experience. Mov Disord 2010;25:2438-44.
26. Krack P, Batir A, Van Blercom N, Chabardes S, Fraix V, Ardouin C, *et al*. Five-year follow-up of bilateral stimulation of the subthalamic nucleus in advanced Parkinson's disease. N Engl J Med 2003;349:1925-34.
27. Lehrl S, Triebig G, Fischer B. Multiple choice vocabulary test MWT as a valid and short test to estimate premorbid intelligence. Acta Neurol Scand 1995;91:335-45.
28. Massano J, Garrett C. Deep brain stimulation and cognitive decline in Parkinson's disease: A clinical review. Front Neurol 2012;3:66.
29. Merola A, Zibetti M, Angrisano S, Rizzi L, Lanotte M, Lopiano L. Comparison of subthalamic nucleus deep brain stimulation and Duodopa in the treatment of advanced Parkinson's disease. Mov Disord 2011;26:664Z60.
30. Merola A, Zibetti M, Angrisano S, Rizzi L, Ricchi V, Artusi CA, *et al*. Parkinson's disease progression at 30 years: A study of subthalamic deep brain-stimulated patients. Brain 2011;134:2074-84.
31. Metzler P, Rudolph M, Voshage J, Nickel B. The concept of amnesia and quantitative assessment of amnesic disorders. Fortschr Neurol Psychiatr 1991;59:207-15.
32. Mikos A, Zahodne L, Okun MS, Foote K, Bowers D. Cognitive declines after unilateral deep brain stimulation surgery in Parkinson's disease: A controlled study using Reliable Change, part II. Clin Neuropsychol 2010;24:235-45.
33. Müller H, Hasse-Sander I, Horn R, Helmstaedter C, Elger CE. Rey Auditory-Verbal Learning Test: Structure of a modified German version. J Clin Psychol 1997;53:663-71.
34. Okun MS, Fernandez HH, Wu SS, Kirsch-Darrow L, Bowers D, Bova F, *et al*. Cognition and mood in Parkinson's disease in subthalamic nucleus versus globus pallidus interna deep brain stimulation: The COMPARE trial. Ann Neurol 2009;65:586-95.
35. Ory-Magne F, Brefel-Courbon C, Simonetta-Moreau M, Fabre N, Lotterie JA, Chaynes P, *et al*. Does ageing influence deep brain stimulation outcomes in Parkinson's disease? Mov Disord 2007;22:1457-63.
36. Perozzo P, Rizzone M, Bergamasco B, Castelli L, Lanotte M, Tavella A, *et al*. Deep brain stimulation of the subthalamic nucleus in Parkinson's disease: Comparison of pre- and postoperative neuropsychological evaluation. J Neurol Sci 2001;192:9-15.
37. Pillon B, Ardouin C, Damier P, Krack P, Houeto JL, Klinger H, *et al*. Neuropsychological changes between "off" and "on" STN or GPi stimulation in Parkinson's disease. Neurology 2000;55:411-8.
38. Rektorova I, Hummelova Z, Balaz M. Dementia after DBS surgery: A case report and literature review. Parkinsons Dis 2011;2011:679283.
39. Sáez-Zea C, Escamilla-Sevilla F, Katati MJ, Mínguez-Castellanos A. Cognitive effects of subthalamic nucleus stimulation in Parkinson's disease: A controlled study. Eur Neurol 2012;68:361-6.
40. Schroeder U, Kuehler A, Lange KW, Haslinger B, Tronnier VM, Krause M, *et al*. Subthalamic nucleus stimulation affects a frontotemporal network: A PET study. Ann Neurol 2003;54:445-50.
41. Shulman KI. Clock-drawing: Is it the ideal cognitive screening test? Int J Geriatr Psychiatry 2000;15:548-61.
42. Smeding HM, Speelman JD, Koning-Haanstra M, Schuurman PR, Nijssen P, van Laar T, *et al*. Neuropsychological effects of bilateral STN stimulation in Parkinson disease: A controlled study. Neurology 2006;66:1830-6.
43. Smeding HMM, Speelman JD, Huizenga HM, Schuurman PR, Schmand B. Predictors of cognitive and psychosocial outcome after STN DBS in Parkinson's Disease. J Neurol Neurosurg Psychiatry 2011;82:754-60.
44. Strutt AM, Simpson R, Jankovic J, York MK. Changes in cognitive-emotional and physiological symptoms of depression following STN-DBS for the treatment of Parkinson's disease. Eur J Neurol 2012;19:121-7.
45. Tröster AI, Fields JA, Testa JA, Paul RH, Blanco CR, Hames KA, *et al*. Cortical and subcortical influences on clustering and switching in the performance of verbal fluency tasks. Neuropsychologia 1998;36:295-304.
46. Tröster AI. Neuropsychology of deep brain stimulation in neurology and psychiatry. Front Biosci 2009;14:1857-79.
47. Tröster AI, Woods SP, Fields JA. Verbal fluency declines after pallidotomy: An interaction between task and lesion laterality. Appl Neuropsychol 2003;10:69-75.
48. Witt K, Daniels C, Reiff J, Krack P, Volkmann J, Pinsker MO, *et al*. Neuropsychological and psychiatric changes after deep brain stimulation for Parkinson's disease: A randomised, multicentre study. Lancet Neurol 2008;7:605-14.
49. Witt K, Pulkowski U, Herzog J, Lorenz D, Hamel W, Deuschl G, *et al*. Deep brain stimulation of the subthalamic nucleus improves cognitive flexibility but impairs response inhibition in Parkinson disease. Arch Neurol 2004;61:697-700.
50. Woods SP, Tröster AI. Prodromal frontal/executive dysfunction predicts incident dementia in Parkinson's disease. J Int Neuropsychol Soc 2003;9:17-24.
51. York MK, Dulay M, Macias A, Levin HS, Grossman R, Simpson R, *et al*. Cognitive declines following bilateral subthalamic nucleus deep brain stimulation for the treatment of Parkinson's disease. J Neurol Neurosurg Psychiatr 2008;79:789-95.
52. York MK, Wilde EA, Simpson R, Jankovic J. Relationship between neuropsychological outcome and DBS surgical trajectory and electrode location. J Neurol Sci 2009;287:159-71.
53. Zahodne LB, Okun MS, Foote KD, Fernandez HH, Rodriguez RL, Kirsch-Darrow L, *et al*. Cognitive declines one year after unilateral deep brain stimulation surgery in Parkinson's disease: A controlled study using reliable change. Clin Neuropsychol 2009;23:385-405.
54. Zangaglia R, Pacchetti C, Pasotti C, Mancini F, Servello D, Sinforiani E, *et al*. Deep brain stimulation and cognitive functions in Parkinson's disease: A three-year controlled study. Mov Disord 2009;24:1621-8.