

Ambiguous idiom processing in Parkinson's disease patients

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Patients affected by Parkinson's disease (PD) can provide crucial information about the involvement of the motor system and prefrontal cortex in processing idioms including action verbs, since dopamine modulates the activity of these structures, and, consequently, different levels of this neurotransmitter can induce different cognitive impairments. In order to investigate the ability to process ambiguous idioms containing an action verb in patients, we asked 15 PD patients, in both OFF- and ON-phases, and 15 healthy matched participants to judge the plausibility of literal and idiomatic sentences, each presented at a self-paced rate. Patients in OFF-phase were faster in reading idiomatic than literal sentences, supporting the view that the motor system is not involved in online idiom processing. However, patients during OFF-phase were impaired in judging the plausibility of idiomatic ambiguous sentences, possibly due to the reduction of dopamine in prefrontal regions. The involvement of the motor system was evident in the ON-phase for literal sentences, suggesting that motor activation is strictly dependent on the context.

Keywords: Action verbs; Idiomatic sentences; Parkinson's disease; Prefrontal cortex.

There is still no agreement concerning the modalities through which idioms (e.g., in Italian *tagliare la corda*, to cut the rope, meaning to escape), one of the most common forms of figurative language, are processed. Early theories of idiom comprehension assumed a literal meaning priority and a search for a figurative interpretation only when the literal one was rejected (Bobrow & Bell, 1973), while others considered idioms mainly as long, morphologically complex words stored as such in the mental lexicon (Swinney & Cutler, 1979). Alternatively, the

configuration hypothesis (Cacciari & Tabossi, 1988) claimed that idioms undergo a linguistic analysis until enough information has accumulated to prompt the recognition of the idiomatic nature of the string and the activation of the figurative meaning. More recent data have suggested that not all idiomatic expressions are processed alike (Nenonen, Niemi, & Laine, 2002), with a distinction, for example, between ambiguous (the literal interpretation is also plausible) and unambiguous idioms (Papagno & Caporali, 2007).

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Concerning the anatomical substrate, a widely distributed network involving both hemispheres contributes to idiomatic processing; in particular, in the case of ambiguous idioms, the left temporal and the bilateral prefrontal cortex are involved (see Cacciari & Papagno, 2012, for a review).

The issue concerning how idioms, especially ambiguous ones, are processed is of particular interest when they contain an action verb (as in the Italian idiom *tirare la corda*, literally to pull the rope, meaning to exaggerate). Indeed, according to the strong version of embodied models of cognition, the motor system would be involved in the comprehension of idiomatic sentences containing an action verb (e.g., Boulenger, Hauk, & Pulvermüller, 2009; Boulenger, Shytrov, & Pulvermüller, 2012). Boulenger et al. (2012), using magnetoencephalography (MEG), showed that, compared to literal sentences, processing of idioms in a silent reading task modulates anterior frontotemporal activity very early, already 150–250 ms after the critical disambiguating word. Similarly, in the same time windows, the premotor cortex showed somatotopic activation modulated by the specific verb used (e.g., a verb implicating an arm movement specifically activated the arm motor area). Boulenger et al. (2012) suggest that parallel compositional and abstract context-driven semantic processes contribute to the understanding of the idiom meaning, since the meaning of action words embedded in sentences is reflected by somatotopic activation of the precentral motor system. However, only sentences including arm verbs reliably recruited the arm motor region, whereas the effect in the leg region fell short of reaching significance. Crucially, no control sentences—that is, sentences containing a mental verb rather than an action verb—were included, making it likely that participants were “expecting” action verbs for all items and did not “switch off” from an action verb mode of processing. In contrast to Boulenger et al. (2012), some functional magnetic resonance imaging (fMRI) studies (e.g., Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Raposo, Moss, Stamatakis, & Tyler 2009; Romero Lauro, Mattavelli, Papagno, & Tettamanti, 2013) found no motor activation

in response to action verbs presented in metaphorical or idiomatic sentences. Accordingly, Cacciari et al. (2011) used transcranial magnetic stimulation (TMS) to assess whether reading literal, nonliteral (i.e., metaphorical, idiomatic), and fictive motion sentences modulated the activity of the motor system. Single-pulse TMS was delivered at the end of the sentence over the leg motor area in the left hemisphere, and motor evoked potentials (MEPs) were recorded from the right gastrocnemius and tibialis anterior muscles. MEPs were larger when participants were presented with literal, fictive, and metaphorical motion sentences than with idiomatic motion or mental sentences, suggesting that the excitability of the motor system is modulated by the motor component of the verb, which is preserved in fictive and metaphorical motion sentences but not in idiomatic ones, possibly because in idioms the relationship between the idiom constituent words and the idiomatic meaning is arbitrary and overlearned.

In the present study, we investigated idiomatic sentence processing in Parkinson's disease (PD) patients. PD is a neurodegenerative disorder that severely affects the motor system, with a progressive loss of dopaminergic cells in the substantia nigra, which indirectly concerns the motor cortex. Previous evidence suggests that PD patients might be overall impaired in processing action verbs as compared to object naming (Boulenger et al., 2008; Cotelli et al., 2007; Herrera & Cueto, 2012; Herrera, Rodríguez-Ferreiro, & Cueto, 2012; Rodríguez-Ferreiro, Menéndez, Ribacoba, & Cueto, 2009).

PD patients can provide additional information about the involvement of the motor system in processing action verbs in nonliteral contexts—that is, action verbs lacking any actual motion component. However, in PD patients we can also investigate the role of another structure, which is involved in idiom comprehension—namely, the prefrontal cortex (Romero Lauro, Tettamanti, Cappa, & Papagno, 2008; Zempleni, Haverkort, Renken, & Sotwe, 2007; see also Papagno & Romero Lauro, 2010, for a review). Indeed, dopamine modulates the activity of this area, and, consequently, different

levels of this neurotransmitter could induce different cognitive impairments.

In light of the above, we aimed at investigating how idiomatic sentences containing an action verb are processed in PD patients tested in both ON-phase (i.e., after intake of L-dopa therapy) and OFF-phase (i.e., off the effect of medication). The task consisted in deciding about the plausibility of a sentence visually presented at a self-paced rate. A control group of neurologically unimpaired participants were also tested to provide a baseline measure of the effect of the different verb types (action vs. nonaction) and context (figurative vs. literal for action verbs) in reading rate and plausibility judgements. Healthy participants were expected to show slower response times (RTs) and lower accuracy for idiomatic sentences than literal ones, as previously reported (Romero Lauro et al., 2008, 2013). In the case of PD patients in OFF-phase, as dopamine supports sentence comprehension (see, for example, Grossman et al., 2001), we would expect increased RTs particularly in idiomatic sentences, due to idiom comprehension tapping on prefrontal functions (Romero Lauro et al., 2008; Zemleni et al., 2007; see Kaasinen & Rinne 2002, for a review on the different manifestation of reduced dopamine and dopamine receptors on cognitive functions). Indeed, in patients already on levodopa therapy, temporary cessation of medication led to impairment on tests sensitive to frontal lobe functions (Lange et al., 1992). In ON-phase, according to the previous literature reporting an impairment in PD patients tested in ON-phase for action naming (see, for example, Cotelli et al., 2007; Fernandino et al., 2013a; Herrera et al., 2012), we would expect slower RTs and lower accuracy with literal action sentences than with control (mental) ones; however, PD patients should also perform as well as healthy participants with idiomatic sentences. Mental sentences were sentences including a cognition verb (i.e., *to desire*, *to think*); they were included as control sentences for two reasons: First, if all sentences were action ones, it could not be excluded that participants were “expecting” action verbs for all items and did not “switch off”

from an action verb mode of processing; second, we wanted to compare whether a literal sentence not including an action verb would be processed faster than both a sentence depicting an action and a sentence with an action verb used without any actual action meaning but with a figurative (abstract) one.

METHOD

Participants

Fifteen (eight male and seven female) Italian right-handed (as assessed by means of the Edinburgh Handedness Inventory, Oldfield, 1971) PD patients participated in the study. Their mean age was 54.3 years (range = 42–68, $SD = 7$), and their mean education was 10.8 years (range = 5–18, $SD = 3.8$). All participants had normal or corrected-to-normal vision. None of them had a history of neurological or psychiatric disease other than PD. PD patients with signs of cognitive deterioration were excluded from the study. Indeed, all the recruited patients were candidate to brain deep stimulation. All participants were fully informed about the experimental procedure and signed an informed consent prior to the experiment. Participants performed the experiment twice, using the same sentences in a different random order: Both testing sessions took place at the hospital and were interposed by a minimum of 48 hours. Seven PD patients were tested first when being off antiparkinsonian medication for at least 12 hours (OFF-phase) and in the second session 60 min after intake of L-dopa therapy (ON-phase). The remaining eight patients were tested first in the ON-phase and then in the OFF-phase. Motor disabilities were evaluated using the motor Part III of the Unified Parkinson's Disease Rating Scale (UPDRS Part III, Fahn & Elton, 1987) in OFF- and ON-phases. All patients were candidates for deep brain stimulation of the subthalamic nucleus, which requires lack of cognitive deterioration (see, for example, Okun et al., 2012), so cognitive impairment was excluded by means of an extensive

Table 1. PD patients' demographic and clinical data

Patient	Age (years)	Education (years)	Sex	Age at onset (years)	Type	Side	UPDRS off	UPDRS on	LEDD
1	59	11	F	47	a, t	R	32	8	1320
2	44	13	M	39	b, r	R	42	14	941
3	49	18	M	37	a, t	L	17	8	1640
4	68	13	F	56	a	R	29	15	898
5	65	8	F	61	b	L	35	18	700
6	55	5	F	49	a, t	R	36	16	200
7	51	10	M	47	b	L	44	8	1100
8	58	8	F	52	t, a	L	31	9	1360
9	51	13	M	40	a	L	43	22	750
10	57	8	M	50	a	R	41	24	1368
11	55	8	F	49	a, t	L	40	8	851
12	42	13	M	37	t, a	R	26	13	345
13	55	8	M	40	t	L			
14	49	18	F	44	t	L	36	15	
15	56	8	M	51	a	L			

Note: PD = Parkinson's disease; UPDRS = Unified Parkinson's Disease Rating Scale; LEDD = levodopa equivalent daily dose; a = acinetic; b = bradycinetic; t = tremor; F = female; M = male; R = right; L = left.

neuropsychological assessment. In particular, they were submitted to the Montreal Cognitive Assessment (MoCA, Nassredine et al., 2005), the Digit Span Forward and Backward (Monaco, Costa, Caltagirone, & Carlesimo, 2013; Orsini et al., 1987) in order to assess working memory (WM), Verbal Fluency on phonemic cue (Novelli et al., 1986) to evaluate language production and executive functions, and the Attentional Matrices (Spinnler & Tognoni, 1987; see Tables 1 and 2 for PD patients' demographic and clinical data and neuropsychological evaluation).

This baseline assessment was performed in a separate session, before the experimental study.

Fifteen healthy right-handed volunteers also participated in the study. They were seven males and eight females with a mean age of 53.37 years (range = 40–63, $SD = 7.23$) and mean education of 12.56 years (range = 8–18, $SD = 3.88$).

Stimuli

We selected 25 familiar Italian verbs denoting an action. For each action verb we created two types of sentence: (a) 50 literal sentences, half plausible

(e.g., *The man breaks the wall with his car*) and half implausible (*The man breaks the wall with the ice*); (b) 50 idiomatic (ambiguous) sentences, half plausible (e.g., *The man breaks the ice with the girl*) and half implausible (*The man breaks the ice for the prize*). Fifty sentences of similar length and syntactic structure containing a nonaction verb were created as control sentences, again half plausible (e.g., *The worker desires an increase of his salary*) and half implausible (*The worker desires the button of his cat*). Ten participants matched for age, educational level, and social environment to the PD patients were asked to rate the interpretability of implausible sentences on a scale ranging from 0 (not at all interpretable) to 5 (fully interpretable). The mean score was 0.146 (range = 0–1), confirming that implausible sentences were not considered interpretable. All sentences had the same verbal tense and were comparable for length. Each sentence included four parts: the subject (a noun phrase, Part I), a verb phrase (Part II including only the verb), and two complements (Parts III and IV). For example, the idiomatic sentence "*The man breaks the ice with the girl*" was divided as following: *the man/breaks/the ice/with the girl*. Importantly,

Table 2. Neuropsychological evaluation

Patient	MOCA	Verbal Fluency on phonological cue (≥ 17)	Digit span		Attentional Matrices (≥ 31)
			Forward (≥ 3.75)	Backward (≥ 2.65)	
1	25.5	44	5.75	3	42.5
2	21	18	4.5	3	37.25
3	29	41	5.5	4	47
4	n.a.	n.a.	n.a.	n.a.	n.a.
5	26	39	4.5	3	45.5
6	12	36	4.5	2	37.25
7	26	41	5.96	2.98	49
8	27	38.3	7	5.1	51.75
9	24	37	6.45	5.02	60
10	27	28	4.04	5.1	60
11	27	52	6.04	7.1	51
12	n.a.				
13	n.a.				
14	29	41	5.68	4.64	45
15	25	52	5.96	3.9	n.a.

Note: MOCA = Montreal Cognitive Assessment; n.a. = not assessed.

plausibility (or implausibility) of the sentence was driven by Part IV only, so that before reading Part IV it was not possible to infer whether the sentence was plausible or not. To sum up, participants could understand (disambiguate) whether the sentence was literal or idiomatic by reading Part III and could judge about plausibility by reading Part IV.

Sentences were balanced for mean written word frequency (Corpo e Lessico di Frequenza dell'Italiano Scritto [COLFIS]; Bertinetto et al., 2005): More specifically, the written frequency of nonaction verbs (mean 733.4) was matched to that of action verbs (mean = 1020.84), $t(48) = 1.07$, $p = .29$. We used the same noun phrase for each of the six types of sentence, and, as for the verb phrase, the written frequencies of the content words of the third and fourth segments were matched across all types of sentence (see Appendix). Psycholinguistic characteristics of the stimuli that are known to affect comprehension latencies were controlled as follows: A written booklet containing the sentences was presented to 23 healthy age-matched (mean age 55.7 years, $SD = 10.99$) participants who were asked to

assign a concreteness rating to the sentential meaning (from 1: "no concrete action at all" to 5: "totally concrete action"). Literal sentences were judged as conveying a concrete action (mean = 4.7, $SD = 0.6$, range = 2.5–5), and concreteness was significant, $F(2, 44) = 47.02$, $MSE = 0.84$, $p < .00001$: Literal action sentences were considered more concrete than idiomatic (mean = 2.8, $SD = 0.6$, range = 1.4–3.9) and nonaction verb sentences (mean = 2.3, $SD = 1.1$, range = 1.2–4.7). The same participants were also asked to rate on a 5-point scale the comprehensibility of the sentences (from 1: "not at all comprehensible" to 5: "fully comprehensible"). The mean comprehensibility values showed that all sentences were highly comprehensible (mean = 4.4, $SD = 1$), with no difference ($p = .061$) among the three types of sentence (idiomatic sentence mean comprehensibility = 4.3, $SD = 0.7$, range = 2.3–5; nonaction verb sentences mean comprehensibility = 4.6, $SD = 0.4$, range = 3.6–5; and literal action sentences mean comprehensibility = 4.4, $SD = 0.6$, range = 3.1–5), although there was a trend for mental sentences to be considered more comprehensible. For the 25 idioms,

we controlled how much the idiom meaning was known (idiom familiarity). We asked 20 additional participants to rate each idiom on a rating scale (from 1: unfamiliar idiom, to 3: totally familiar idiom). The idioms were judged as highly familiar (range = 2.3–2.9, mean familiarity = 2.68, $SD = 0.19$). A different group of 20 participants were presented with the list of idiomatic sentences intermingled with literal sentences and were asked to write down the first meaning they thought about for each sentence. In 93% of their answers on idioms, participants produced the idiomatic meaning first.

In sum, the sentences were balanced for length and constituent word frequency and had high comprehensibility scores. For idiomatic sentences the dominant meaning was the figurative one.

Procedure

Sentences were presented on a 17" PC screen using E-Prime. The four parts of each sentence were sequentially presented at a self-paced rate: Participants had to press a key to make the various parts of the sentence appearing. After all the four parts of the sentence had been sequentially presented, one at a time, a fixation cross appeared indicating that the plausibility judgement had to be provided. Participants pressed a left key for plausible sentences and a right key for implausible sentences (the response keys assignment was reversed for half participants) using the index and middle fingers of their dominant hand. After the judgement, the alert "next sentence" appeared on the screen, and participants pressed the key bar for the next sentence to appear. No feedback was given during the task. Participants were instructed to judge the plausibility of the sentences as accurately and as fast as possible. The different sentences were presented in random order. Before the experiment, participants familiarized with the procedure by performing a practice session in which 20 sentences (10 plausible and 10 implausible, different from those used in the real experiment) were presented.

At the end of the procedure, PD patients were asked to explain the meaning of the idiomatic

sentences. All of them were able to produce a correct definition.

Statistical analyses

Participants' mean RTs (ms) for reading each segment were recorded. RTs were excluded from the analysis when they fell outside a range of 200–3500 ms for each part and when the response was wrong. Analyses were carried out separately for controls, PD patients in ON-phase, and PD patients in OFF-phase, our goal being to compare performance with the different types of sentence within each group/condition—namely, the performance of controls, patients in ON (dopamine available), and patients in OFF (lack of dopamine). Indeed, other variables could have affect PD performance, such as the interval between the ON- and OFF-phases being not the same for each patient as well as the time of the day in which the experimental session was run. This would have made a direct comparison not completely reliable. Repeated measures ANOVAs with type of sentence as main factor were carried out on RT and accuracy. A first analysis was performed on cumulative reading times for Part III (in which the meaning of the action verb—literal or figurative—was disambiguated) to look for possible differences at this stage depending on type of sentence. Then, a repeated measures ANOVA was carried out on plausibility judgement RT for correct responses with type of sentence (literal action, idiomatic, nonaction) as within-subjects variables. Post hoc comparisons with Bonferroni correction applied followed significant effects and interactions. Since the patients were presented with the same sentences twice, we checked whether there was an effect of task repetition. An ANOVA with phase order (first OFF or first ON) as between factor revealed no significant effect on either accuracy or RT, ruling out any effect of task repetition on patients' performance. Accordingly, phase order was not further considered in the following analyses.

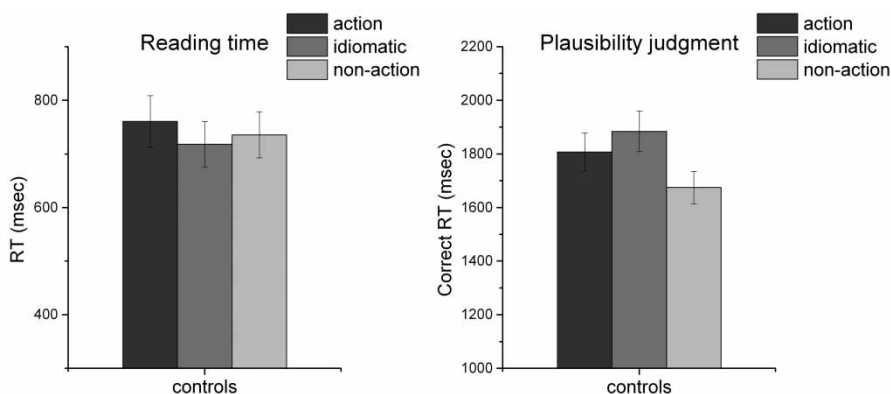


Figure 1. Mean reaction times (RTs) for reading Part III and for providing a plausibility judgement, for nonaction, idiomatic, and action sentences for controls. Error bars represent standard error from the mean.

RESULTS

Control participants

The ANOVA on participants' reading time for Part III (i.e., the sentence segment in which the action verb—literal or figurative—was disambiguated, but it was not yet possible to judge about the plausibility) did not reveal any significant effect for sentence type, $F(2, 28) = 2.54$, $p = .097$, $MSE = 2715$. Analysis on RT for plausibility judgement revealed a significant main effect of sentence type, $F(2, 28) = 10.47$, $p < .001$, $MSE = 16,193.5$, reflecting faster responses for nonaction than for idiomatic sentences ($p = .001$; see Figure 1), whereas literal action sentences did not differ from either idiomatic or nonaction sentences. Finally, the analysis on accuracy mirrored the pattern found on RT, revealing a significant effect of sentence type, $F(2, 28) = 5.09$, $p = .013$, $MSE = 0.002$, with accuracy being higher for nonaction (98%) than for idiomatic (92%) sentences ($p = .02$; see Figure 2), whereas literal action sentences (94%) did not significantly differ from either idiomatic or control ones.

Patients

Table 3 reports the mean RTs in phase ON and OFF for Part III reading and plausibility judgements. A first analysis showed that UPRDS

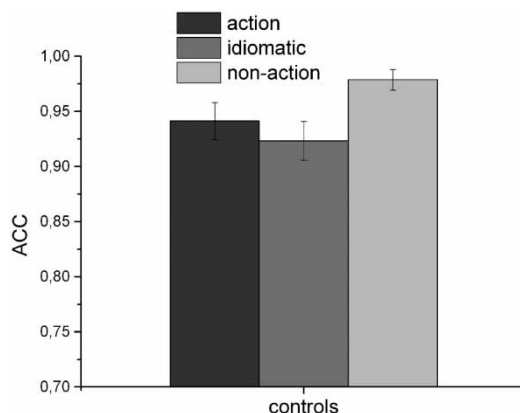


Figure 2. Mean accuracy for controls in the three types of sentence. Error bars represent standard error from the mean. ACC = mean accuracy.

scores were significantly lower in phase ON than in phase OFF, $t(11) = 9.19$, $p < .001$.

In ON-phase, patients behaved similar to controls. Indeed, in reading Part III, sentence type did not affect reading time, $F(2, 28) = 1.04$, $p = .37$, $MSE = 4762.6$, while in plausibility judgements, the effect of sentence type was significant, $F(2, 28) = 3.49$, $p = .044$, $MSE = 26,832.2$, with patients being faster in responding to nonaction than to literal action sentences ($p = .027$), whereas RT for idiomatic sentences did not significantly differ from either nonaction ($p = .43$) or literal action ($p = 1.0$) sentences. Finally, analysis

Table 3. Mean RTs on Part III and for plausibility judgements in patients in ON- and OFF-phase

Sentence segment	ON patients			OFF patients		
	Nonaction	Idiomatic	Literal	Nonaction	Idiomatic	Literal
Part III	1074.04	1037.74	1053.95	1058.67	987.52	1084.18
Plausibility judgements	2391.55	2488.49	2548.02	2431.53	2682.55	2443.32

Note: RT = reaction time, in ms.

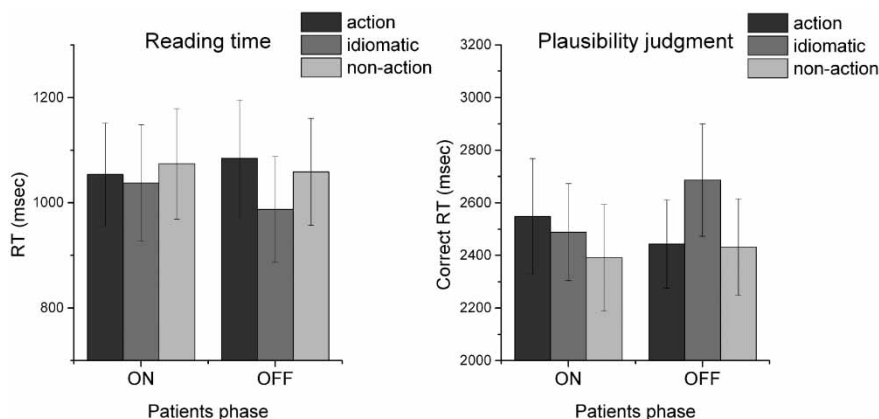


Figure 3. Mean reaction times (RTs) for reading Part III and for providing a plausibility judgement, for nonaction, idiomatic, and action sentences for patients in ON- and OFF-phase. Error bars represent standard error from the mean.

on accuracy showed a significant effect of sentence type, $F(2, 28) = 16.01$, $p < .001$, $MSE = 0.004$, patients in ON-phase being more accurate with nonaction (95%) than with idiomatic (83%, $p < .001$) and literal action sentences (84%, $p = .007$), whereas idiomatic and literal action sentences did not differ from each other ($p = 1.0$).

In OFF-phase, the main effect of sentence type in reading Part III was significant, $F(2, 28) = 9.08$, $p = .001$, $MSE = 4144$, with RT for idiomatic sentences being faster than that for nonaction ($p = .05$) and literal action ($p = .001$) sentences, whereas reading RT for Part III did not differ for nonaction and literal action sentences ($p = .89$). In plausibility judgements, the effect of sentence type was significant, $F(2, 28) = 9.6$, $p = .001$, $MSE = 32,387.5$, but differently from that for the ON-phase. Indeed, responses were slower for idiomatic than for nonaction and literal

sentences ($p = .008$ for both), whereas nonaction and literal action sentences did not significantly differ from each other ($p = 1.0$). Analysis on accuracy showed a significant effect of sentence type, $F(2, 28) = 6.84$, $p = .004$, $MSE = 0.005$, with patients being more accurate with nonaction (90%) than with action literal sentences (80%, $p = .009$) and idiomatic sentences (84%, $p = .15$, $p = .049$ uncorrected), whereas action literal and idiomatic sentences did not significantly differ ($p = .42$; see Figures 3 and 4).

DISCUSSION

We investigated the processing of ambiguous idioms containing an action verb in a group of PD patients tested in OFF- and ON-phase and in a group of matched healthy participants. More

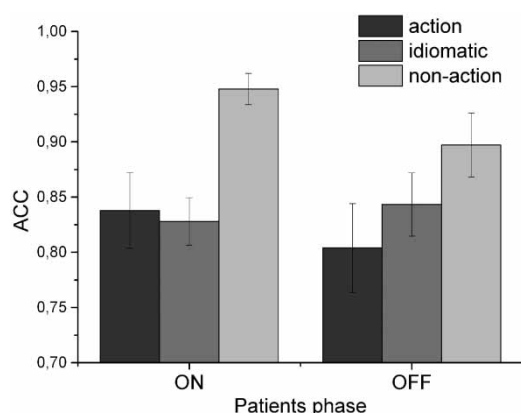


Figure 4. Mean accuracy for patients in ON- and OFF-phase in the three types of sentence. Error bars represent standard error from the mean. ACC = mean accuracy.

specifically, we investigated (a) whether PD patients in ON-phase show the same pattern of performance as controls with ambiguous idiomatic sentences including a verb denoting action, and (b) whether the lack of dopamine modulation in the prefrontal cortex overall affects idiom processing. Our task required participants to silently read a sentence containing a literal action verb, an idiomatic action verb, or a mental verb (control sentences) and to decide about the plausibility of the sentence. The sentence was divided into four segments, and each segment was individually presented at a self-paced rate: Participants had to press a key to make the various parts of the sentence appear. Our analyses focused on plausibility judgement accuracy and RT for correct plausibility judgements. Reading time in reading Part III (i.e., the part of the sentence in which the meaning of the action verb—literal or figurative—was disambiguated) was also considered as potentially important in revealing the way idiomatic sentences are processed.

As previously found in the literature on idiom processing, especially ambiguous idioms, healthy participants were slower and less accurate in providing plausibility judgements on this type of sentence. Indeed, slower RTs and lower accuracy have been repeatedly found for idiomatic than for literal sentences in neurologically unimpaired

populations (Fogliata et al. 2007; Oliveri, Romero, & Papagno, 2004; Rizzo, Sandrini, & Papagno, 2007; Schettino et al., 2010), with idiomatic sentences tapping on prefrontal functions (see Papagno & Romero, 2010, for a review).

The type of sentence did not affect reading time for Part III in either healthy controls or patients in ON-phase. PD patients in ON-phase performed overall better (in terms of both higher accuracy and faster RT) with mental-verb sentences than with literal action sentences, in line with previous studies reporting an impairment in action naming in PD patients on medication (see, for example, Cotelli et al., 2007; Herrera et al., 2012; Rodriguez-Ferreiro, Cueto, Herrera, Menéndez, & Ribacoba, 2010). In our study, PD patients in ON-phase also performed worse with idiomatic than with nonaction sentences, as did healthy participants. The lower performance of ON-phase PD patients with idiomatic processing may depend on idiomatic action sentences requiring more prefrontal processing and thus being more demanding, as in the case of healthy participants. However, in case of ON-phase PD patients, the difficulty in processing idiomatic sentences may depend on the action verbs used in the idiomatic context also involving the motor system (as in the case of literal action sentences). Further research may disentangle this issue, by comparing idioms with and without action verbs to verify whether the type of verb somehow affects idiom processing (note that in our study only action verbs were used in idiomatic sentences).

Nonetheless, the fact that patients in OFF-phase were faster in reading idiomatic sentences when the disambiguating word appeared (Part III) seems to support the hypothesis that the motor system is not involved in online idiom processing. Idioms are familiar, overlearned sentences, whose online processing is likely to be automatic and therefore less sensitive than processing of “new” sentences to the general cognitive slowing associated to dopamine reduction.

The pattern is reversed in plausibility judgements, a task that requires the reactivation and retention of the whole sentence. In this case, the reduced amount of dopamine in the prefrontal

region, which is crucial for idiomatic meaning interpretation (see, for example, Papagno, Lucchelli, Muggia, & Rizzo, 2003; Romero Lauro et al., 2008) negatively affects idiomatic sentence processing, which imposes the highest cognitive load, since two meanings are checked for plausibility, the figurative and the literal one.

Our results challenge those of a recent study (Fernandino et al., 2013b), in which PD patients were slower to respond to literal and idiomatic action sentences than to abstract sentences, suggesting that the sensory-motor system plays a role in processing figurative language. However, patients ON and OFF medication were tested together, the different types of sentence were never directly compared, and no data on executive functions are reported: It could be argued that patients were slower in responding to idiomatic sentences because they needed additional executive control, which was not available, as suggested for our patients in OFF. Finally, patients read the whole sentence at a time, preventing investigation of online processing and the effect of disambiguation.

In conclusion, in the case of idioms, online processing seems to activate only the figurative meaning in a purely automatic way, when the disambiguating word appears, supporting the configurational hypothesis (Cacciari & Tabossi, 1988). This explanation is in line with neurophysiological and neuroimaging data: Idiomatic meaning per se does not activate the motor system (Cacciari et al., 2011; Raposo et al., 2009; Romero Lauro, Mattavelli, Papagno, & Tettamanti, 2013). When a plausibility judgement is required, the sentence has to be reactivated, and both interpretations have to be checked, requiring additional cognitive resources. These are limited in PD patients (Grossman et al., 2000), especially, as expected, in OFF-phase. Our data, therefore, point to the role of dopamine in modulating prefrontal activity, which is crucial in ambiguous idiom interpretation.

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APPENDIX

Analyses of word segment frequency in the experimental sentences

(C = control, IA = idiomatic action, LA = literal action.)

Third segment

Mean frequency IA 335, LA 209.24, C 359.84

C vs. LA: $t(48) = 1.62, p = .11$

LA vs. IA: $t(48) = 1.05, p = .29$

C vs. IA: $t(48) = 0.22, p = .82$

Fourth segment

Mean frequency IA 406.2, LA 407.64, C 392.36

C vs. LA: $t(48) = -0.13, p = .89$

C vs. IA: $t(48) = 0.13$