ETHICAL SAFETY OF DEEP BRAIN STIMULATION: A STUDY ON MORAL DECISION-MAKING IN PARKINSON'S DISEASE

Manuela Fumagalli, PhD [a], Sara Marceglia, PhD [a], Filippo Cogiamanian, MD [b], Gianluca Ardolino, MD [b], Marta Picascia [c], Sergio Barbieri, MD [b], Gabriella Pravettoni, PhD [d,e], Claudio Pacchetti, MD [b], and Alberto Priori, PhD * [a,f]

[a]Centro Clinico per la Neurostimolazione, le Neurotecnologie ed i Disordini del Movimento, Fondazione IRCCS Ca' Granda, Ospedale Maggiore Policlinico, via Francesco Sforza 35, Milan, Italy. [b]U.O. Neurofisiopatologia, Fondazione IRCCS Ca' Granda, Ospedale Maggiore Policlinico, via Francesco Sforza 35, Milan, Italy. [c]Unità Operativa Parkinson e Disordini del Movimento, IRCCS Istituto Neurologico Mondino, Via Mondino 2, Pavia, Italy. [d]Dipartimento di Economia, Management e Metodi Quantitativi, Università degli Studi di Milano, via Festa del Perdono 7, Milan, Italy. [e]Applied Research Unit for Cognitive and Psychological Science, Istituto Europeo di Oncologia, via Giuseppe Ripamonti 435, Milan, Italy. [f]Dipartimento di Fisiopatologia Medico-Chirurgica e dei Trapianti, Università degli Studi di Milano, via Francesco Sforza 35, Milan, Italy.

*** Corresponding author:**

Prof. Alberto Priori

Centro Clinico per la Neurostimolazione, le Neurotecnologie ed i Disordini del Movimento,

Fondazione IRCCS Ca' Granda, Ospedale Maggiore Policlinico,

Via Francesco Sforza 35, 20122 Milan, Italy.

e-mail: alberto.priori@unimi.it

telephone: +39 02 5503 3621

fax: +39 02 5503 3855

Keywords: Parkinson's Disease; Deep Brain Stimulation; Subthalamus; Moral decision; Ethics.

Abstract

Introduction. The possibility that deep brain stimulation (DBS) in Parkinson's disease (PD) alters patients' competence of decisions and actions, even temporarily, raises important clinical, ethical and legal questions. Abnormal moral decision-making can lead to ethical rules violations. Previous experiments demonstrated the subthalamic (STN) activation during moral decision-making. Here we aim to study whether STN DBS can affect moral decision-making in PD patients.

Methods. Eleven patients with PD with bilateral STN DBS implant performed a computerized moral task in ON and OFF conditions. A control group of PD patients without DBS implant underwent the same experimental protocol. All patients underwent a motor, cognitive and psychological assessment.

Results. STN stimulation is not able to modify neither reaction times nor responses to moral task both comparing the ON and OFF state in the same patient (reaction times, $p = .416$) and also comparing patients treated with DBS versus those treated only with the best medical treatment (reaction times: $p = .408$, responses: $p = .776$).

Conclusions. Moral judgment is the result of a complex process, that requires cognitive executive functions, problem-solving, anticipations of consequences of an action, conflict processing, emotional evaluation of context and of possible outcomes, and involves different brain areas and neural circuits. Our data show that STN DBS leaves unaffected moral decisions and therefore that the perturbation by DBS of a single part of this brain network does not affect the entire system functioning. In conclusion, the technique can be considered safe on moral behavior.

Introduction

Despite its undoubtedly beneficial effects on motor symptoms and quality of life [1], subthalamic deep brain stimulation (STN DBS) in patients with Parkinson's disease (PD) can alter decision-making and behavior, becoming an ethical and social challenge for personality, moral agency and action responsibility [2-4].

STN has a role in premature and impulsive response selection [5, 6] and its stimulation increases impulsivity during conflictual decisions [7]. However, the experimental work in this field provided heterogeneous results. Some experiments involving high-conflict decision task demonstrated increased errors during STN DBS [7-12], and others reported that impulse control disorders can occur [13-15] or worsen with DBS [13, 16]. Conversely, others found no DBS effects on behavior [13, 16] or showed that impulse control disorders can even improve after DBS [14, 16-20]. Although impulsive decision-making and changes in behavior are reversible decreasing DBS strength, turning DBS off, or with an appropriate management of drug treatment[21], the possibility that DBS can alter patients' competence of decision and of action, even temporarily, raises important clinical, ethical and legal questions.

An altered competence of decision and action can be reflected in an abnormal moral decision-making, also possibly inducing ethical rules violations[22]. We have previously shown that STN is actively involved in moral decisions in PD patients through a specific neurophysiological modulation [23]. This however did not address the STN DBS effect on moral decisions because STN activity could just mirror the activation of other brain structures.

Here we aim to study whether STN DBS can affect moral decision-making by comparing the performances during a moral task [23] of PD patients in ON and OFF DBS conditions to those of PD patients without DBS implant.

Materials and Methods

Patients

We recruited eleven patients with idiopathic PD (5 men and 6 women; mean ± standard deviation: age 63 ± 4.8 years, disease duration 11.9 ± 4.3 years, education 8.7 ± 4.2 years) and with bilateral STN DBS implant occurred no less than 6 months before the experiment and with optimal stimulation parameters (experimental group). The control group included eleven patients with idiopathic PD and without DBS implant (6 men and 5 women; mean ± standard deviation: age 65 ± 9.2 years, disease duration 7.5 ± 3.7 years, education 10.9 ± 3.6 years) who were treated with the best medical treatment for PD.

All participants did not present behavioral nor psychiatric disorders, and all of them spoke native Italian (Table 1). Patients were recruited at the Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan and at the Neurological Institute C. Mondino, Pavia. All patients gave written informed consent. The study was conducted in accordance with the Declaration of Helsinki and approved by the institutional review board.

Neuropsychological assessment

To exclude cognitive impairment all patients underwent a complete neuropsychological evaluation that includes the Mini Mental State Examination (MMSE) [24], short and long term memory tests (Digit Span (Orsini et al., 1987), Corsi Block-Tapping test (Orsini et al., 1987), Babcock Story Recall Test (Novelli et al., 1986a), a logical deductive reasoning test (Raven Colored Progressive Matrices (Basso et al., 1987)), executive functions tests (frontal assessment battery – FAB (Apollonio et al., 2005), Phonological Verbal Fluency test (Novelli et al., 1986b)), an attention test (Attentional Matrices (Spinnler & Tognoni, 1987a)) and a constructional apraxia test (Costructional Apraxia Test (Spinnler & Tognoni, 1987b)) (Table 2).

The neuropsychological battery was performed twice by the experimental group: before DBS surgery and 6 months after DBS surgery.

Moral task

The moral task is described in Fumagalli et al., 2011 [23]. Patients were tested during the best ON-drug medication condition. The experimental group performed the task in the STN DBS ON condition and in the STN DBS OFF condition in random order. For the STN DBS OFF condition, the DBS device was turned off by the physician 30 minutes prior to the session.

Two parallel versions of the moral task were used and, as well as stimulation conditions, the versions of the task were randomized and counterbalanced (Figure 1A).

The control group similarly performed the moral task twice with the same time intervals, without the STN DBS manipulation. RTs and types of response (agree, disagree) were stored for further analysis (Figure 1A).

Motor, cognitive and psychological assessment

Patients underwent a motor, cognitive and psychological assessment by using the UPDRS III, the MMSE [24], and five 100 mm Visual Analogue Scales (VASs) [25]: a mood VAS (0 corresponding to good mood), a happiness VAS (0 corresponding to happiness), an anxiety VAS (0 corresponding to anxiety), a movement difficulty VAS (0 corresponding to absence of motor difficulty) and a motor fatigue VAS (0 corresponding to maximum motor fatigue). VASs were performed twice: in STN DBS ON and OFF conditions for experimental group, and in the first and the second experimental session for the control group. UPDRS III and MMSE were evaluated when patients from the experimental group were in STN DBS ON condition (Figure 1B) and when control patients were in the first session.

Statistical Analyses

Neuropsychological assessment

In the experimental group, corrected scores obtained by all tests performed before DBS surgery and 6 months after DBS surgery were compared by paired t-tests for dependent sample.

To compare neuropsychological performances of the experimental group before and after DBS surgery and the control group, respectively two paired t-tests for independent sample were run (Table 2).

RTs

Normality test was performed on RTs with One-Sample Kolmogorov-Smirnov Test. To evaluate whether RTs obtained at the moral task by the experimental group differed in ON and OFF stimulation, a two-way ANOVA was run with sentence type (moral conflictual, moral non conflictual, and neutral) and DBS stimulation (ON, OFF) as within factors.

To evaluate the role of gender, a three-way mixed-model ANOVA was applied with sentence type (moral conflictual, moral non conflictual, and neutral) and DBS stimulation (ON, OFF) as within factors and gender as between factor (man, woman).

The role of education was investigated using a three-way mixed-model ANOVA with sentence type (moral conflictual, moral non conflictual, and neutral) and DBS stimulation (ON, OFF) as within factors and education as between factor (5, 8, 13, 17 years of education).

The same analyses were performed on the control group RTs comparing the two sessions in place of DBS conditions (session 1, session 2).

To assess whether the experimental and the control group were comparable, paired t-tests were calculated for the following variables: age, disease duration, education, levodopa equivalent dose, UPDRS III score, MMSE score, VASs scores (in ON stimulation for the experimental group, in the session 1 for the control group). A chi-square test was run to evaluate whether the experimental and the control groups differed for gender.

To compare RTs obtained in the experimental and control groups, a three-way ANOVA was run with group (experimental, control group), condition (ON/OFF, session 1/session 2) and sentence type (moral conflictual, moral non conflictual, and neutral) as within factors.

Type of Response

Normality test was performed on type of response with One-Sample Kolmogorov-Smirnov Test. Because responses to moral sentences cannot be defined as correct or incorrect, to analyze the type of response, the most frequent response given by the control group for each moral conflictual and moral non conflictual sentence was considered as the reference response. The *percentage of reference-like responses*, that is the percentage of responses given at each sentence by the experimental group in ON and in OFF stimulation that agrees with the reference response, was calculated. For example, at the sentence *Abortion is a murder* the majority of patients from the control group responded “I agree” (reference response). The percentage of patients from the experimental group tested in ON stimulation that agreed with the sentence was 45% (percentage of reference-like response in ON), and the percentage of patients from the experimental group and in OFF stimulation that agreed with the sentence was 36% (percentage of reference-like response in OFF). To assess whether DBS stimulation affects the type of response, paired t-tests between percentage of reference-like response in ON and OFF stimulation in moral conflictual and moral non conflictual sentences were performed.

Motor and psychological variables

Normality test was performed for mood VAS, happiness VAS, anxiety VAS, movement difficulty VAS, movement fatigue VAS with One-Sample Kolmogorov- Smirnov Test.

In the experimental group, the effect of DBS stimulation was assessed with paired t-test for each variable. Differences were considered significant at $p < .05$.

Results

Neuropsychological assessment

In the experimental group, no significant differences were found between neuropsychological tests performed before DBS surgery and 6 months after DBS surgery.

The comparison between neuropsychological performances obtained by the experimental group tested before DBS surgery and the control group revealed a significant difference only in the short-term verbal memory test (Digit Span), that was better performed by the control group. However, both groups (in mean) performed this task normally.

By comparing neuropsychological performances obtained by the experimental group tested 6 months after DBS surgery and the control group, data showed that there was only a significant different performance at the MMSE score, that was higher in the control group, but in both groups indicated a non pathological performance (Table 2).

RTs

One-Sample Kolmogorov-Smirnov Test on RTs for moral conflictual, moral non conflictual, and neutral sentences collected from both experimental and control groups were normally distributed ($p > .05$ for all variables).

In the experimental group, analysis showed that RTs significantly differed between sentence types (moral conflictual, moral non conflictual, and neutral) but that RTs are unaffected neither by DBS stimulation, nor gender nor education.

Results in the control group resembled those in the experimental group: RTs were significantly different between the three sentence types, but did not differ considering the session, gender and education.

Comparing the experimental and control group, cognitive, psychological and motor variables revealed that groups did not differ for age, disease duration, years of education, levodopa equivalent dose, MMSE score, VASs scores, UPDRS III score, and gender.

Comparing the two groups (Figure 2), data revealed that RTs were similar in DBS and control patients (Table 3).

Response type

One-Sample Kolmogorov-Smirnov Test for moral conflictual, moral non conflictual and neutral responses obtained by patients from the experimental group in ON and OFF stimulation and by patients from the control group in the session1 and 2 showed a normal distribution ($p > .05$ for all variables).

In ON and OFF stimulation the percentage of reference-like responses for moral conflictual sentences did not differ, nor it did the percentage of reference-like responses for moral non conflictual sentences (Table 3) (Figure 3).

Motor and psychological variables

One-Sample Kolmogorov-Smirnov Tests for mood VAS, happiness VAS, anxiety VAS, movement difficulty VAS, movement fatigue VAS for both experimental (ON and OFF stimulation) and control groups (session 1, session 2) revealed that all variables were normally distributed ($p > .05$ for all variables). In the experimental group, VASs were not influenced by DBS condition. The same was observed in the control group, considering the effect of session (Table 3).

Discussion

This study aimed to investigate whether electrical STN stimulation can affect moral decisions. Findings revealed that STN DBS does not modify reaction times and type of responses in the moral task in PD patients. A point of strength of our work is that there was no change both comparing the ON and OFF state in the same patient, and also comparing patients treated with DBS versus those receiving only the best medical treatment. The negative findings in both the comparisons showed that both stimulation per se and the surgical procedure per se have no effect on moral decision.

We have previously shown in PD patients in ON dopaminergic therapy, that STN activity, recorded by local field potentials (LFPs), during the same moral task used here is specifically modulated by sentence type: the low frequency LFP oscillation (5-13 Hz) significantly increases during moral conflictual sentences, and not during moral non conflictual and neutral sentences [23]. These findings show that the moral task is an appropriate tool to study the relationship between morality and STN, and that STN is involved in moral decision-making. Following these observations, in the present study we have shown that DBS interference on STN electrical activity does not result in moral decision alterations. We hypothesized that STN, although implicated in moral decisions, is not the core moral structure, and moreover, that a specific brain structure for morality does not exists, indeed, the 'moral brain' consists of a large functional network including both cortical and subcortical anatomical structures. This anatomically pervasive moral system reflects the complexity of moral function, that involves other emotional, behavioural and cognitive processes, such as theory of mind, problem-solving, anticipations of consequences of an action, conflict processing, emotional evaluation of context and of possible outcomes [22]. To argue that STN DBS is not able to interfere with moral decisions, we have showed that all patients did not present cognitive deficits and that neuropsychological performance remains stable and unaffected by DBS: efficient moral decision processing implies an undamaged cognitive system. From an evolutive point of view, the complexity of moral decision-making associated to a normal cognition ensures that a focal brain damage or a brain alteration through electrical stimulation cannot disrupt morality, preserving human being from pervasive abnormal morality.

Assuming that moral judgments are produced by general, not-specific mechanisms of evaluation and decision (Shenhav and Greene 2010), we compare our findings with studies about STN and (non moral) conflictual decision-making. Our results disagree with studies demonstrating that STN DBS has a negative impact on executive control during attention-demanding tasks or in situations of conflict when habitual or prepotent responses have to be inhibited [10, 12, 26, 29]. An explanation for this discrepancy could be that moral conflictual decisions are processed in a different way than economic and other conflictual decisions. Hence, not all the decisions are affected by STN DBS in PD, thus confirming the multi-faceted nature of decisional processes.

Because moral decision-making reflects the competence of decision and action [22], these findings suggest relevant clinical and ethical implications for DBS consequences on patients' behavior, on decision-making and on judgment ability. We have shown that patients with PD maintain their ability to decide and to judge in moral and ethical fields independently of STN stimulation. It suggest that DBS is a safe procedure and unaltered moral thinking and ability to judge good and bad seems to be guaranteed.

Limitations of the study are the small patients sample and the absence of evaluation of mood changes with standard tests: further confirmations of our findings are needed.

Despite these faults, our findings suggest that patients with STN DBS maintain their ability to decide in various domains, such as in choosing medical treatment or financial arrangements [30], or in relevant professional choices, especially for those patients whose social position makes them responsible for others, for example, physicians, company leaders and politicians.

Acknowledgments

The experiments reported in this manuscript are part of the PhD thesis of Manuela Fumagalli.

This work was supported by Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, (Milan, Italy), Università degli Studi di Milano (Italy), Istituto Neurologico Mondino (Pavia, Italy), Ministero della Sanità (Italy), Ministero dell'Università e della Ricerca Scientifica e Tecnologica (Italy). No conflicts of interest.

References

[1] Deuschl G, Paschen S, Witt K. Clinical outcome of deep brain stimulation for Parkinson's disease. Handb Clin Neurol. 2013;116:107-28.

[2] Bell E, Mathieu G, Racine E. Preparing the ethical future of deep brain stimulation. Surg Neurol. 2009;72:577-86; discussion 86.

[3] Klaming L, Haselager P. Did My Brain Implant Make Me Do It? Questions Raised by DBS Regarding Psychological Continuity, Responsibility for Action and Mental Competence. Neuroethics. 2013;6:527-39.

[4] Schermer M. Ethical issues in deep brain stimulation. Front Integr Neurosci. 2011;5:17.

[5] Baunez C, Humby T, Eagle DM, Ryan LJ, Dunnett SB, Robbins TW. Effects of STN lesions on simple vs choice reaction time tasks in the rat: preserved motor readiness, but impaired response selection. Eur J Neurosci. 2001;13:1609-16.

[6] Desbonnet L, Temel Y, Visser-Vandewalle V, Blokland A, Hornikx V, Steinbusch HW. Premature responding following bilateral stimulation of the rat subthalamic nucleus is amplitude and frequency dependent. Brain Res. 2004;1008:198-204.

[7] Frank MJ, Samanta J, Moustafa AA, Sherman SJ. Hold your horses: impulsivity, deep brain stimulation, and medication in parkinsonism. Science. 2007;318:1309-12.

[8] Ballanger B, van Eimeren T, Moro E, Lozano AM, Hamani C, Boulinguez P, et al. Stimulation of the subthalamic nucleus and impulsivity: release your horses. Annals of neurology. 2009;66:817-24.

[9] Brittain JS, Watkins KE, Joundi RA, Ray NJ, Holland P, Green AL, et al. A role for the subthalamic nucleus in response inhibition during conflict. J Neurosci. 2012;32:13396-401.

[10] Cavanagh JF, Wiecki TV, Cohen MX, Figueroa CM, Samanta J, Sherman SJ, et al. Subthalamic nucleus stimulation reverses mediofrontal influence over decision threshold. Nature neuroscience. 2011;14:1462-7.

[11] Jahanshahi M. Effects of deep brain stimulation of the subthalamic nucleus on inhibitory and executive control over prepotent responses in Parkinson's disease. Front Syst Neurosci. 2013;7:118.

[12] 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.

[13] Kim YE, Kim HJ, Kim HJ, Lee JY, Yun JY, Kim JY, et al. Impulse control and related behaviors after bilateral subthalamic stimulation in patients with Parkinson's disease. J Clin Neurosci. 2013;20:964-9.

[14] Smeding HM, Goudriaan AE, Foncke EM, Schuurman PR, Speelman JD, Schmand B. Pathological gambling after bilateral subthalamic nucleus stimulation in Parkinson disease. J Neurol Neurosurg Psychiatry. 2007;78:517-9.

[15] Zahodne LB, Susatia F, Bowers D, Ong TL, Jacobson CEt, Okun MS, et al. Binge eating in Parkinson's disease: prevalence, correlates and the contribution of deep brain stimulation. J Neuropsychiatry Clin Neurosci. 2011;23:56-62.

[16] Lim SY, O'Sullivan SS, Kotschet K, Gallagher DA, Lacey C, Lawrence AD, et al. Dopamine dysregulation syndrome, impulse control disorders and punding after deep brain stimulation surgery for Parkinson's disease. J Clin Neurosci. 2009;16:1148-52.

[17] Ardouin C, Voon V, Worbe Y, Abouazar N, Czernecki V, Hosseini H, et al. Pathological gambling in Parkinson's disease improves on chronic subthalamic nucleus stimulation. Mov Disord. 2006;21:1941-6.

[18] Bandini F, Primavera A, Pizzorno M, Cocito L. Using STN DBS and medication reduction as a strategy to treat pathological gambling in Parkinson's disease. Parkinsonism Relat Disord. 2007;13:369-71.

[19] Lhommee E, Klinger H, Thobois S, Schmitt E, Ardouin C, Bichon A, et al. Subthalamic stimulation in Parkinson's disease: restoring the balance of motivated behaviours. Brain. 2012;135:1463-77.

[20] Moum SJ, Price CC, Limotai N, Oyama G, Ward H, Jacobson C, et al. Effects of STN and GPi deep brain stimulation on impulse control disorders and dopamine dysregulation syndrome. PLoS One. 2012;7:e29768.
[21] Castrioto A, Lhommee E, Moro E, Krack P. Mood and behavioural effects of subthalamic stimulation in Parkinson's disease. Lancet Neurol. 2014;13:287-305.
[22] Fumagalli M, Priori A. Functional and clinical neuroanatomy of morality. Brain. 2012;135:2006-21.
[23] Fumagalli M, Giannicola G, Rosa M, Marceglia S, Lucchiari C, Mrakic-Sposta S, et al. Conflict-dependent dynamic of subthalamic nucleus oscillations during moral decisions. Social neuroscience. 2011;6:243-56.
[24] Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. Journal of psychiatric research. 1975;12:189-98.
[25] Aitken RC. Measurement of feelings using visual analogue scales. Proceedings of the Royal Society of Medicine. 1969;62:989-93.
[26] Swann N, Poizner H, Houser M, Gould S, Greenhouse I, Cai W, et al. Deep brain stimulation of the subthalamic nucleus alters the cortical profile of response inhibition in the beta frequency band: a scalp EEG study in Parkinson's disease. J Neurosci. 2011;31:5721-9.
[27] van den Wildenberg WP, van Boxtel GJ, van der Molen MW, Bosch DA, Speelman JD, Brunia CH. Stimulation of the subthalamic region facilitates the selection and inhibition of motor responses in Parkinson's disease. J Cogn Neurosci. 2006;18:626-36.
[28] Greenhouse I, Gould S, Houser M, Hicks G, Gross J, Aron AR. Stimulation at dorsal and ventral electrode contacts targeted at the subthalamic nucleus has different effects on motor and emotion functions in Parkinson's disease. Neuropsychologia. 2011;49:528-34.
[29] Zavala B, Brittain JS, Jenkinson N, Ashkan K, Foltynie T, Limousin P, et al. Subthalamic nucleus local field potential activity during the Eriksen flanker task reveals a novel role for theta phase during conflict monitoring. J Neurosci. 2013;33:14758-66.

[30] Delazer M, Sinz H, Zamarian L, Stockner H, Seppi K, Wenning GK, et al. Decision making under risk and under ambiguity in Parkinson's disease. Neuropsychologia. 2009;47:1901-8.

REF DA AGGIUNGERE

Orsini, A., Grossi, D., Capitani, E., Laiacona, M., Papagno, C., & Vallar, G. (1987). Verbal and spatial immediate memory span: Normative data from 1355 adults and 1112 children. The Italian Journal of Neurological Sciences, 8, 539-548.

Novelli, G., Papagno, C., Capitani, E., Laiacona, M., Cappa, S., & Vallar, G. (1986). Tre test clinici di memoria verbale a lungo termine. Taratura su soggetti normali. Archivio di Psicologia Neurologia e Psichiatria, 2(47), 278-296.

Basso, A., Capitani, E., & Laiacona, M. (1987). Raven's Coloured Progressive Matrices: normative values on 305 adult normal controls. Functional Neurology, 2, 189-194.

Appollonio, I., Leone, M., Isella, V., Piamarta, F., Consoli, T., Villa, M., et al. (2005). The Frontal Assessment Battery (FAB): normative values in an Italian population sample. Neurological Sciences, 26, 108–116.

Novelli, G., Papagno, C., Capitani, E., Laiacona, M., Vallar, G., & Cappa, S. (1986). Tre test clinici di ricerca e produzione lessicale. Taratura su soggetti normali. Archivio di Psicologia Neurologia e Psichiatria, 4(47), 477-506.

Spinnler H, Tognoni G (Eds) (1987) Standardizzazione e taratura Italiana di test neuropsicologici. Ital J Neurol Sci 6, 8: 47-50

Spinnler, H., & Tognoni, G. (1987). Standardizzazione e Taratura Italiana di Test Neuropsicologici. The Italian Journal of Neurological Sciences, 6(8), 97-99

FIGURE LEGENDS

Figure 1. Moral task and experimental protocol. (A) Examples of moral conflictual, moral non conflictual and neutral statements. During the task, participants read the sentence on the PC screen: if they agreed/disagreed with the statement they pressed the "A"/"L" key. A black screen was displayed (1 s) before the next statement appeared on the screen. (B) Timeline for the experimental protocol.

Figure 2. Moral task RTs. Histograms represent mean RTs (ms) for moral conflictual, moral non conflictual and neutral sentences in the experimental group in ON and OFF STN DBS conditions and in the control group in the session 1 and 2. Y-axis: mean RTs (ms). Error bars are standard error of the mean.

Figure 3. Moral task percentage of reference-like responses. Histograms represent the percentage of reference-like responses in the experimental group in moral conflictual and moral non conflictual sentences in ON and OFF stimulation. Y-axis: reference-like responses expresses as percentage. Error bars are standard error of the mean.