

Embodied Word Production of Persons with Parkinson's Disease in Distinct Motor Conditions

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Abstract

Embodied cognition theories posit direct interactions between sensorimotor and mental processing. Various clinical observations have been interpreted in this controversial framework, amongst others, low verb generation in word production tasks performed by persons with Parkinson's disease (PD). If this were a sequel of reduced motor simulation of prevalent action semantics in this word class, reduced PD pathophysiology should result in increased verb production and a general shift of lexical contents towards particular movement-related meanings.

17 persons with PD and bilateral Deep Brain Stimulation (DBS) of the subthalamic nucleus (STN) and 17 healthy control persons engaged in a semantically unconstrained, phonemic verbal fluency task, the former in both DBS-off and DBS-on states. The analysis referred to the number of words produced, verb use, and the occurrence of different dimensions of movement-related semantics in the lexical output.

Persons with PD produced fewer words than controls. In the DBS-off, but not in the DBS-on condition, the proportion of verbs within this reduced output was lower than in controls. Lowered verb production went in parallel with a semantic shift. In persons with PD in the DBS-off, but not the DBS-on condition, the relatedness of produced words to own body-movement was lower than in controls.

In persons with PD, DBS induced-changes of the motor condition appear to go along with formal and semantic shifts in word production. The results support the idea of a direct connection between the motor system and lexical processing.

Introduction

Motor Cognition (MC) is a controversially discussed theoretical paradigm, conceptualizing various mental functions as grounded in movement-related processing [1, 2]. In doing so, it contrasts with models, in which cognitive functions result from computations in an arbitrary sign system, where abstract informational bits are combined without a connection to sensorimotor processing [3, 4]. As most other theories of embodied cognition (EC), MC follows the central idea that motor simulation is instrumental for the understanding of, e.g., gestures or semantic concepts related to movement [5–7]. Typical findings discussed in this general framework are, e.g., motor cortex activation upon perceiving action-related words [8], resemblance of electroencephalographic activity during motor performance and observation [9], or language processing facilitated by the simultaneous execution of 'congruent' movements [10]. In a fervid debate, this principle concept has been heavily impugned [2, 11, 12]. Criticized points are, amongst others, biased interpretation of weak effects of questionable significance, the assumption of motor-to-cognitive relatedness based on the co-occurrence of phenomena which are not necessarily interdependent, failed attempts to reproduce results central for the overall theory, and doubts about MC and EC appropriateness to explain high-order cognition in complex real word scenarios [11, 13, 14].

In view of pathological conditions, MC was predominantly discussed in the context of neurological movement disorders. In a reverse conclusion from the mentioned premises, motor system impairment

was posited to hamper the processing of information with movement-related connotations [15–18] as a basis of various cognitive deficits which, depending on the particular formulation of the theory, even include dysfunctions of abstract reasoning [19]. Clinically, this debate is, for example, of interest in the context of Parkinson's disease (PD) as a prevalent condition with both motor and mental sequels [20]. Although widespread cortical involvement in advanced disease stages may easily explain this association [21], less overt cognitive symptoms can already prevail in early PD with leading nigrostriatal brain affection and, first of all, motor symptoms [22]. From the perspective of MC, this appears to tie in with model claims, but, of course, other explanations are possible.

The ambiguity of interpreting subtle cognitive changes in PD can be illustrated using the example of particular biolinguistic findings [23]. It has been shown that persons with versus without PD differ from each other in view of verb processing across a variety of experimental conditions, implying naming, lexical decisions, comprehension and generation [18, 23–26]. Under the premise of higher semantic association of verbs than other word classes with motor action, various researchers discussed this observation as an indication of MC. However, alternatively it has been suggested that word production involves neuroanatomically segregated networks according to the lexical class processed, independently from modal processing. In view of verb generation, particular relevance has been ascribed to frontal opercular brain regions as a target of basal ganglia input related to a variety of cognitive control functions [27, 28]. In lexical processing, this refers, e.g., to the selection of grammatical word forms, particularly numerous in verbs [29, 30]. Since PD is thought to cause dysfunctional signaling in this network, altered use of lexical classes could therefore reflect impaired striatal-frontal executive processing without an association to the motor system and hence MC [28, 31–33].

To delineate in which ways PD impacts on word use, content-related lexical analyses on top of word class assessments might add valuable information. Following central MC claims, the ongoing grade of motor impairment in persons with PD should leave a 'corresponding' trace in mental concepts, e.g., emerging as lexical output in semantically unconstrained verbal fluency tasks [34]. Of note, strongly contrasting movement conditions do occur in one and the same person with PD, for example, as a function of the actual therapy. The best match between clinically observable condition and motor system state is inherently connected with deep brain stimulation (DBS), comprising a neuroanatomically well-defined mechanism of action. In case of PD, it (mostly bihemispherically) delivers electrical impulses to the motor zone of the subthalamic nucleus (STN), which is a core basal ganglia structure promoting pathological signaling in PD [35]. Activation or inactivation of DBS of the STN leads to increased or decreased motor function, respectively, by modulating motor network functions either towards a physiological operating mode (DBS-on) or away from it (DBS-off) [36]. In doing so, the changes of the clinical movement disorder evolve more rapidly and, thus, are better observable than upon starting or stopping pharmacological PD treatment due to prolonged drug-washout [37].

Against this particular background, we sought to identify potential signals of MC-related processing, asking whether persons with PD produced words with closer-to-normal relatedness to movement in a comparably good motor condition (DBS-on) as compared to a worse motor state (DBS-off). Thereby, we

focused on the lexical associations with (i) movement in general, (ii) own-body-movement, (iii) movement of objects, (iv) movement of other beings, under the idea that a potential influence of the motor state on these dimensions could inform about issues outlined above. In a straightforward understanding of MC, we would expect that hypokinetic states, affecting one's own, but not others' mobility, should only reduce lexical own-body movement-relatedness. In an extended MC view, positing motor simulation to be an element of processing any movement-related semantics, hypokinetic states should additionally affect the relatedness of words to external movements. Finally, as a non-MC, amodal language network effect, decreased verb use should be associated with poor motor states (as formerly reported), but not with a change of lexical relatedness to a particular dimension of movement.

To differentiate between these possibilities, word output was assessed in healthy persons and in persons with PD on versus off DBS of the STN, who engaged in a phonemic verbal fluency task without semantic constraints. Raters, blinded for the origin of the cumulated, random order lexical list, evaluated the relatedness of each word produced to the movement dimensions mentioned above. The group and state-related results of these ratings were critically weighed against positions pro and contra MC, discussing them in view of potential associations with the behavioral condition and motor system state.

Methods

We analyzed data from 17 persons with PD and bilateral DBS of the STN and 17 age-matched healthy volunteers as controls. All participants gave written informed consent to the study protocol approved by the ethics committee of the Charité – University Medicine Berlin (protocol number EA2/047/10) and the study was performed in accordance with relevant guidelines and regulations in accordance with the Declaration of Helsinki. Persons with PD fulfilled the diagnostic Brain Bank Criteria and were treated in the Outpatient Clinic for Movement Disorders at the Department of Neurology of the Charité – Universitätsmedizin Berlin. Exclusion criteria were brain diseases other than PD including depressive or psychotic disorders (according to the diagnostic criteria of the German Manual for Psychopathological Diagnosis, AMDP), or major cognitive decline as indicated by less than 15 points in the Parkinson Neuropsychometric Dementia Assessment (PANDA) [38]. Naturally, participants in the control group had additionally to be free of PD. All participants were native German speakers. The persons with PD were treated with bilateral DBS of the STN and dopaminergic medication. For both groups, the relevant demographic and, for the PD group, clinical data including PANDA scores are summarized in Table 1. These basic parameters were tested for potential group differences. Therefore, the t-test or the Mann-Whitney-U-test were used for non-dichotomous data (PANDA scores, age, years of education), depending on the data distribution as assessed by Kolmogorov-Smirnov testing, and the chi-square test for dichotomous data, such as sex or handedness.

Electrode implantation and localization

DBS electrodes were implanted in the department of neurosurgery of the Charité–Universitätsmedizin Berlin (tetrapolar Lead Model 3389; Medtronic). Bilateral STN placement was based on based on atlas

coordinates for the nucleus together with preoperative MRI and intraoperatively guided by micro-electrode recordings as well as by the effect of macro-electrode test stimulations. Localization was controlled by postoperative T2w-MRIs. For determining final electrode positions, the post-operative MRI-data was normalized to the Montreal Neurological Institute (MNI) stereotactic space, and the medio-lateral (x-axis), anterior–posterior (y-axis) and rostro-caudal (z-axis) directed distances of the susceptibility artifacts from the active electrode-contacts to the central MNI reference point were assessed. The specific values for localization and stimulation settings are provided in Table 2.

Task

We analyzed the lexical output of the participants in the non-alternating, phonemic version of the standard German Verbal Fluency (VF) task (Regensburger Wortflüssigkeitstest) [39]. Therefore, participants had to produce as many words as possible beginning with S during two minutes without any word class and semantic constraints. Word or word-stem repetitions, numbers and proper names were defined as errors, which was explained to the participants before the assessment started. The persons with PD performed the task twice, once with active DBS (DBS-on) and another time with the stimulation switched off for at least 30 minutes (DBS-off). These two assessments took place in two separate sessions at intervals of 8 weeks in counterbalanced order (DBS-on first versus DBS-off first), between which the medication remained unchanged (see Table 1). The motor conditions in DBS-on and DBS-off were assessed by the Unified Parkinson Disease Rating Scale (UPDRS, part III) [40]. Words from other VF conditions were not subjected to the analysis, since they were incompatible with the current study aim. In the semantic subtasks (non-alternating: words denominating vegetables / alternating: words denominating animals / furniture) word search was restricted to nouns of predefined semantic categories, not allowing for variations of lexical classes and movement-relatedness. In the alternating phonemic condition (words beginning with G / R) executive (next to lexical) processing demands were imposed, but we sought to avoid any cognitive complexity which could have interfered with the operations in question as a potential confounder of the results.

As formal parameters of task performance in the non-alternating phonemic condition, the mean number of words (total as well as correct words) and error-rates (percentage of false responses per all produced words) were determined. With respect to the research question, the production of nouns and verbs was further differentiated as percentage values of the words generated, and an analysis of motor-relatedness of the generated words was performed. We analyzed the lexical output from all study participants including false responses, which inform about underlying semantic concepts as correct responses do [41]. Any word produced was listed once, regardless of whether it was named by different study participants, resulting in a corpus of 728 different words. Since there is no data for the German word corpus on the lexical contents of interest here, this word list, interindividually randomized in its order, was presented to 16 healthy native German speakers who had to evaluate defined semantic aspects [34]. These raters were not aware of the origin of the words or the aim of the study, and had to rate any single word under four motor-related semantic aspects on a 0-10 scale (minimum 0 = no association at all, maximum 10 = strongest possible association). The word dimensions to be rated addressed the MC-

derived question whether particular motor system states, different between groups and DBS conditions, impacted on movement-associated word contents. Since the evaluation of lexical movement-relatedness in general was deemed as too unspecific, own-body and external perspectives were additionally accounted for. Thus, any listed word had to be rated with respect to its relatedness to (i) movement in general (e.g., comparably high for BIKE, comparably low for TOWER), (ii) movement of the own body (e.g., comparably high for FOOT or THROW, comparably low for AIRPLANE or THINK), (iii) movement of another living object (e.g. another human or animal, e.g. words like PET or FLY), and (iv) movement of an inanimate object (e.g., comparably high for BALL, comparably low for HOUSE). The resulting 2.912 evaluations (728 words in four dimensions) per rater were provided without a time limit, mostly demanding about six hours for completion, distributed over an individually defined number of sessions. Raters were instructed to mark words with unknown meaning, so that entries with less than eight ratings (<50% of the available evaluations) could be excluded (see results section). For the remaining words, mean values of the ratings were calculated for further analysis [34].

Statistically, potential differences of lexical class use and the above ratings of movement-related semantics were explored between the groups and, within the PD group, between DBS-on and DBS-off conditions. Inhomogeneous data distribution did not allow for one multifactorial approach, so that independent-samples t-tests- or Mann-Whitney-U-tests for group comparisons and paired t-tests or Wilcoxon-tests were used, depending on the data distribution as assessed by Kolmogorov-Smirnov testing.

For all significant results, effect sizes are reported as Cohens d for t-tests ($d = 0.2$: small effect; $d = 0.5$: medium effect; $d = 0.8$: strong effect) and R^2 for non-parametric tests ($R^2 = 0.02$: small effect; $R^2 = 0.13$: medium effect; $R^2 = 0.26$: strong effect) according to Cohen [42].

Results

Persons with and without PD were not significantly different with respect to age, years of education, handedness or sex-distribution within the respective groups. The mean total PANDA scores were significantly lower in the PD group on STN-DBS (controls 24.9 ± 3.5 versus persons with PD 20.4 ± 5.6 ; $t(32) = 2.825$, $p = .008$, $d = .969$). To control for the known and selective VF deficit in persons with PD and STN-DBS, we also calculated the netPANDA, i.e., the total PANDA except the VF subtask therein [43], in order to gain an orienting value of cognitive function apart from VF, being the subject of this study. In the group comparison of the netPANDA, no significant difference was identified (controls 18.6 ± 3.2 versus STN DBS 16.1 ± 4.6 ; $p = .072$). These overview data are summarized in Table 1. As expected, individuals with PD showed marked improvement of motor symptoms by DBS, evidenced by the mean UPDRS III scores in the on (21 ± 9.5) compared with the off condition (39.5 ± 14.2 ; $t(16) = -7.654$, $p < .001$, $d = -1.856$). The persons without PD had no motor impairment according to this scale.

In view of VF task performance, persons with PD produced significantly fewer words than persons without PD (25.6 ± 11), both in the DBS-on (17.9 ± 8.4 ; $t(32) = 2.310$, $p = .027$, $d = .792$) and the DBS-off

(15.9 ± 8.6 ; $t(32) = 2.854$, $p = .008$, $d = .979$) condition. This pattern remained if only correct words were included in the analysis (Controls 24.2 ± 10.7 versus PD DBS on 15.7 ± 8.1 ; $Z = -2.572$, $p = .009$, $R^2 = .19$; PD DBS off 14.6 ± 8.4 , $Z = -2.449$, $p = .013$, $R^2 = .18$). The on average slightly higher word production in persons with PD on versus off DBS was insignificant in the direct comparison between both conditions within the PD group ($t(16) = 1.603$, $p = .129$).

With respect to the lexical class of the individual VF output, by far more nouns than verbs were produced, regardless of the group, with small fractions of other word classes (i.e., adverbs, adjectives, false responses including names or numbers). Persons without PD produced on average $16 \pm 15\%$ verbs and $71 \pm 23\%$ nouns, whereas persons with PD in the off-DBS condition produced significantly fewer verbs ($5 \pm 8\%$; $Z = -2.178$, $p = .029$, $R^2 = .14$) and more nouns ($88 \pm 11\%$; $Z = -2.058$, $p = .039$, $R^2 = -.12$). Corresponding differences were no longer statistically significant in the comparison between persons without PD and persons with PD in the on-DBS condition (verbs $11 \pm 10\%$, $Z = -.695$, $p = .497$; nouns $82 \pm 14\%$, $Z = -1.330$, $p = .189$). The change of word class use between both treatment states within persons with PD was significant for verb generation ($Z = -2.103$, $p = 0.035$, $R^2 = .26$), but did not reach the significance threshold for the production of nouns ($Z = -1.810$, $p = 0.072$). No significant differences were identified with respect to error-rates, neither between groups, nor between treatment states (for an overview of these results see Table 3).

From the 728 different words produced over all participants, 18 were marked as unfamiliar to the external raters, so that no semantic categorization was provided (2% of all words). Concerning the ratings of the remaining 710 words, no differences were identified with respect to the relatedness of the lexical output to movement in general, to movements of other bodies, and to movements of objects between persons without PD and persons with PD, be they on or off DBS. In contrast to this, the own-body movement relatedness of the lexical output was rated as significantly lower for persons with PD in the DBS-off condition than for persons without PD ($t(32) = 3.044$, $p = 0.005$, $d = 1.044$). This difference became insignificant in the comparison between persons with PD in the DBS-on condition and persons without PD ($t(32) = 1.553$, $p = 0.130$). Further, no significant difference of the relatedness of the word output to any of the studied movement categories was seen in the comparison between DBS stimulation conditions (on – off) within the PD group. These results are visualized in Figure 1. A data summary is provided in Table 4.

Apart from this main analysis, we further explored whether the disappearance of lowered lexical own-body movement-relatedness in persons with PD from the DBS-off to the DBS-on state was exclusively due to the accompanying verb increase, because this could indicate that the semantic result was unrelated to the processing of meaning, but instead an epiphenomenon of a word class effect (since verbs imply higher own-body movement relatedness than nouns). Alternatively, if the result of lowered own-body movement-relatedness in the off-DBS state of persons with PD also prevailed in nouns, this would suggest that motor-related processing of word meaning also drove the general result pattern. It turned out that the own-body movement-relatedness of nouns was rated lower for persons with PD in the off-DBS state than for persons without PD ($t(32) = 2.070$, $p = 0.047$, $d = 0.710$). The group difference

vanished when persons with PD were in the DBS-on condition. Between DBS-on and DBS-off conditions in persons with PD, no significant difference of own-body movement-relatedness was identified in nouns. For verbs, ratings of own-body movement-relatedness were generally higher than for nouns. Relatively infrequent production rate led to completely missing verb production in a subset of participants in either group and condition, mostly in the DBS-off state, in which only eight of the seventeen persons with PD continued to produce verbs. Group or DBS-related differences of the own-body movement-relatedness of the remaining verbs were not identified. For a summary of these results, see Table 4.

Discussion

In the current study, we investigated whether intraindividual motor system state changes influenced semantic and formal aspects of word generation. Therefore, persons with PD on as well as off DBS and healthy participants performed a phonemic VF task, so that lexical output could be analyzed per condition and group with respect to movement-relatedness and word class properties.

In comparison to healthy participants, persons with PD in the DBS-off condition produced fewer words and, within this decreased lexical output, proportionally fewer verbs. Further, the words they generated were rated as less associated with meanings implying own-body movement, whereas this was not true of other movement aspects. This appeared to be a mixed effect from the reduction of verbs, generally entailing high movement-relatedness, and less own-body movement relatedness of nouns. The group differences were no longer significant, when persons with PD were on DBS. Between DBS conditions, no statistical distinction of VF-related performance was shown, while motor change, as assessed by the UPDRS, was significant. On average, values for own-body movement-relatedness and verb use in the on-DBS state were in between those measured in the off-state in persons with PD and the corresponding values in healthy participants.

Principally, altered semantics and verb use could be conceived as a phenomenon without a specific relation to PD brain pathology, since everyday living conditions alone can frame lexical properties of persons or groups [44]. In PD, growing hypokinesia changes existential circumstances, mostly related to agent-based motor behavior, and gradual alignment of mental concepts traceable on lexical levels could simply be a response to permanent mismatch between actual experience and unrealistic expectations [45–56]. However, if changed word use in persons with PD were only based on this, it should – as a slow, learning-based adaptation to enduring change – be inert to short-lived motor functional shifts by intermittent DBS in/activation. Yet, only in the DBS-off, but not in the DBS-on condition significant differences of lexical semantics and word class use were identified in comparison to persons without PD. Therefore, this framework alone does not comprehensively explain the obtained result pattern.

Concerning effects of acute motor change on lexical properties, two views deserve particular mention. Firstly, in the context of DBS, modulation of word class use was conceptualized in a non-MC account, viewing low verb generation as a dysexecutive symptom in PD. Based on the assumption that striatal processing is crucial for inhibitory operations in motor as well as cognitive behaviors, PD was proposed

to impair the release of words with numerous grammatical alternatives, as is the case in verbs. In this view, co-activation of their variable conjugational forms at the beginning of the lexemic retrieval process, imply high suppression demands for holding back all lexical candidates apart from the best-suited option. As this selection process was presumed to be a frontostriatal function, its impairment could underlie verb production problems in persons with PD [27, 29–31]. This would tie in with the finding that lowered verb use in persons with PD off-DBS was no longer significantly different from normal levels in the on-DBS condition, i.e., after partial normalization of striatal function. It further appears to tie in with previous findings, demonstrating that DBS of the STN not only acts on motor processing, but also supports impaired language-related executive operations, such as conceptual switching during word production [57–59]. However, this concept does not explain the overall semantic result pattern.

In this regard, a second view deserves a mention. Word class and content-related findings could be considered as coherent consequences of a DBS-induced gain of mental concepts related to own-body movement, promoting an increase of verb use (i.e., of the use of words with high motor relatedness) along with a congruent semantic shift in nouns [18, 23–26]. Such a direct impact of motor system states on lexical operations is reminiscent of typical MC claims [2, 11, 13, 14]. Data potentially supporting such positions are controversially discussed, for example, the activation of motor cortical areas during action word processing in functional imaging [8, 60], possibly indicating ‘modal’ cognitive processing or, alternatively, a post-lexical phenomenon without functional relevance, as well as behavioral observations, such as the Action Sentence Compatibility Effect (ACE) [2, 10], highly cited and, at the same time, put into question for a lack of reproducibility (Papesh, 2015). Against this background, the current data are of interest, because DBS of the STN brings the motor network of persons with PD in a closer-to-physiological state, observable as a rapidly evolving relief of clinical symptoms [61–64]. As known from many other investigations, it approximately halved the motor UPDRS in persons with PD, so that – according to this scale – the average movement function on-DBS was quite in the middle between the off-DBS state and the motor condition of persons without PD. Of note, lexical differences became only significant contrasting the UPDRS-defined motor conditions 40 points away from each other, but not at the also significant 20-point-distances, prevailing between persons with PD on-DBS and persons without PD as well as within persons with PD on versus off DBS. Thus, whereas motor states may acutely impact on the processing of words, this effect seems altogether relatively subtle.

In sum, the results (abnormally low verb production together with decreased own-body movement-relatedness of nouns in PD off-DBS; normalization of these abnormalities in the on-DBS condition) are compatible with the idea that momentary motor system states impact on the availability or prevalence of corresponding mental concepts, traceable on the level of word output. This pattern, suggesting a relatively direct link between motor and lexical processing, ties in with basic MC positions. It further provides a framework of low verb generation in PD, in addition and complementary to the proposal of a dysexecutive basis of this finding. These considerations are cautiously formulated for a number of reasons. Importantly, there is no data for the German word corpus on lexical movement-relatedness, so that the semantics in question were derived from the ratings of a group of native German speakers, who were unaware of the data origin and the study aim, as done in a previous study [34]. The scale used for

this purpose ranged from 0 to 10 (minimum to maximum relatedness) and, although lexical own-body movement-relatedness was on average about twenty-five percent higher in persons without PD than in persons with PD in the DBS-off state, this difference was small in absolute numbers, since it referred to overall low ratings (around 2). In this regard, it is worthwhile to note that the current aim was to study potential indications of motor-to-lexical interactions, be they weak or strong, but not to quantify potential effects. The explorative tests targeted two main questions, firstly, whether previous reports on low verb use in the context of DBS-treated PD could be confirmed and, secondly, if verb reduction was accompanied by diminished motor semantics in non-verbs. Indeed, the results suggest that this combination was given, but future trials might confirm it in further cohorts.

Overall, the current data suggest that PD influences formal as well as content aspects of word generation, susceptible to DBS of the STN. This and the particular nature of the semantic shift in PD is compatible with the view that interactions between motor and cognitive functions have relatively direct neuronal underpinnings. From a theoretical perspective, this is of interest in the context of the debate about the existence and nature of MC; under clinical aspects, the results raise the question whether certain cognitive changes in PD might be less separable from motor dysfunction than commonly assumed.

Declarations

Author contributions

FK: Concept, Methods, Data Evaluation, Resources, Writing; MB: Assessment of External Ratings, Data Evaluation; FE: Data Assessment, Review and Critique, HOT: Concept, Statistics, Tables and Figure, Review and Critique

Additional Information (including a Competing Interests Statement)

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Tables

Table 1: demographic and clinical sample characteristics

	STN DBS	Cntr.	p-value
Age (years)	65.1 (9.1)	66.9 (8.1)	0.519
Education (years)	10.0 (1.5)	10.7 (2.0)	0.256
PANDA total (points)	20.4 (5.6)	24.9 (3.5)	0.008*
netPANDA net (points)	16.1 (4.6)	18.6 (3.2)	0.072
Sex ratio (female / male)	4 / 13	4 / 13	1.0
Handedness (left / right)	2 / 15	3 / 14	0.628
Clinical Characteristics (PD group)			
Side of onset (left / right / bilateral)	3 / 13 / 1		
Disease Duration (years)	15 (5.5)		
DBS duration (years)	3.6 (2.2)		
UPDRS III DBS on	21.0 (9.5)		
UPDRS III DBS off	39.5 (14.2)		
LEDD DBS (mg)	553 (399)		

Values are the mean and standard deviations in brackets. PANDA scores were raised in the on-DBS state of persons with PD. Abbreviations: PANDA = Parkinson Neuropsychometric Dementia Assessment; UPDRS = Unified Parkinson's Disease Rating Scale; LEDD = Levodopa equivalent daily dosage.

Table 2: DBS Parameters

	Right STN	Left STN
Amplitude (V)	2.9 (1.3)	2.9 (1.2)
Pulse width (µs)	63.5 (9.9)	67.1 (13.1)
Frequency (Hz)	129 (33)	129 (33)
Impedance (Ω)	975 (543)	883 (463)
TEED _{1sec}	107.2 (95.9)	122.9 (122.5)
Polarity (monopolar / bipolar)	13 / 4	15 / 2
Contact (single / double)	12 / 5	13 / 4
<i>Electrode Localization</i>		
x-axis (mm)	11.64 (0.76)	-11.82 (0.99)
y-axis (mm)	-14.73 (1.04)	-14.15 (1.05)
z-axis (mm)	-7.13 (1.3)	-7.23 (1.63)

$TEED_{1sec} = \text{total electrical energy delivered} = (\text{voltage}^2 \times \text{pulse width} \times \text{frequency}) / \text{impedance}$

Table 3: VF task results

	Cntr	DBS on	DBS off	DBS on vs. Cntr	DBS off vs. Cntr	on - off
Words total	25.6 (11.0)	17.9 (8.3)	15.9 (8.6)	0.027*	0.008*	0.129
Words correct	24.2 (10.7)	15.7 (8.1)	14.6 (8.4)	0.006*	0.013*	0.344
Error rate (%)	6 (6)	13 (13)	8 (12)	0.245	0.865	0.118
Verbs (%)	16 (15)	11 (10)	5 (8)	0.496	0.034*	0.035*
Nouns (%)	71 (23)	82 (14)	88 (11)	0.193	0.041*	0.070

Overview of VF performance in phonemic, non-alternating task. Correct word count is computed as the number of total words minus false responses. Error rates were calculated as the percentage of false responses per total word count; verb and noun ratios were computed as the number of words belonging to the respective lexical class per total word count.

Table 4: Mean ratings of motor relatedness

scale	Cntr	DBS on	DBS off	DBS on vs. Cntr	DBS off vs. Cntr.
general	3.0 (0.5)	3.0 (0.8)	2.8 (0.7)	<i>0.893</i>	<i>0.218</i>
own body	2.1 (0.5)	1.9 (0.4)	1.6 (0.4)	<i>0.130</i>	<i>0.005*</i>
other body	2.6 (0.5)	2.4 (0.6)	2.3 (0.5)	<i>0.426</i>	<i>0.116</i>
objects	2.0 (0.4)	2.1 (0.9)	2.0 (0.8)	<i>0.650</i>	<i>0.918</i>
<i>Own-body relatedness by lexical class</i>					
nouns	1.8 (0.3)	1.7 (0.4)	1.6 (0.4)	<i>0.285</i>	<i>0.047*</i>
verbs	4.2 (1.2)	4.0 (1.7)	4.4 (1.0)	<i>0.813</i>	<i>0.104</i>

Values are the means and standard deviations (in brackets) as well as p-values for the corresponding comparisons. Bottom: comparisons of the own-body movement-relatedness for produced verbs and nouns separately. The verb analysis only included 12 persons without PD, 12 persons with PD on DBS, and 8 persons with PD off DBS, since the remaining participants did not produce verbs.

Figures

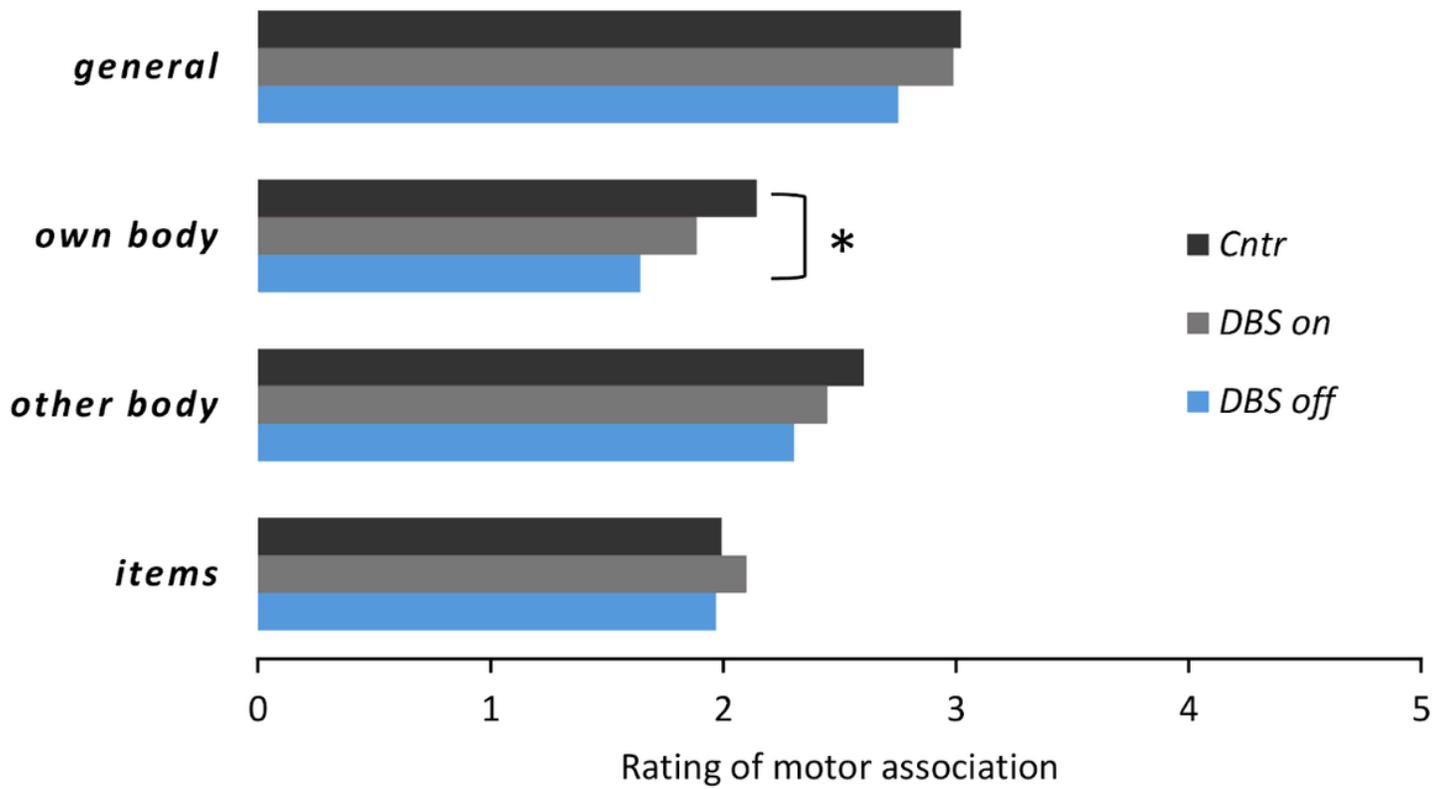


Figure 1

Ratings per group and scale Mean ratings for the different dimensions of motor-relatedness of produced words per group and condition; significant differences are marked with an asterisk (for low average ratings of motor relatedness the actual scale ranging from 0-10 scale is cut off > 5).