Emotion and object processing in Parkinson's disease

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ABSTRACT

The neuropsychological literature on the processing of emotions in Parkinson's disease (PD) reveals conflicting evidence about the role of the basal ganglia in the recognition of facial emotions. Hence, the present study had two objectives. One was to determine the extent to which the visual processing of emotions and objects differs in PD. The other was to assess the impact of cognitive load on the processing of these types of information. Thirty-one patients with idiopathic PD (IPD) under dopamine replacement therapy (DRT) were compared to 30 control subjects on emotion and object recognition tasks. Recognition of objects was more accurate and faster than recognition of facial expressions of emotion, for both groups of subjects. In a second experiment using an N-back procedure with the same stimuli—a more demanding task with a higher cognitive load—patients with IPD were as accurate as control subjects in detecting the correct sequential presentation of stimuli, but were much slower in their decision responses. This indicates that IPD patients under DRT are not impaired in encoding emotion or object information, but that they have difficulty with the processing demands of the N-back task. Thus, patients with IPD appear to be more sensitive to cognitive load than to type of information, whether facial emotions or objects. In this perspective, one must consider that a deafferented dopaminergic system has problems processing more complex information before one can posit the existence of deficits affecting a specific type of information.

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1. Introduction

The involvement of the basal ganglia in the processing of emotion has been widely studied for nearly two decades. Studies of patients with lesions in or dysfunction of the basal ganglia have reported deficits in the processing of emotional prosody, in both the perceptive and expressive modalities (Breitenstein, Van Lancker, Daul, & Waters, 2001; Dara, Monetta, & Pell, 2008; Weddell, 1994). In line with these findings, neuroimaging studies have also shown neural activation within these subcortical structures during the response to emotions from vocal expressions (Kotz et al., 2003; Wildgruber et al., 2005). Also consistent with the involvement of the basal ganglia in emotional processing is an fMRI study by Phillips et al. (1997), who found activation of the right putamen for the processing of intense disgust.

Patients in the early stages of Huntington's or Parkinson's disease are impaired in the recognition of facial expressions of emotions (Dujardin et al., 2004; Lawrence, Goerendt, & Brooks, 2007; Sprengelmeyer et al., 1997, 2003). Specifically, patients with Huntington's disease (HD), who suffer from degeneration of medium-sized spiny striatal neurons, are severely impaired in the ability to recognize facial expressions of disgust, while their interpretation of other emotions is relatively preserved (e.g., Sprengelmeyer, Schroeder, Young, & Epplen, 2006). This impaired recognition of disgust has also been found with vocal expressions of disgust (Hayes, Stevenson, & Coltheart, 2007).

In Parkinson's disease (PD), the evidence as to whether emotion processing is negatively affected and, if so, which specific emotions—if there is such a selective disturbance as that found in HD—is not clear. Sprengelmeyer et al. (2003) examined emotional information processing in PD patients under different conditions: while unmedicated PD patients presented with higher deficits in the recognition of disgust, this specific impairment was not observed in medicated PD patients, even at a more advanced stage of the disease. In these authors' view, the administration of dopaminergic treatment exerts a corrective effect on the performance of patients with PD in the recognition of facial emotions. Dujardin et al. (2004) presented evidence of a broader impairment in the recognition of facial emotions in PD, not limited to expressions of disgust. These authors reported that patients with PD had an impairment in decoding the facial expressions of sadness and anger. Paradoxically, injection of levodopa in healthy subjects leads

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to an impairment in the recognition of emotions (Delaveau, Salgado-Pineda, Wicker, Micallef-Roll, & Blin, 2005).

A few studies, however, present a more complex picture of the involvement of dopaminergic neuromodulation in the recognition of disgust in PD. In their first study, Lawrence, Calder, McGowan, and Grasby (2002) found that acute dopaminergic blockade in healthy subjects temporarily triggers an impairment in the recognition of anger, but not of disgust or other emotions. These authors therefore hypothesized that PD, characterized by a loss of dopaminergic nigrostriatal neurons, is associated with impaired anger recognition. Consistent with these findings, Lawrence et al. (2007) found that PD patients who were suddenly withdrawn from dopamine replacement therapy performed worse than healthy controls in the recognition of anger only, with no difference between the performance of patients with PD and control subjects for the processing of disgust or other emotions. Finally, the severity of the disease appears to determine how subjects respond to emotional stimuli. Yip, Lee, Ho, Tsang, and Li (2003) found that patients with bilateral disease performed worse on an extensive emotion recognition battery (facial and prosodic recognition and identification) than patients with right-sided disease, who only had difficulty with the identification tasks.

The results of the above-mentioned studies of PD patients suggest that the basal ganglia are involved in the processing of emotions. However, this does not appear to be a uniform observation, as some studies failed to show any such impairment. For instance, Adolphs, Schul, and Tranel (1998) found that PD subjects were similar to healthy controls in the recognition of emotions, but suggest that the nature of the dysfunction of the basal ganglia is not sufficient to compromise the processing of this type of information in PD. Pell and Leonard (2005) found little evidence of impairment in processing facial expression of emotions in PD. These authors, however, considered the role of the basal ganglia in the processing of emotion from static faces relative to speech prosody to be more limited. These findings suggest that brain circuits involving subcortical brain areas highlight an adaptive intentional control of behavior, where representations of emotional content are generated in a task-dependent mode (see Elmer & Holmes, 2006).

In sum, the neuropsychological literature on the processing of emotions in PD reveals conflicting evidence about the role of the basal ganglia in the recognition of facial expressions. One interpretation for such divergent results is that corrective dopaminergic treatment (DRT) may compensate for some of these deficits, as the findings of impaired recognition of facial emotions included unmedicated or off-medicated patients (e.g., Dujardin et al., 2004; Lawrence et al., 2002, 2007; Sprengelmeyer et al., 2003;). From this perspective, dysregulation of dopaminergic striatal afferentation is sufficient to reveal impairment in the recognition of emotions.

DRT also appears to modulate the visual recognition of living objects. For example, the performance of parkinsonian patients in the identification of animals is significantly poorer in patients off medication than when they are under DRT (Righi, Viggiano, Paganini, Ramat, & Marini, 2007). These deficits in the recognition of living objects, revealed in the absence of medication and silenced by dopaminergic treatment, suggest that dopaminergic modulation plays a critical role in visual recognition. Until now, all studies have focused on how patients with PD processed emotions, without contrasting their performance in response to another type of information. Thus, it is not clear whether the impairment observed is specifically caused by a disturbance in the processing of emotions or whether it is a reflection of more generalized and nonselective companion deficits in visual information processing.

A related question pertains to the nature of the tasks used in these studies. Rating facial emotions along a continuum, identifica-

tion or recognition of facial emotions were the tasks of choice in most studies cited. These tasks may not be sensitive enough to reveal problems in emotion processing, when patients with PD are taking DRT. Cognitive deficits in memory, executive function and spatial abilities are often observed in the early stages of the disease (e.g., Amick, Schendan, Ganis, & Cronin-Golomb, 2006; Dubois & Pillon, 1997; Taylor & Saint-Cyr, 1995). It is thus conceivable that tasks that tap into higher processes relying on more complex analysis of information could detect deviant cognitive patterns.

Hence, the aim of the present study was twofold. One objective was to determine the extent to which the visual processing of emotions and objects differs in PD. If emotions and objects are treated similarly, it would be difficult to argue that PD patients are specifically impaired in the processing of emotions. The other was to assess the impact of cognitive load, or task difficulty, on the processing of these types of information, using a more ecologically valid approach to the study of visual processing of emotions. Such an approach would help tease out whether it is the difficulty of the task or the type of information which is implicated in the observed impairment, if any.

2. Experiment 1

As mentioned above, it remains unclear whether patients with PD are selectively impaired in their ability to recognize facial expressions of emotions. It is possible that categories of visual information other than emotional information are also affected, thus reflecting a more generalized impairment of visual recognition in PD. The aim of this first experiment was to provide an initial comparison of the recognition of two types of visual information: facial emotions and objects. To do this, we compared patients with idiopathic PD (IPD) to a matched group of healthy controls on tasks of emotion and object recognition.

2.1. Methods

2.1.1. Participants

Thirty-one individuals with a diagnosis of IPD (15 women, 16 men) participated in the study. The patients were recruited from Clinique Sainte Anne, Quebec, Canada. The participants were French-Canadian individuals who had received a diagnosis of probable IPD from a movement disorder specialist (E.P.), using the Hughes Diagnostic Criteria for PD (Hughes, Daniel, Kilford, & Lees, 1992). Patients with a significant comorbid vascular medical history not related directly to their PD (e.g., diabetes, coronaropathy, high blood pressure) or with focal sensory or perceptual deficits were not included in the study. Patients who scored 24 or lower on the Mini-Mental State Examination (Folstein, Folstein, & MacHugh, 1975) were also excluded. The severity of clinical symptoms was assessed according to the Hoehn and Yahr (1967) five-point rating scale. Hoehn and Yahr ratings ranged between 1 and 2.5. All patients had been receiving stable medication doses for at least 2 months and were not affected by motor or affective fluctuations during their waking day. Subjects were not depressed and not demented, according to classical cut-off scores (e.g., Schrag, Barone, Brown, Leentjens, & McDonald, 2007) on the Beck Depression Inventory (Beck & Steer, 1987) and the Mattis Dementia Rating scale (e.g., Kulisevsky & Pagonagabarra, 2009), respectively.

The patients with IPD were compared to 30 healthy controls (16 women, 14 men) who were recruited from among the patients' relatives. There was no difference in age or level of education between the two groups of participants (all *p*'s > .05). The study was carried out according to the principles laid out in the Helsinki declaration and was approved by the Clinique Sainte Anne's ethics committee. The demographic and clinical characteristics of IPD patients and healthy controls are presented in Table 1.

Table 1
Demographic and clinical characteristics of participants.

	IPD group $N = 31$ 15 women, 16 men	Control group $N = 30$ 16 women, 14 men	Statistical result
Mean age, year (SD)	65.37 (7.04)	65.10 (7.89)	$p = 0.893$
Mean education, year (SD)	13.14 (4.54)	13.04 (3.88)	$p = 0.925$
Mean duration of disease, year (SD) (diagnosis date)	4.79 (2.85)		
Hoehn & Yahr stage	Range: 1–2.5		
Mean L-Dopa daily dose, mg (SD)	618.42 (250.67)		
Dopamine agonist daily dose, mg (SD) (Mirapex equivalent dose)	1.45 (1.01)		

2.1.2. Facial expressions of emotion stimuli

Twenty individual faces (10 men, 10 women), displaying expressions of anger, fear, sadness, happiness and disgust were taken from standardized sets of pictures (MSFDE: Beaupré & Hess, 2005; NimStim: Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002) and used as the emotion stimuli in this experiment. The pictures were 7.6 × 12.6 cm in size and were shown in black and white on a computer screen.

2.1.3. Object stimuli

Four objects drawn from each of five categories (animal, clothing, fruit, tool, vegetable) were taken from a standardized set of exemplars (Brosseau & Cohen, 1996), for a total of 80 stimuli. The pictures were 7.6 × 12.6 cm in size and were shown in black and white on a computer screen.

2.1.4. Procedure

Subjects were seated in front of a computer screen (PC Toshiba Satellite Pro A200). For each trial, a fixation cross appeared in the center of the screen for 1000 ms. Two emotion labels were then displayed simultaneously, one to the left and one to the right of the screen for 1500 ms. They were followed by a picture of facial emotion which remained in the center of the screen until a response was made. Subjects were instructed to press the left button if the facial expression corresponded to the emotion label that had appeared on the left side of the screen or the right button if the picture corresponded to the emotion label that had appeared on the right side of the screen. The emotion stimuli were presented in randomized order for each participant. A gender recognition task was used as a prior practice in order to familiarize participants with the procedure and use of computer. The object recognition procedure was identical to that followed for emotions, except that participants had to determine which of two object category labels described the picture shown. Reaction time (RT; in ms) and accuracy of responses were recorded. The experiment was run with SuperLab software (version 2.0; Cedrus Corporation, 2008). Half of the subjects began with the emotion recognition task and the other half with the recognition of objects.

2.2. Results

2.2.1. Recognition of facial emotion

A Group (IPD, Control) × Emotion (Anger, Disgust, Fear, Happiness and Sadness) ANOVA on response times, with repeated measures on the second factor revealed a main effect of Emotion ($F_{(4224)} = 94.35$, $p < .01$, $\eta^2 = 0.63$). Post hoc tests with Bonferroni correction for multiple comparisons showed that the recognition of happiness was faster for all subjects ($p < .05$). A Group × Emotion ANOVA on correct scores, with repeated measures on the second factor revealed no difference in accuracy between the two groups or between emotions ($p > .05$). Mean accuracy values were .74 (±.28) and .67 (±.28) for the control and patient groups, respectively. Fig. 1a shows the mean response times of the two groups of participants in the recognition of facial emotions.
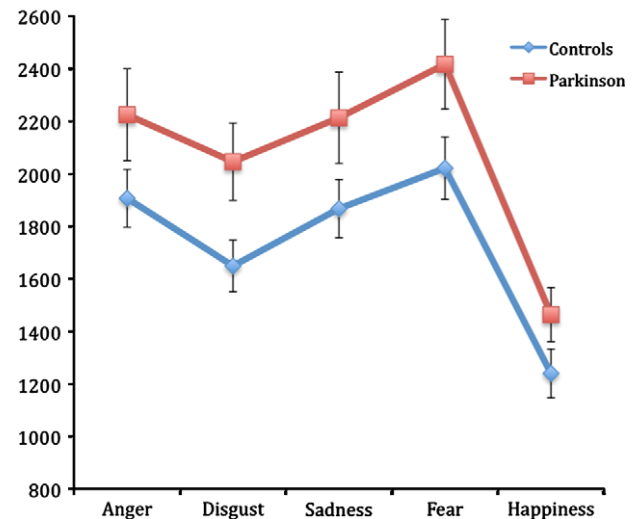

Fig. 1a. Mean response times (ms) for recognition of the five facial emotions.

2.2.2. Recognition of objects

A Group (IPD, Control) × Object Category (Animals, Fruit, Tools, Clothing, Vegetables) ANOVA on response times, with repeated measures on the second factor showed that objects were not all processed in the same way ($F_{(4, 220)} = 13.26$, $p < .01$, $\eta^2 = 0.19$). Post hoc tests with Bonferroni correction for multiple comparisons revealed that recognition of animal exemplars was faster for all subjects ($p < .05$). Fig. 1b shows the mean response scores of the two groups of participants in the recognition of objects.

Mean accuracy measures for objects were .80 (±.33) and .72 (±.34) for the control and IPD groups, respectively. A chi-square test was used to assess differences in accuracy between the two
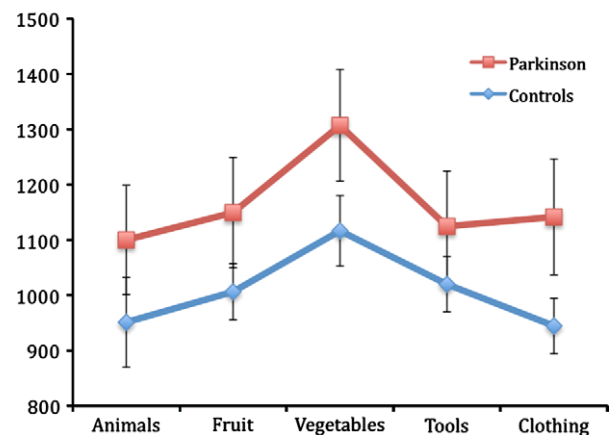

Fig. 1b. Mean response time (ms) for recognition of the five object categories.

groups as nonparametric statistical procedures do not require the assumption of a normal distribution. The analysis revealed that control subjects were significantly more accurate than IPD patients in the recognition of animals only (χ^2 (1, N = 58) = 4.88, p = .027, η^2 = 0.29).

2.2.3. Comparing the processing of emotions and objects: RT

A Pearson product-moment correlation was computed to determine the degree of association between the RT measures for the five facial expressions of emotions (Anger, Disgust, Fear, Happiness and Sadness). A correlation analysis revealed that the RTs for the emotion recognition task were highly correlated (r's > 0.70). Internal consistency was high (alpha = 0.96) and allowed us to combine the five RTs into a global emotion measure. The same procedure was also applied to mean RT measures for the recognition of objects (alpha = 0.96). A Group (IPD, Control) × Type of information (Emotions, Objects) ANOVA with repeated measures on the second factor revealed a main effect of Type of information ($F_{(1, 54)}$ = 388.3, p < .01, η^2 = 0.88). Post hoc tests showed that all subjects were faster at recognizing objects. Fig. 1c shows the overall mean response scores of the two groups of participants in the recognition of facial emotions and objects.

2.2.4. Comparing the processing of emotions and objects: accuracy

A Pearson's correlation coefficient was computed between the five facial expressions of emotions (Anger, Disgust, Fear, Happiness and Sadness) to determine whether the mean accuracy measures were correlated. A correlation analysis revealed that the accuracy scores for the emotion recognition task were also highly correlated (r's > 0.70) and the accuracy measures were therefore collapsed under a single variable (Emotion). The same procedure was applied to accuracy measures for object categories. A Group (IPD, Control) × Type of information (Emotions, Objects) ANOVA with repeated measures on the second factor revealed a main effect of Type of information ($F_{(1, 54)}$ = 26.7, p < .01, η^2 = 0.33). For both groups, objects were recognized more accurately than emotions.

Finally, Pearson product-moment correlation coefficients were computed between medication dosage (Mirapex-eq.; Thobois, 2006) and performance to determine whether DT was associated with recognition of objects or facial emotions. All correlations yielded nonsignificant coefficients, as presented in Table 2.

2.3. Discussion

The results of experiment 1 showed that the performance of IPD patients is comparable to that of healthy subjects in all aspects of
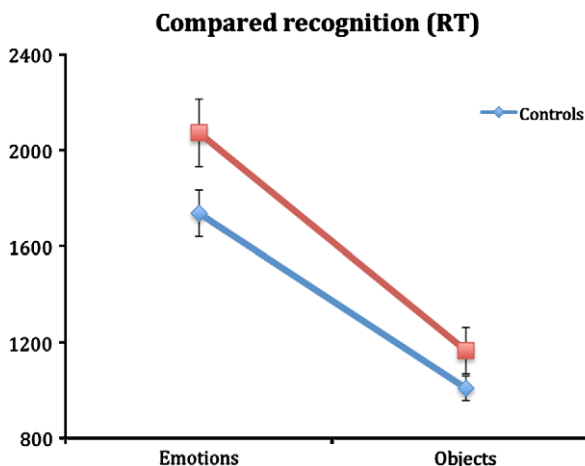
Table 2
Pearson product-moment correlation coefficient matrix between medication (Mirapex-eq.) and performance. All p's > .05. (a) Recognition task, (b) N-back task.

	Mean response time		Mean accuracy score	
Emotions				
Medication	.069		.069	
Objects				
Medication	.175		.025	
	0-back	1-back	2-back	3-back
Emotions: response time				
Medication	.137	.342	.188	.138
Emotions: accuracy score				
Medication	.215	.375 (p = 0.049)	.035	.003
Objects: response time				
Medication	.09	.088	.014	−.049
Objects: accuracy score				
Medication	−.196	−.113	−.083	−.057

the recognition of facial emotions. Impairment in this type of information was only observed in previous studies conducted on unmedicated patients with IPD (Dujardin et al., 2004; Lawrence et al., 2002; Sprengelmeyer et al., 2003). It is thus possible that the dopaminergic modulation of cortico-striatal functions exerts a limited contribution to emotion recognition but, if it does exist in unmedicated parkinsonian patients, it is corrected by DRT. A similar pattern of responses was observed in the processing of object information, with the possible exception of animal exemplars. It may be that the processing of living objects is more difficult for patients with IPD, as a dissociation in the processing of objects from different semantic categories had also been observed in a previous study (Righi et al., 2007).

An interesting result of this experiment is that there is a clear difference in the recognition of emotions and objects. Recognition of objects was more accurate and faster than recognition of facial expressions of emotion, for both groups of subjects. The representation of the organization and functional properties of objects depends on a neural network involving visual associative cortical areas. Evidence from lesion studies has shown that the lateral occipital complex plays a central role in the visual recognition of objects (Grill-Spector, Kourtzi, & Kanwisher, 2001). With respect to the recognition of emotions, PET studies have revealed a different pattern of cortical activation. The neural representation of facial expression is mediated by a more complex neural circuit involving different cortical limbic and paralimbic regions (Paradiso et al., 1997), among others. Specifically, it has been shown that the anterior frontal cortex, the amygdala, the middle temporal gyrus, and the fusiform gyrus, as well as the right anterior cingulate are activated during the recognition of facial expressions (Streit et al., 1999; see also Clark, Neargarder, & Cronin-Golomb, 2008). Signal clarity remains an issue as expressions of emotion are more easily confused than tools and animals.

In summary, nondepressed and nondemented patients with IPD who are taking DRT for optimal effects are not selectively impaired in the recognition of emotions and behave similarly to healthy controls in the recognition of both object and emotion stimuli. Although the task used here was relatively difficult (mean accuracy scores varied between .67 and .80), it is possible that simple recognition is not sensitive enough to detect the involvement of striatal networks in visual recognition. A more demanding task involving executive demands may more clearly reveal the contribution of the basal ganglia and related circuits.

3. Experiment 2

The aim of the second experiment was to examine whether emotion and object information are differentially processed in a

Fig. 1c. Mean response time (ms) for compared recognition of facial emotions and objects.

task requiring a higher cognitive load as, in most previous studies, simple emotion recognition had been the procedure of choice. It has been suggested that the executive deficits often seen in PD reflect a basal ganglia dysfunction, through frontostriatal circuitry. A widely used task in studies of executive functions involving working memory (WM) is the *N-back* procedure. N-back tasks such as the one employed in the present study involve both maintenance and manipulation of material in WM and have been shown to consistently activate the inferior/ventrolateral prefrontal cortex, which is sensitive to WM load (Cohen et al., 1997). For instance, neuroimaging and neuropsychological studies in healthy volunteers have shown that frontal regions are continuously involved when subjects attend to various forms of the *N-back* procedure (Jansma, Ramsey, Coppola, & Kahn, 2000; Smith & Jonides, 1997). In the present study, we sought to investigate the performance of IPD patients on a WM (N-back) task with emotion and object stimuli. The strong involvement of prefrontal cortical regions in various WM components (Fletcher & Henson, 2001) and recent findings implicating the basal ganglia in the modulation of WM performance (Moustafa, Sherman, & Frank, 2008) suggest that we should observe a reduced performance in patients with IPD, as compared to an age- and education-matched healthy control group.

3.1. Methods

3.1.1. Participants
The subjects were the same ones who took part in experiment 1.

3.1.2. Stimuli and equipment
The facial emotion stimuli and equipment were the same as those used in the first experiment. In all, 54 blocks of four emotion stimuli each and 54 blocks of four objects were constructed, with one exemplar of four of the emotions (Anger, Disgust, Fear, Happiness and Sadness) and one exemplar of four of the object categories (Animals, Fruit, Tools, Clothing, Vegetables) included in each block, respectively. Stimuli were ordered within the blocks such that all emotions or object categories appeared with equal frequency and were also equally represented in first, second, third or fourth position within a block. No two exemplars of the same object or emotion category appeared within the same block. In half of the blocks, the expression of Disgust was presented with equal frequency immediately after the expression of Happiness, or one, two or three positions after (0-back, 1-back, 2-back or 3-back, respectively). The same stimulus ordering was applied to the construction of object blocks and the relative position of Clothing and Fruit exemplars.

3.1.3. Procedure
Subjects were tested individually, seated in front of a computer screen. Each trial began with the presentation of a fixation cross in the center of the screen for 1000 ms. Four facial emotions were then sequentially presented in the middle of a screen, with a duration of 750 ms each. Participants were asked to indicate whether or not the expression of Disgust followed the expression of Happiness, in the Emotion condition, and whether a Clothing item followed a Fruit in the Object condition. Subjects were asked to press the left button of a computer mouse for YES and the right one for NO. There was an interval of 1000 ms between the subject's response and the start of the next trial. Participants were instructed to respond as fast and as accurately as possible; assignment of YES and NO buttons was counterbalanced across participants. A task asking about the gender order of presentation ("Is a woman's face followed by a man's face?") was used as a prior practice in order to familiarize participants with the N-back procedure. Half of the subjects started with the Emotion N-back task followed by the Object N-back task. The other half completed the

tasks in reverse order. Reaction time and accuracy measures were recorded for all subjects.

3.2. Results

3.2.1. Emotion N-back task
A Group (IPD, Control) × N-back (0-, 1-, 2-, 3-back) ANOVA on RTs, with repeated measures on the second factor, revealed a main effect of N-back condition ($F_{(3159)} = 8.93$, $p < 0.1$, $\eta^2 = 0.38$) only. Post hoc tests with Bonferroni correction revealed that all subjects took longer to respond to 0-back, when expressions of disgust were presented immediately after expressions of happiness ($p < 0.05$). Fig. 2a shows the performance of the two groups of subjects in the N-back task with the facial emotions.

A chi-square test was used to assess differences in accuracy between the two groups as nonparametric statistical procedures do not require the assumption of a normal distribution. No difference in accuracy between the two groups or between N-back conditions was found (all p's > .05).

3.2.2. Object N-back task
A Group × Stimulus distance ANOVA with repeated measures on the second factor revealed a main effect of Group ($F_{(1, 53)} = 6.15$, $p = .016$, $\eta^2 = 0.10$), showing that patients with IPD were significantly slower than healthy controls in all N-back conditions. A main effect of Stimulus distance was also found ($F_{(3159)} = 9.82$, $p < .01$, $\eta^2 = 0.16$) with all subjects taking longer to respond when Clothing items were presented immediately after fruit exemplars (0-back condition). Fig. 2b shows the performance of the two groups of subjects in the N-back task with the objects.

A chi-square test was used to assess differences in accuracy between the two groups. No difference in accuracy between the two groups or between stimulus interval was found (all p's > .05).

3.2.3. Comparing the processing of emotion and object stimuli on the N-back task
A Group (IPD, Control) × Type of information (Emotions, Objects) × Stimulus distance (0-, 1-, 2-, 3-back) ANOVA on RTs, with repeated measures on the second and the last factors revealed a main effect of Group ($F_{(1, 51)} = 7.02$, $p = .01$, $\eta^2 = 0.12$), with control participants being significantly faster than IPD patients in processing emotion and object information in all N-back positions. A main effect of Stimulus distance ($F_{(3153)} = 14.57$, $p < .01$, $\eta^2 = 0.22$) was also found,
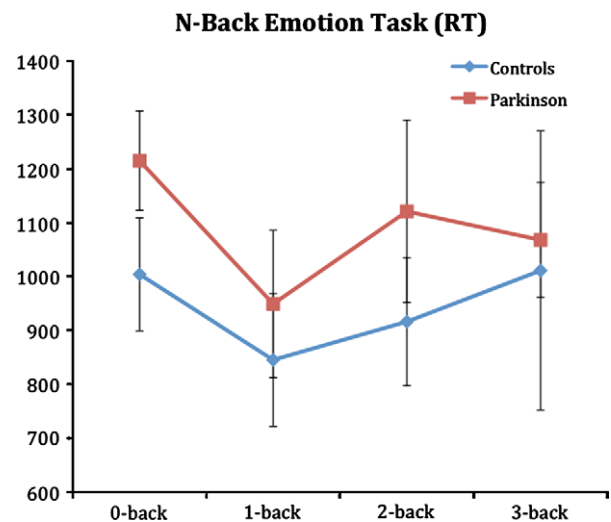
Fig. 2a. Mean response time (ms) in N-back task for emotions.
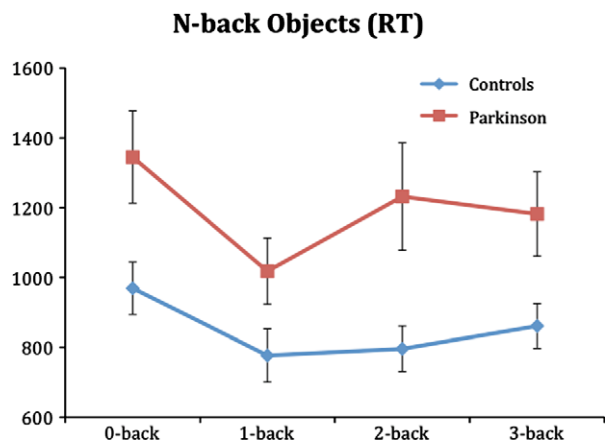
N-back Objects (RT)

Fig. 2b. Mean response time (ms) in N-back task for objects.

showing that response times were always longer in 0-back positions for emotions as well as for objects.

3.3. Discussion

The same type of stimuli as were used in the first experiment were used in this second experiment. The cognitive demands for the N-back task, however, were higher than those required to perform the simple recognition task. Although patients with IPD were as accurate as control subjects in detecting the correct sequential presentation of stimuli, they were nonetheless much slower in their decision responses. This finding indicates that IPD patients are not impaired in encoding emotion or object information; instead, it would appear that they have difficulty with the processing demands of the N-back task. The results also showed slower RTs in the 0-back condition, with Disgust following Happiness in the Emotion condition, and with Clothing items following a Fruit in the Object condition.

The N-back task taps into processes involving cognitive functions such as WM that depend upon the integrity of the dorsolateral prefrontal cortex (Carlson et al., 1998; Jansma et al., 2000; Smith & Jonides, 1997) and the striatum (Walsh, Williams, Brammer, Bullmore, & Kim et al., 2007). Deficits in WM function have frequently been reported in PD (Lewis, Slabosz, Robbins, Barker, & Owen, 2005; Owen, Iddon, Hodges, Summers, & Robbins, 1997). However, this is in contrast with the present results, where spared accuracy was observed on the part of IPD patients, for both types of information. Patients with IPD only appeared slower at processing information and this appears consistent with previous studies that also found slower responses in various cognitive tasks (Gauntlett-Gilbert & Brown, 1998; Hocherman, Moont, & Schwartz, 2004).

4. General discussion

A possible explanation of the nature of reaction time deficits in PD may be due to nonspecific factors such as a general slowing of all cognitive effects (bradyphrenia). This impairment is not restricted to cognitive abilities but is distributed over other cerebral functions. Bradykinesia is a core symptom of PD (e.g., Berardelli, Rothwell, Thompson, & Hallett, 2001; Wolters, 2008) and there is evidence linking both motor and cognitive slowing specifically to the dopaminergic depletion in the basal ganglia. On the other hand, clinical evidence has also demonstrated cognitive slowing in disorders primarily attributable to cortical pathology, such as frontotemporal dementia (Carlin et al., 2000). It is thus possible that cognitive slowing in PD results from disturbance of the frontal cortex. However, a more plausible explanation is that cognitive slowness may result from both brain areas, particularly due to dysfunction of the corticobasal ganglia pathways. The functional organization of the cortico-striato-thalamo-cortical loops in parallel segregated circuits in the sensory motor, limbic, and associative domains is now well established (Alexander, DeLong, & Strick, 1986; Parent & Hazrati, 1995); only their level of convergence and cross-communication is still a matter for debate.

Specifically, in the dorsal (motor) striatum, the dorsolateral putamen and dorsolateral region of the caudate receive input from the primary motor cortex and the supplementary motor area. This loop is concerned with movement preparation, amplitude and velocity. In the ventral (limbic) striatum, including the nucleus accumbens, both ventral parts of the putamen and caudate nucleus receive fibers from the limbic and paralimbic cortices, as well as from the amygdala and hippocampus. In the associative striatum, most of the head, body and tail of the caudate nucleus mainly receive afferent projections from the prefrontal cortex. Dysfunction of such associative loops between the caudate nucleus and the prefrontal cortex, resulting from striatal dopamine deficiency, may underlie the slowed cognitive processes observed in IPD patients. It is therefore significant that DRT may not be adequate to reduce this type of deficits; previous studies had also found that levodopa did not improve a range of cognitive abilities (e.g., Godbout & Doyon, 2000; Lewis et al., 2005).

In conclusion, it is important to consider that nondepressed and nondemented patients with IPD appear to be more sensitive to cognitive load than to type of information—specifically, facial emotions or objects. This strongly suggests that a deafferented dopaminergic system is broadly susceptible to the processing of more complex information before deficits for a specific type of information can be revealed. It remains to be determined, with off- and on-medication patients with PD, whether these observations can be generalized to a wider range of cognitive abilities.

Acknowledgments

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