Not all sounds sound the same: Parkinson's disease affects differently emotion processing in music and in speech prosody

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Does emotion processing in music and speech prosody recruit common neurocognitive mechanisms? To examine this question, we implemented a cross-domain comparative design in Parkinson's disease (PD). Twenty-four patients and 25 controls performed emotion recognition tasks for music and spoken sentences. In music, patients had impaired recognition of happiness and peacefulness, and intact recognition of sadness and fear; this pattern was independent of general cognitive and perceptual abilities. In speech, patients had a small global impairment, which was significantly mediated by executive dysfunction. Hence, PD affected differently musical and prosodic emotions. This dissociation indicates that the mechanisms underlying the two domains are partly independent.

Keywords: Dissociation; Emotion recognition; Music; Parkinson's disease; Speech prosody.

INTRODUCTION

We listen to music mostly because of its emotional power. Music communicates emotions such as happiness, sadness, or fear, consistently and universally (e.g., Fritz et al., 2009; Juslin & Laukka, 2003). Pleasurable responses to music recruit ancient neural circuitries of emotion and reward that also respond to basic biological reinforcers like food and sex (Blood & Zatorre, 2001; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). It has been suggested that a reason why music induces emotions is that it engages neural pathways that are tuned to sounds of greater biological relevance—namely, emotional vocalizations (e.g., Hauser & McDermott, 2003; Juslin, Liljeström, Västfjäll, & Lundqvist, 2010; Juslin & Västfjäll, 2008; Nieminen, Istók, Brattico,

Tervaniemi, & Huotilainen, 2011; Patel, 2008a, 2008b; Peretz, 2010). If so, we can hypothesize that the same neurocognitive mechanisms are set into action for emotion processing in music and in speech prosody (i.e., nonverbal segmental and suprasegmental vocal cues that communicate emotions, such as pitch, loudness, tempo, rhythm, and timbre; e.g., Grandjean, Bänziger, & Scherer, 2006). This hypothesis can be tested by implementing a comparative design between the two domains in Parkinson's disease (PD): Does PD affect emotion processing in music and speech in a similar way? Although some studies have documented impairments in emotion recognition in speech prosody in PD (Gray & Tickle-Degnen, 2010), effects for music have hardly been investigated. We compare for the first time the impact of PD on emotion recognition in music and in speech prosody. This

direct comparison will throw light on the degree of putative overlap across domains. It will also contribute to a better understanding of the clinical phenomenology of PD.

Emotions in music and in speech prosody: How close?

The links between emotions in music and speech have long been speculated on (e.g., Scherer, 1995), but systematic empirical research on this topic is recent. In a landmark meta-analysis, Juslin and Laukka (2003) pointed out that the recognition accuracy rates and the acoustic profiles associated with anger, fear, sadness, happiness, and tenderness are similar in music performance and vocal expression. More recently, Curtis and Bharucha (2010) showed that the musical interval of a minor third, which is associated with the perception of sadness, parallels the pitch contour modulation of sad emotional speech. Furthermore, the spectral differences between major and minor thirds and sixths are similar to the differences between excited and subdued speech (Bowling, Gill, Choi, Prinz, & Purves, 2010). On the basis of the notion that music and speech prosody communicate emotions through similar codes, Juslin and colleagues (Juslin & Laukka, 2003; Juslin et al., 2010; Juslin & Västfjäll, 2008) hypothesized that music may engage the brain modules that also respond to vocal expressions. The voice-like cues of music would be well suited to co-opt neural systems evolved for vocal emotions. This hypothesis has often been put forward in recent years (Hauser & McDermott, 2003; Nieminen et al., 2011; Patel, 2008a; Peretz, 2010), though empirical support for the overlap of neurocognitive mechanisms is scarce. On one hand, there is tentative evidence that mechanisms are partly common across domains: Expertise in one domain, music, is associated with enhanced processing of emotions in the other domain, prosody (Lima & Castro, 2011b; Thompson, Schellenberg, & Husain, 2004). On the other hand, direct cross-domain comparisons are rare, and they would be critical to approach the overlap hypothesis.

Ilie and Thompson (2006) compared how identical acoustical manipulations of intensity, rate, and pitch height in music and speech influence subjective ratings on valence, energy arousal, and tension arousal. They found similar effects across domains, but they also found domain-specific effects. For instance, loud speech and loud music were both perceived as more unpleasant, energetic and tense than their softer counterparts, suggesting that intensity manipulations produce domain-general effects.

However, pitch height manipulations had opposite effects in the two domains: High-pitched speech was perceived as more positive than low-pitched speech, whereas high-pitched music was perceived as more negative than low-pitched music. It is thus possible that emotions in music and speech also involve domain-specific mechanisms (see also Ilie & Thompson, 2011). This is a plausible heuristic hypothesis. Approached from the musical side, it does justice to the fact that mechanisms beyond those related to speech, such as rhythmic entrainment and musical expectancies, may be involved in musical emotions (Juslin et al., 2010; Juslin & Västfjäll, 2008). Approached from the speech side, it is compatible with the notion that emotional prosody is not a unitary process; it involves multiple operations in a distributed network of cortical and subcortical systems (Leitman et al., 2010; Schirmer & Kotz, 2006), and these systems may not be all similarly engaged by music (for a review, Peretz, 2010). For example, Omar et al. (2011) found that, in frontotemporal degeneration, both emotion recognition in music and in nonverbal vocal expressions (e.g., laughter) were impaired, but the anatomical pattern of brain damage linked with performance in the two domains overlapped only partially: Grey matter losses in the orbitofrontal cortex, medial prefrontal cortex, and insula were more strongly associated with behavioral performance in music than in voice. This study examined nonverbal expressions, not emotional speech prosody proper, though. One strategy to determine whether music and speech recruit common mechanisms consists of focusing on a disorder that may affect the recognition of emotions in prosody and examining the extent to which it affects similarly the recognition of emotions in music (Patel, 2008b). We implemented this comparative approach on patients with idiopathic PD.

PD and emotion recognition

The neuropathological hallmark of PD is the progressive loss of dopamine neurons in the substantia nigra pars compacta and the subsequent striatal dopamine deficiency, which leads to a cascade of dysfunctions in basal ganglia and dopaminergic pathways (Obeso et al., 2008; Péron, Dondaine, Le Jeune, Grandjean, & Vérin, 2012). Apart from the well-known motor syndrome, these pathological changes affect diverse cognitive and emotional functions because basal ganglia are richly interconnected with the rest of the brain: They receive broad cortical inputs and project back to the cortex via the thalamus, thereby modulating activity

in a variety of cortical regions (e.g., Nambu, 2008; Utter & Basso, 2008). Some neuropsychological studies indicate that PD patients recognize emotions in speech prosody less accurately than healthy controls—that is, patients may be less able to identify emotions as communicated by the *tone of voice* (e.g., Pell & Leonard, 2003; Péron et al., 2012; Yip, Lee, Ho, Tsang, & Li, 2003; but see Garrido-Vásquez et al., 2012; Mitchell & Bouças, 2009). In a meta-analytic review of 28 comparisons, Gray and Tickle-Dengnen (2010) concluded that the size of this effect is very heterogeneous across samples, though it has been observed with different emotion recognition tasks, such as forced-choice and rating tasks. Patients' difficulties appear to be more severe for negative emotions (anger, disgust, fear, and sadness) than for happiness and surprise. Additionally, they are not secondary to comorbid depression and do not vary as a function of the level of motor disability and medication status—that is, between on and off dopa conditions. As for emotion recognition in facial expressions, frequently PD patients are not impaired (e.g., Adolphs, Schul, & Tranel, 1998; Cohen, Gagné, Hess, & Pourcher, 2010; Pell & Leonard, 2005; Ventura et al., 2012).

These results suggest that the basal ganglia are involved in the neurocognitive network underlying vocal emotions, a notion consistent with studies showing that patients with focal lesions in these structures also display prosodic deficits (Paulmann, Pell, & Kotz, 2008). Furthermore, functional magnetic resonance imaging (fMRI) studies unveiled that the putamen and caudate are recruited by emotional prosody categorization tasks (Frühholz, Ceravolo, & Grandjean, 2012; Kotz et al., 2003; Leitman et al., 2010; but see Johnstone, Reekum, Oakes, & Davidson, 2006; Mitchell & Ross, 2008). One hypothesis is that basal ganglia dysfunction in PD might impair, at an intermediate stage of processing, the meaningful perceptual sequencing of dynamic, time-dependent information; the striatum would act as a binding mechanism for the emotionally significant acoustic parameters that unfold in the speech stream, paving the way for further cortical emotion recognition processes (Kotz & Schwartze, 2010; Meyer, Steinhauer, Alter, Friederici, & Cramon, 2004; Paulmann & Pell, 2010; Pell & Leonard, 2003). Alternatively, the basal ganglia might be primarily involved in later stages of processing, mediating executive processes required for higher order operations in emotion recognition tasks, such as decision making and labeling (Benke, Bösch, & Andree, 1998; Mitchell & Bouças, 2009; Paulmann, Ott, & Kotz, 2011). According to the meta-analysis by Gray and Tickle-Degnen (2010), prosodic difficulties in PD might be related to the patients' executive and working memory impairments. This possibility deserves further empirical analysis.

Whether PD affects emotion processing in music has hardly been investigated. To the best of our knowledge, only one study examined this question. Using a forced-choice task, Tricht, Smeding, Speelman, and Schmand (2010) compared how 20 patients and 20 controls recognized happiness, sadness, fear, and anger in music excerpts taken from the classic repertoire. Patients were less accurate than controls for anger and fear, but not for happiness and sadness. This pattern was independent of depression symptoms and could not be attributed to executive dysfunction or low-level music perception impairments. However, several issues require clarification. Performance reached ceiling levels for two of the four emotions (happiness and sadness); the fact that the stimuli were taken from the classical repertoire makes it difficult to tease apart emotion and familiarity effects, and the number of negative and positive emotions was unbalanced (3 vs. 1, respectively), precluding conclusions regards effects of valence.

The current study

The goal of this study is to compare how PD affects emotion recognition in music and in speech prosody. An identical profile of impairments will suggest that the two domains recruit common neural substrates in a functionally similar manner. By contrast, differential effects will indicate that emotion processing in music and prosody is dissociated—that is, that they are partly independent in some way. This would be evidence for domain-specific mechanisms. Nondemented PD patients were compared with matched healthy controls. We examined four emotions in each domain, two of which were negative. The emotion recognition task was identical across domains: Participants listened to each music excerpt, or spoken sentence, four times, and each time they rated how much the stimulus expressed one of the four emotions. Such a rating task is highly sensitive (Adolphs et al., 1998; Adolphs & Tranel, 1999; Adolphs, Tranel, & Damasio, 2001) and puts fewer demands on working memory and decisional/executive processes than forced-choice tasks. Based upon the reviewed literature, for speech prosody we predicted that PD patients would display a deficit and that this deficit could be moderated by executive abilities. For music, no specific predictions were made. Participants were tested in facial expressions too, taken as a control measure to

disentangle auditory-specific from general emotion mechanisms (Patel, 2008b). They completed a comprehensive neuropsychological assessment to determine whether domain-general cognitive processes—namely, executive and working memory abilities—or low-level processing defects could account for putative impairments in emotion recognition. Additionally, we explored a possible dissociation between music perception and emotion recognition in music. Evidence concerning this issue is mixed (Stewart, Kriegstein, Dalla Bella, Warren, & Griffiths, 2008). Peretz, Gagnon, and Bouchard (1998) examined I.R., a brain-damaged patient who had normal emotion recognition but impaired music perception and recognition, suggesting independent pathways. On the other hand, McDonald and Stewart (2008) found that amusic individuals (impaired music perception) had abnormal emotional responses to music, suggesting association (they reported fewer psychological changes while listening to music and stronger negative feelings about imposed music).

METHOD

Participants

Twenty-four patients with idiopathic PD, nondemented and controlled for the presence of depression, were recruited through the Movement Disorders Unit at the Department of Neurology of the Hospital de S. João, Porto, Portugal. The diagnosis was confirmed by experienced neurologists based on the criteria of the United Kingdom Parkinson's Disease Brain Bank (Hughes, Daniel, Kilford, & Lees, 1992). The severity of motor symptoms corresponded to the Stages 1 to 3 (maximum 5) of the Hoehn and Yahr scale (Hoehn & Yahr, 1967) and to an average score of 17.9 (maximum 56) in the motor scale of the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn, Elton, & UPDRS program members, 1987). Motor symptoms were characterized as left dominant ($n = 9$), right dominant ($n = 10$), or bilateral ($n = 5$). Disease subtype (Schiess, Zheng, Soukup, Bonnen, & Nauta, 2000) was classified as mixed ($n = 6$), akinetic-rigid ($n = 12$), or tremor-dominant ($n = 6$). The patients were optimally medicated during the testing sessions (on state) with carbidopa/L-dopa ($n = 23$), dopamine agonist ($n = 19$), monoamine oxidase B (MAO-B) inhibitor ($n = 13$), catechol-O-methyltransferase (COMT) inhibitor ($n = 5$), amantadine ($n = 2$), or anticholinergics ($n = 1$). Four of them were also taking antidepressants (sertraline, $n = 2$; fluoxetine, $n = 1$; trazodone, $n = 1$).

The patients were compared with 25 healthy controls of similar age, education, and musical training. Patients and controls had no other known neurological or psychiatric conditions. The clinical and demographic characteristics of participants are presented in Table 1. They were assessed in two individual sessions lasting two hours each; the sessions with patients were scheduled for the time of the day in which their motor symptoms were typically least severe. This study was approved by the ethics committee of the Hospital de S. João, and written informed consent was obtained according to the Declaration of Helsinki. Participants were financially compensated for their time.

Neuropsychological assessment and music perception skills

The results of neuropsychological and music perception tests are also summarized in Table 1. Comorbid dementia was excluded using the Mini-Mental State Examination (MMSE; inclusion criterion ≥ 24; Folstein, Folstein, & McHugh, 1975), and depression using the Geriatric Depression Scale (inclusion criterion ≤ 9, one patient and one control scored borderline, 10; Yesavage et al., 1983). All participants had acceptable hearing thresholds, as determined by pure-tone audiometric screening (minimum 30 dB HL for frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz in the better ear). Verbal intelligence was assessed with the Vocabulary test of the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III); scores in this test correlate strongly with the full-scale IQ (Wechsler, 2008). Auditory working memory was assessed with the forward and backward Digit Span test of the WAIS–III. To examine executive functions, one-minute phonemic (letters F, A, S) and semantic (animals) verbal fluency tests were used, as well as a Stroop task. In this Stroop task, participants named colors as fast as possible in two conditions: (a) baseline, in which the stimuli consisted of nonlinguistic items (XXXX) printed in blue, pink, green, or grey; (b) conflict condition, in which the stimuli consisted of written words (*azul*, blue; *rosa*, pink; *verde*, green; or *cinza*, grey) printed in an incongruent ink color (e.g., the word *azul*, blue, printed in green ink), and participants named the color of the ink, independently of the word. There were 112 items in each condition. The color naming latencies in the baseline condition were taken as a proxy for processing speed; the difference in latencies between the conflict and baseline conditions (interference cost produced by the incongruity between the written word and the color) was taken

TABLE 1
Background and neuropsychological characteristics of participants with Parkinson's disease and healthy controls

Characteristics	Patients (n = 24)	Controls (n = 25)	p
Age (years)	61.8 (11.8)	59.2 (11.9)	.45
Education (years)	7.8 (4.3)	9.6 (5.0)	.17
Gender	17M/7F	12M/13F	.1
Musical training (years)	0.1 (0.4)	0.5 (1.3)	.16
Hoehn and Yahr stage	1.9 (0.5)	—	—
Motor UPDRS (/56)	17.9 (9.1)	—	—
Disease duration (years)	8.3 (4.9)	—	—
Age of disease onset	53.5 (10.3)	—	—
MMSE (/30; cutoff 24)	28.3 (1.5)	28.9 (0.9)	.11
Vocabulary WAIS–III (raw score, /66)	38.4 (13.3)	40.3 (13.5)	.62
Digit Span WAIS–III (number of digits recalled)			
Forward (/9)	5.1 (1.3)	5.4 (1.2)	.5
Backward (/9)	4.1 (1.4)	4.1 (0.9)	.99
Verbal Fluency (number of items produced)			
Letters F, A, S	25.5 (10)	27.7 (9.5)	.42
Animals	14.5 (5.2)	17.1 (5.5)	.1
Stroop test (color naming latencies, s/item)			
Baseline (no conflict)	1.1 (0.4)	0.9 (0.2)	**.03**
Interference (conflict condition – baseline)	1.1 (0.8)	0.5 (0.3)	**.002**
Geriatric Depression Scale (/30; cutoff 9)	3.6 (2.7)	2.5 (2.7)	.17
Benton Facial Recognition Test (/27)	21 (3.4)	21.8 (3)	.41
PALPA-P minimal pairs discrimination (/32)	31.5 (0.8)	31.6 (0.6)	.38
Montreal Battery of Evaluation of Amusia			
Scale (/30)	21.9 (6.4)	21.3 (5.8)	.72
Rhythm (/30)	22.7 (4.4)	23 (4.5)	.79
Meter (/30)	22.1 (4.3)	21.3 (5.5)	.55

Note. Standard deviations are given in parentheses. M = male. F = female. UPDRS = Unified Parkinson's Disease Rating Scale. MMSE = Mini-Mental State Examination. WAIS–III = Wechsler Adult Intelligence Scale–Third Edition. PALPA-P = Psycholinguistic Assessments of Language Processing in Aphasia, Portuguese version. Values in bold correspond to significant differences between PD patients and controls.

as a proxy for cognitive control. To ensure that participants had normal perception of speech and faces in nonemotional contexts, we used, respectively, the nonword minimal pair discrimination test of the Portuguese Psycholinguistic Assessments of Language Processing in Aphasia (short form; Castro et al., 2007) and the Benton Facial Recognition Test (short form; Benton, Sivan, Hamsher, Varney, & Spreen, 1994).

As can be seen in Table 1, the two groups scored similarly in all the tests except in the Stroop task. This indicates that the sampled patients had well-preserved general cognitive abilities, probably because they were in relatively early stages of the disease. With respect to the Stroop task, patients took longer than controls to name colors in the baseline condition. This is likely to be a consequence of the nonspecific slowing down associated with dopamine depletion in basal ganglia (Cohen et al., 2010; Gauntlett-Gilbert & Brown, 1998). They also had greater interference cost, which indicates executive impairment. Executive difficulties occur frequently in the early stages of PD and are due to the dysfunction in the prefrontal-striatal loop (e.g., Kehagia, Barker, & Robbins, 2010).

We assessed perceptual–cognitive musical abilities with the Montreal Battery of Evaluation of Amusia (MBEA; Peretz, Champod, & Hyde, 2003). Three tests were used, which cover both melody- and duration-related musical dimensions: Scale (melody based), Rhythm, and Meter (both duration based). The Scale test examines sensitivity to out-of-key tones. Participants perform same/different judgments on 30 pairs of short melodies in which half are identical, and half differ on a single scale-violated tone. The Rhythm test assesses sensitivity to changes in duration; a similar task is used (same/different judgments) where the difference of the melodies lies in the duration of two adjacent tones, so that the rhythmic grouping by temporal proximity is changed. The Meter test assesses the ability to distinguish duple from triple meters; participants listen to 30 stimuli, half of them in duple meter and half in triple meter. The task consists of categorizing each stimulus as a march or a waltz. The performance on these tests was above 70% correct. Crucially, no differences were observed between patients and controls (see Table 1). Hence, PD does not seem to compromise perceptual–cognitive musical abilities.

Emotional stimuli and task

The music stimuli consisted of 40 short excerpts of instrumental music expressing sadness, fear, happiness, and peacefulness (10 stimuli per emotion; mean duration = 12.4 s), taken from the database by Vieillard et al. (2008). They consist of a melody with accompaniment produced in piano timbre and follow the rules of the Western tonal system. Emotions are instantiated through structural features such as mode, dissonance, pitch range, tone density, tempo, and rhythm. These excerpts communicate effectively the intended emotions; this was confirmed with different tasks (perceptual categorization, gating, and dissimilarity judgments; Vieillard et al., 2008) and in different age groups (young, middle-aged, and older adults; Lima & Castro, 2011a). The speech stimuli consisted of 40 spoken sentences expressing four emotions: sadness, fear, happiness, and surprise (10 stimuli per emotion; mean duration = 1.5 s). They were taken from a validated database on emotional prosody (Castro & Lima, 2010). The sentences have emotionally neutral semantic content (e.g., "Ela viajou de comboio," *She travelled by train*; "O quadro está na parede," *The painting is on the wall*), and the emotional quality is conveyed solely through variations in prosodic features—pitch, tempo, rhythm, and timbre. They were recorded by two female speakers. We showed that the emotion-specific acoustic profiles of these stimuli are similar to those previously described in the literature, and that the intended emotions are perceived with high accuracy. The selection of music and speech stimuli was based on a pilot study to ascertain that emotions in both modalities were expressed with equivalent accuracy and intensity; this was done to ensure cross-domain comparability. Fifteen adults who did not participate in the neuropsychological study (mean age = 26.4 years; $SD = 10.8$; range = 19–51) performed a forced-choice task and provided intensity judgments (6-point scale) on a larger set of stimuli; the final set used herein was selected so that both domains had identical recognition accuracy (ca. 90% correct for happiness, and 80% correct for the remaining emotions) and perceived intensity (ca. 4 for all emotions, maximum 6). Facial expressions also consisted of a set of 40 stimuli expressing sadness, fear, happiness, or surprise. They were selected from the Karolinska Directed Emotional Faces database (Lundqvist, Flykt, & Öhman, 1998) and were matched with music and speech stimuli for recognition accuracy and intensity (on the basis of the same pilot study). Faces were color frontal views of male and female amateur actors with no beards, moustaches, earrings, eyeglasses, or visible make-up; Goeleven, Raedt, Leyman and Verschuere (2008) confirmed that the faces convey the intended emotions effectively.

The emotion recognition task was identical for music, speech, and facial expressions. The 40 stimuli in each modality were presented four times in randomized order. On each presentation, participants rated on a 7-point scale, from 0 (not at all) to 6 (very much), how much the stimulus expressed one emotion only: sadness, fear, happiness, or peacefulness/surprise. Thus, each stimulus was rated regarding the four possible emotions (one at a time), not only the intended one (for a similar procedure, e.g., Adolphs et al., 1998; Adolphs et al., 2001). The four emotion labels were explained and exemplified to ensure that they were adequately understood. There were six practice trials in each modality to familiarize participants with the rating scale and stimuli. Responses were collected using a seven-button response pad from Cedrus Corporation, Model RB-730, attached to an Apple MacBook Pro computer running SuperLab 4.0.1 (Abboud, Schultz, & Zeitlin, 2006). On each trial, participants were presented with the stimulus while the emotion and the scale to be rated appeared on the screen. Even though there was no time limit, they were encouraged to respond fast and intuitively (not after long deliberation). In the case of speech and music, they were told that they did not have to wait until the end of the stimulus to respond. The experimenter advanced to the next trial by pressing the space bar only when participants were ready to move forward (variable interstimulus interval); we did so to control for the effects of fatigue on the task. Care was taken that participants knew which emotion they were rating and that they used the scale correctly. The presentation order of the emotion recognition tasks was counterbalanced across participants. Reactions times (RTs) were also collected to make sure that the observed results were not due to speed–accuracy trade-offs; RTs were measured from the stimulus onset until the button press corresponding to the rating.

Measures and statistical analyses

We obtained two different types of data from emotion recognition tasks, and these were used for the comparisons between PD patients and matched controls: *correlations* between participant ratings across the four emotions and the ratings given by an independent reference sample of controls;

and *derived accuracy*, based on the emotion that received the highest rating.

Correlations

This measure has been used in neuropsychological studies by Adolphs and colleagues (e.g., Adolphs et al., 1998; Adolphs & Tranel, 1999; Adolphs et al., 2001) and Gosselin et al. (2005), whose procedure on the related statistical analyses we also adopted. First, the ratings provided by each participant on the four categories for a given stimulus were correlated with the mean ratings given for that stimulus by an independent sample of 35 healthy adults (norms; mean age = 19.6 years; SD = 3.3; range = 18–38). The higher the correlation (between participant ratings and the norms), the more typical the performance can be considered—in the sense that the rating profile is closer to the profile of the independent, normative sample. Pearson correlations were computed for each stimulus and participant. These correlations were z-transformed, averaged across the 10 stimuli expressing a specific emotion, and inverse z-transformed to obtain the mean correlation for that category. After that, the mean correlations for each category (z-transformed means) were submitted to standard statistical analyses; the patients' correlations were compared with those of matched controls in analyses of variance (ANOVAs) and analyses of covariance (ANCOVAs; see below). This measure is an index of the entire range of emotions perceived in each stimulus. It provides lower variance and avoids possible floor and ceiling effects (Adolphs et al., 1998; Adolphs et al., 2001; Gosselin et al., 2005).

Derived accuracy

Accuracy was derived as follows: When the highest of the four ratings provided for a stimulus corresponded to the intended emotion, the response was classified correct; when it corresponded to a nonintended emotion, the response was classified as an error; and when the highest rating was assigned to more than one emotion with identical magnitude (e.g., giving 6 for sadness and also for fear, and lower ratings for the other categories), the response was classified ambivalent. Ambivalent responses indicate that more than one emotion was perceived with the same magnitude. This measure is an index of sensitivity to the intended emotions.

We analyzed results for each emotion modality separately by computing ANOVAs with emotion as repeated measures factor (sadness, fear, happiness, and peacefulness/surprise) and group (PD and controls) as between-subjects factor. We also carried out ANCOVAs with performance on Stroop as a covariate (baseline and interference) in order to partial out variability in processing speed and executive control. This was done because PD patients performed worse than controls on the Stroop task (see Table 1), and performance on this test correlated with performance on emotion recognition (music: baseline, $r = -.42$, interference, $r = -.45$; speech: baseline, $r = -.54$, interference, $r = -.6$; faces: baseline, $r = -.39$, interference, $r = -.47$; all ps < .01). Significant main effects and interactions were followed up in post hoc tests using Fisher's least-significant difference (LSD) comparisons. Pearson correlations were computed to examine associations between emotion recognition, music perception, and clinical variables. Whenever appropriate, effect sizes are expressed as partial eta squared (η_p^2). Further analyses conducted to approach specific aspects of the results are detailed in the Results' section.

RESULTS

Emotion recognition in music and speech prosody

Music

We first focused on the correlations between participant ratings and the independent norms. These are depicted for patients and matched controls in the upper panel of Figure 1. Generally, happy music elicited the highest correlation with norms ($r = .95$, ps < .001), followed by peaceful (.67) and sad music (.64, $p = .39$); fear elicited the lowest correlation (.40, ps < .01) [main effect of emotion, $F(3, 141) = 131.78$, $p < .001$, $\eta_p^2 = .74$]. PD patients were selectively impaired in the recognition of happiness: Their correlations were significantly lower than those of matched controls in happy music only ($p < .001$), and similar in the other emotions (ps > .16) [main effect of group, $F(1, 47) = 3.7$, $p = .06$, $\eta_p^2 = .07$; interaction Group × Emotion, $F(3, 141) = 2.91$, $p = .03$, $\eta_p^2 = .06$]. The impairment is independent of the patients' executive dysfunction and general slowing, because it remained unaltered after controlling for these variables in an ANCOVA ($p = .001$) [main effect of group, $F(1, 45) = 0.4$, $p = .53$, $\eta_p^2 = .01$; interaction Group × Emotion, $F(3, 135) = 3.35$, $p = .02$, $\eta_p^2 = .07$].

We also examined possible trade-offs with RTs. Patients and controls did not differ in the time taken to respond (5,653 ms and 4,891 ms, respectively),
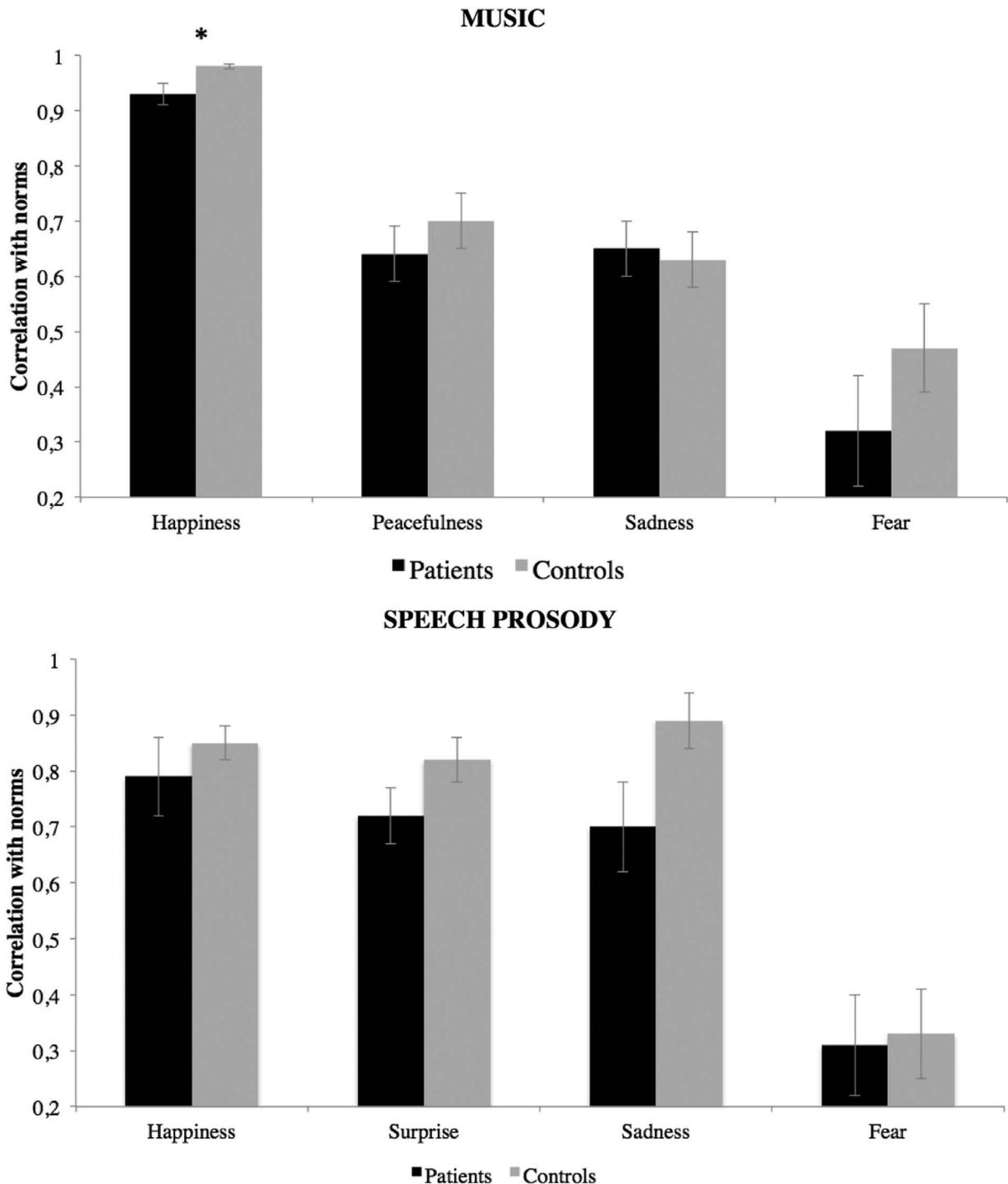
MUSIC

SPEECH PROSODY

Figure 1. Correlations between participant and normative ratings for each emotion, in music (upper panel) and speech prosody (lower panel), for patients and controls. Error bars show standard errors.

$F(1, 47) = 2.78$, $p = .10$, $\eta_p^2 = .06$, and no associations were found between RTs and correlations with norms (averaged across emotions, $r = -.11$, $p = .43$); this also held for happiness, in which patients had impaired performance ($r = -.27$, $p = .06$). Thus, the quality of the ratings was independent of the time taken to respond.

We then analyzed derived accuracy data. The upper part of Table 2 displays the percentage of correct responses in the diagonal cells (bold), and the distribution of misidentifications and ambivalent responses in rows. The percentage of categorizations was higher for the intended ("correct") than for the nonintended response categories. The

TABLE 2
Distribution of responses for each emotion in music and speech prosody, for patients and controls

Modality	Group	Emotion	Distribution of responses (%)				
			Happiness	*Peacefulness*	*Sadness*	*Fear*	*Ambivalent*
Music	Patients	Happiness	**82 (3.6)***	5	0	0	13*
		Peacefulness	15	**39 (5)***	14	4	28
		Sadness	3	25	**37 (6.6)**	5	29
		Fear	13	10	19	**30 (5.9)**	28
	Controls	Happiness	**95 (2)**	2	0	0	2
		Peacefulness	18	**55 (5.9)**	9	1	18
		Sadness	4	32	**29 (4.9)**	6	28
		Fear	20	8	18	**31 (6.5)**	22
		Emotion	*Happiness*	*Surprise*	*Sadness*	*Fear*	*Ambivalent*
Speech prosody	Patients	Happiness	**60 (7)**	11*	1	1	27
		Surprise	23*	**48 (6.6)**	3	1	24
		Sadness	5	8	**50 (6.9)**	7	30
		Fear	13	27	4	**27 (5.1)**	29
	Controls	Happiness	**48 (6.3)**	26	0	0	26
		Surprise	10	**56 (5)**	4	2	28
		Sadness	4	4	**63 (6.2)**	6	22
		Fear	10	28	10	**27 (4.6)**	25

Note. Diagonal lines in bold indicate correct identifications. Standard errors are given in parentheses.
*Patients were significantly different from controls, $p < .05$.

exception was sadness in controls, which was confused with peacefulness. The trend to confuse sadness with peacefulness was observed in previous studies with the same stimuli (Gosselin et al., 2005) and is particularly evident in older listeners (Lima & Castro, 2011a), as it is in those sampled herein. Overall, accuracy was highest for happiness (88% correct, $ps < .001$), followed by peacefulness (47%, $ps < .05$); sadness (33%) and fear (31%) had similar scores ($p = .63$) [main effect of emotion, $F(3, 141) = 66.03$, $p < .001$, $\eta_p^2 = .58$]. Patients scored as high as controls for sadness and fear ($ps > .29$), but they were less accurate for the two positive emotions: This was significant for peacefulness ($p = .03$) and marginal for happiness ($p = .06$) [main effect of group, $F(1, 47) = 1.4$, $p = .25$, $\eta_p^2 = .03$; interaction Group $\times$ Emotion, $F(3, 141) = 2.9$, $p = .04$, $\eta_p^2 = .06$][1]. After controlling for performance on the Stroop task, the difference between

patients and controls was significant for happiness ($p = .04$) and for peacefulness ($p = .02$) [main effect of group, $F(1, 45) = 0.06$, $p = .81$, $\eta_p^2 = .00$; interaction Group $\times$ Emotion, $F(3, 135) = 3.77$, $p = .01$, $\eta_p^2 = .08$]. RTs did not correlate with categorization rates (averaged across emotions, $r = -.01$, $p = .95$; for happiness, $r = -.1$, $p = .49$; for peacefulness, $r = .19$, $p = .2$). We also examined possible group differences in the distribution of nonintended categorizations (the three nonintended categories and ambivalent responses entered as repeated measures factor in additional ANOVAs). For peacefulness, sadness, and fear, the distribution of nonintended responses was similar across groups (interaction Group $\times$ Category, *ns*, $ps > .05$). The groups were also similar for happy music, except that patients provided more ambivalent categorizations than controls ($p < .001$) [interaction Group $\times$ Category, $F(3, 141) = 6.79$, $p < .001$, $\eta_p^2 = .13$].

Altogether, these results reveal that PD affected the recognition of happiness and peacefulness in music, but left intact the recognition of sadness and fear. This selective impairment for the positive emotions was not secondary to the patients' executive dysfunction and general slowing. It could not be explained by trade-offs with latencies too.

Speech prosody

Correlations between participant ratings and the norms for speech prosody are presented in the lower

[1] Because accuracy rates for sadness and fear were relatively low (see Table 2), we cannot dismiss the possibility that the absence of differences between patients and controls for these emotions reflects a floor effect. To approach this concern, we reanalyzed the data considering only the subset of excerpts that reached the highest categorization accuracies (5 for sadness, 41% correct on average, and 5 for fear, 38% correct). This analysis confirmed that patients and controls did not differ ($ps > .6$). The fact that there were also no differences in the correlation data, which are immune to floor effects, lends further support to the conclusion that PD did not affect the recognition of sadness and fear in music.

panel of Figure 1. They were higher for happiness ($r = .82$), surprise (.77), and sadness (.79, $ps > .4$), and lower for fear [.32, $ps < .001$; main effect of emotion, $F(3, 141) = 41.47$, $p < .001$, $\eta_p^2 = .5$]. PD patients were slightly worse than controls across emotions, as indicated by a marginally significant main effect of group, $F(1, 47) = 2.92$, $p = .09$, $\eta_p^2 = .06$ [interaction Group × Emotion, ns, $F(3, 141) = 2.05$, $p = .11$, $\eta_p^2 = .04$][2]. These difficulties are secondary to the patients' executive dysfunction and general slowing, because when performance on Stroop entered the analysis as a covariate (both baseline and interference indexes), the effect was far from reaching significance, $F(1, 45) = 0.04$, $p = .94$, $\eta_p^2 = .00$ [interaction Group × Emotion, ns, $F(3, 135) = 0.42$, $p = .74$, $\eta_p^2 = .01$]. To examine directly the role of executive abilities and processing speed, we carried out a mediation analysis using the method proposed by Preacher and Hayes (2008) to assess mediation involving multiple simultaneous mediators. This method generates bootstrap confidence intervals (95% CI) for combined and specific effects of a set of variables (potential mediators) on the relationship between an independent and a dependent variable. Group was the independent variable, and global performance on the emotion task the dependent variable. Baseline and interference indexes of the Stroop test entered the model as potential mediators. The indirect effects of group on emotional prosody recognition—that is, mediated effects—were estimated using a bootstrapping procedure (20,000 resamples). This analysis revealed that the patients' difficulties in recognizing emotions were mediated by performance on Stroop: For the two indexes combined, the total effect coefficient (± standard error) was $-.2617 \pm .1530$, $t(49) = -1.7102$, $p = .09$, and it differed significantly from the direct effect coefficient, $.0281 \pm .1389$, $t(49) = -0.202$, $p = .84$, as indicated by the 95% CI of total indirect effects $[-.5000, -.1227]$, with a point estimate of $-.2897$; for the specific effects of the two indexes, the interference index (executive control) had a significant mediating influence on emotion recognition, 95% CI $[-.4313, -.0602]$, while the baseline index (processing speed) did not, 95% CI $[-.2950, .013]$. This is evidence that cognitive control had a specific and unique role in determining the patients' difficulties.

Patients had slightly longer RTs than controls (3,972 ms and 3,212 ms, respectively),

$F(1, 47) = 3.89$, $p = .05$, $\eta_p^2 = .08$, but no associations were found between latencies and correlations with norms ($r = -.22$, $p = .13$).

Derived accuracy rates are presented in the lower part of Table 2. Categorizations were higher for the intended than for the nonintended emotions of the sentences, with the exception of fear, which was confused with surprise (for similar trends in misclassifications, Castro & Lima, 2010; Lima & Castro, 2011b). Accuracy was higher for happiness (54% correct), surprise (52%), and sadness (56%, $ps > .5$) than for fear (27%, $ps < .01$) [main effect of emotion, $F(3, 141) = 13.86$, $p < .001$, $\eta_p^2 = .23$]. The patients' categorizations were generally of similar magnitude to that of controls—that is, no impairment was detected in this measure [main effect of group, ns, $F(1, 47) = 0.15$, $p = .7$, $\eta_p^2 = .00$; interaction Group × Emotion marginally significant, $F(3, 141) = 2.18$, $p = .09$, $\eta_p^2 = .04$; none of the emotions was significant in post hoc comparisons, all $ps > .16$][3]. Additionally, RTs and accuracy were not associated ($r = .01$, $p = .94$).

The analyses on the distribution of nonintended responses revealed that patients and controls were similar for sadness and fear (interactions Group × Category, ns, $ps > .4$). For happiness, though, patients responded with surprise less often than controls ($p = .001$) [interaction Group × Category, $F(3, 141) = 3.16$, $p = .03$, $\eta_p^2 = .06$], and for surprise they responded more often with happiness ($p = .003$) [interaction Group × Category, $F(3, 141) = 3.02$, $p = .03$, $\eta_p^2 = .06$]. This pattern remained unaltered after partialing out performance on Stroop [happiness, $p < .001$; interaction Group × Category, $F(3, 135) = 5.83$, $p < .001$, $\eta_p^2 = .11$; surprise, $p = .002$; interaction Group × Category, $F(3, 135) = 5.22$, $p = .002$, $\eta_p^2 = .1$]. These differences in misclassifications suggest that patients were more likely than controls to provide higher ratings for happiness (vs. surprise) whenever the sentences were positively valenced. To examine whether this bias influenced the effect of PD on accurate categorizations, we reanalyzed the data using *unbiased hit rates* (Hu; Wagner, 1993). Hu corresponds to the joint probability that a given stimulus category is accurately recognized when it is presented, and that a response category is accurate when it is used. The ANOVA on Hu scores failed to

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[2] An inspection of Figure 1 suggests that the patients' prosodic difficulties were larger for sadness than for the other emotions. However, given that the interaction Group × Emotion was not significant, we refrained from analyzing possible emotion-specific effects, thereby avoiding Type I errors.

[3] To confirm that the lack of differences between patients and controls for fear was not due to the low accuracy rates obtained in this emotion (see Table 2), we have recalculated the ANOVA including only the subset of stimuli that reached the highest accuracies (34% correct on average); no effects of PD were detected ($p > .6$).

find significant effects of group on accuracy [main effect of group, *ns*, $F(1, 47) = 0.47$, $p = .49$, $\eta_p^2 = .01$; interaction Group × Emotion, *ns*, $F(3, 141) = 1.81$, $p = .15$, $\eta_p^2 = .04$].

Overall, these results show that PD patients had a subtle impairment on speech prosody, which was significantly mediated by executive dysfunction. Patients also had qualitative differences in the distribution of nonintended responses.

The global pattern of results for music and speech was replicated when the analyses were repeated without the four patients who were taking antidepressants. The results were also independent of the laterality of the motor symptoms.

Emotion recognition in facial expressions

Figure 2 presents the correlations between participants and normative ratings for facial expressions. They were highest for happiness ($r = .82$, *ps* < .01), intermediate for sadness (.79) and surprise (.77, $p = .07$), and lowest for fear (.32, *ps* < .01) [main effect of emotion, $F(3, 141) = 331.68$, $p < .001$, $\eta_p^2 = .88$]. Differences between patients and controls did not reach statistical significance in either analysis: in the ANOVA, main effect of group, $F(1, 47) = 3.9$, $p = .06$, $\eta_p^2 = .08$; interaction Group × Emotion, *ns*, $F(3, 141) = 0.59$, $p = .62$, $\eta_p^2 = .01$; in the ANCOVA including performance on Stroop, main

effect of group, *ns*, $F(1, 45) = 0.37$, $p = .54$, $\eta_p^2 = .08$; interaction Group × Emotion, *ns*, $F(3, 135) = 0.64$, $p = .59$, $\eta_p^2 = .01$. A mediation analysis indicated that neither cognitive control, 95% CI [−.3630, .0343], nor processing speed, 95% CI [−.1925, .0375], had a specific contribution for performance on the recognition of facial expressions. Patients and controls had similar RTs (3,381 ms and 2,849 ms, respectively), $F(1, 47) = 1.95$, $p = .17$, $\eta_p^2 = .04$; RTs were not associated with the correlations with norms ($r = −.17$, $p = .24$).

Table 3 depicts the percentage of correct categorizations in diagonal cells (bold), and the distribution of misidentifications and ambivalent responses in rows. As in the correlation data, accuracy was highest for happiness (92% correct, *ps* < .01), intermediate for sadness (61%) and surprise (65%, $p = .33$), and lowest for fear (35%, *ps* < .01) [main effect of emotion, $F(3, 141) = 50.91$, $p < .001$, $\eta_p^2 = .52$]. Patients did not differ from controls [main effect of group, *ns*, $F(1, 47) = 2.53$, $p = .12$, $\eta_p^2 = .05$; interaction Group × Emotion, *ns*, $F(3, 141) = 0.97$, $p = .97$, $\eta_p^2 = .02$]. RTs did not correlate with accuracy ($r = −.09$, $p = .52$). The distribution of nonintended responses was similar in both groups and for all emotions (interactions Group × Category, *ns*, *ps* > .2).

These results show that our sample of PD patients had normal recognition of emotions in facial expressions.
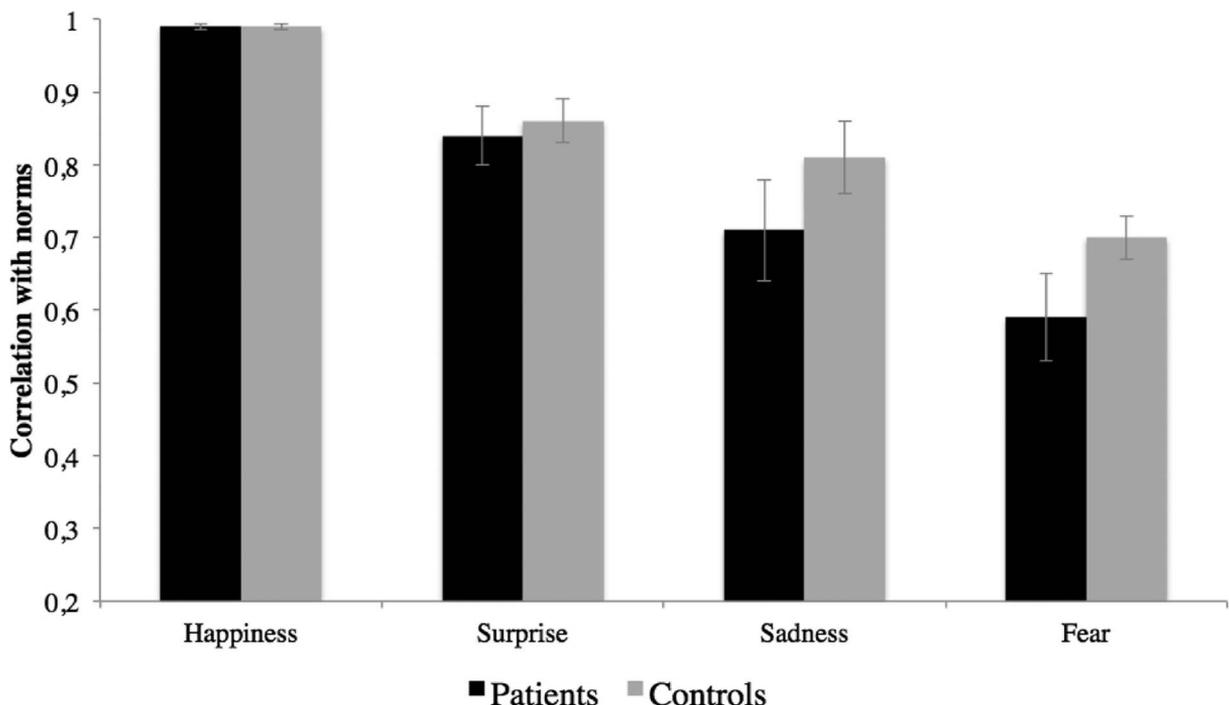

Figure 2. Correlations between participant and normative ratings in each facial expression for patients and controls. Error bars show standard errors.

TABLE 3
Distribution of responses for each emotion in facial expressions, for patients and controls

Emotion	Distribution of responses (%)				
	Happiness	*Surprise*	*Sadness*	*Fear*	*Ambivalent*
Patients					
Happiness	**92 (3)**	4	0	0	4
Surprise	3	**62 (5.7)**	2	10	23
Sadness	3	11	**58 (6.2)**	8	21
Fear	3	25	13	**27 (4.6)**	32
Controls					
Happiness	**92 (3.2)**	2	0	0	6
Surprise	2	**68 (5.8)**	4	5	20
Sadness	1	8	**64 (6.6)**	8	21
Fear	0	18	13	**43 (4.5)**	24

Note. Diagonal lines in bold indicate correct identifications. Standard errors are given in parentheses.

Correlations between emotion recognition, music perception, and clinical variables

We examined whether performance in the three emotion modalities was associated. We also examined whether emotion recognition in the two experimental modalities—music and speech—correlated with music perceptual–cognitive abilities, magnitude of depression symptoms, and clinical variables, specifically disease duration and severity. These analyses were based on the *z*-transformed correlations with norms, averaged across the four emotions for each modality. Table 4 presents the correlation coefficients, as well as the partial coefficients that were calculated taking into account demographic and domain-general cognitive variables. Partial correlations were computed to guarantee that the

detected associations are not artifacts of variability in these confounds.

A correlation was found between emotion recognition in music and speech, even after partialing out variability in demographic and cognitive characteristics. This indicates that the two auditory modalities engage common mechanisms to a significant extent. Emotion recognition in facial expressions was also correlated with the two auditory modalities, a result that may reflect the operation of modality-independent levels of emotion processing (Peelen, Atkinson, & Vuilleumier, 2010). After controlling for demographic and cognitive confounds, performance on the music perceptual–cognitive tests (MBEA) did not correlate with emotion recognition in music, with the exception of the Scale test. Further analyses conducted for specific

TABLE 4
Correlations between emotion recognition, music perception, and clinical variables

Variable	Emotion recognition			
	Music		*Speech prosody*	
	r	*Partial r*[a]	*r*	*Partial r*
Emotion perception in speech prosody	.61*	.37*	—	—
Emotion perception in faces	.67*	.51*	.63*	.4*
Montreal Battery of Evaluation of Amusia				
Scale	.61*	.36*	.42*	.08
Rhythm	.54*	.28	.33*	.07
Meter	.27	.08	.19	.01
Geriatric Depression Scale	−.09	−.11	−.11	−.11
Hoehn and Yahr stage	.04	.17	−.22	−.13
Motor UPDRS	−.12	−.1	−.41*	−.45
Disease duration (years)	−.34	−.34	−.49*	−.49
Age of disease onset (years)	−.51*	−.34	−.29	−.49

Note. UPDRS = Unified Parkinson's Disease Rating Scale.
[a]Controlled for demographic (age, education, and gender) and cognitive (MMSE, Vocabulary, Digit Span, Verbal Fluency, Stroop test) characteristics, where MMSE = Mini-Mental State Examination.
*$p < .05$.

emotions revealed that the Scale test correlated only with the recognition of fear ($r = .37$, $p = .02$), not with the other emotions ($ps > .1$). This suggests that sensitivity to scale-violated tones is important to perceive fear in music, probably because out-of-key notes were a salient and distinctive feature of scary music (Vieillard et al., 2008). Emotion recognition in music and speech was not significantly associated with depressive symptomatology, disease severity (Hoehan & Yahr stage, motor UPDRS), and age of onset or duration (see Table 4). The absence of associations between emotion recognition and clinical variables is consistent with previous findings (Gray & Tickle-Degnen, 2010; Péron et al., 2012).

DISCUSSION

We showed that PD affects differently emotion recognition in music and in speech prosody. As for music, patients were impaired in the recognition of positive emotions, specifically happiness and peacefulness, and normal in the recognition of negative emotions, sadness and fear. These impairments could not be attributed to low-level music processing problems, depression symptoms, and domain-general cognitive difficulties. Hence, they appear to be a primary consequence of PD. As for speech prosody, patients had a subtle general impairment, which was mediated by their executive dysfunction. To the best of our knowledge, this is the first report of a neuropsychological dissociation between emotion recognition in music and in speech prosody. It substantiates that the neurocognitive mechanisms underlying these two auditory emotion domains are partly independent. It was already known that emotion recognition impairments in PD may vary as a function of stimulus modality—that is, auditory versus visual (e.g., Gray & Tickle-Degnen, 2010; Péron et al., 2012)—but this dissociation within the auditory modality is a new finding. We also uncovered a dissociation between (normal) music perceptual–cognitive abilities and (impaired) emotion recognition in music.

It has been held that emotion processing in music and speech might engage common neurocognitive mechanisms (Juslin et al., 2010; Juslin & Västfjäll, 2008; Patel, 2008a, 2008b; Peretz, 2010). Previous studies provided some evidence for this hypothesis: The acoustic encoding of specific emotions is similar across domains (Bowling et al., 2010; Curtis & Bharucha, 2010; Juslin & Laukka, 2003), and musical expertise modulates the recognition of emotional prosody (Lima & Castro, 2011b; Thompson et al., 2004). The present results add to

these by showing that emotion recognition in music and speech correlates moderately, even after controlling for cognitive and demographic variables. However, perceiving emotions is a higher order process comprising multiple cognitive operations and neural systems (e.g., Koelsch, 2010; Leitman et al., 2010; Schirmer & Kotz, 2006). Up to now, the extent to which all or only part of these are similarly engaged by both domains was unspecified. Observing that impairments in music and speech are dissociated in PD is clear evidence that the overlap is partial. Importantly, the impairments do not seem to merely reflect general emotion mechanisms, as patients had normal processing of emotions in facial expressions. The claim that mechanisms are only partly shared fits in nicely with previous findings indicating that analogous manipulations of acoustic parameters elicit similar, but also opposite, effects in affective ratings for music and speech (Ilie & Thompson, 2006). Because the hallmark neuropathological changes in early PD are in basal ganglia and dopamingergic pathways (e.g., Obeso et al., 2008), they are a likely locus for the dissociation between domains. It might be that they are engaged differently by emotions in music and in speech. In the following paragraphs we discuss the patients' impairments for emotion recognition, as well as the possible underlying mechanisms for these impairments.

PD and emotion recognition in music

We observed for the first time that PD has a detrimental impact on the recognition of happiness and peacefulness in instrumental music. This impairment does not seem to be a consequence of low-level processing abnormalities because patients performed as well as controls in well-validated tests of music perceptual–cognitive abilities (MBEA; Peretz et al., 2003). It is also not related to the patients' general executive difficulties and cannot be accounted for by familiarity effects, as the excerpts were unfamiliar to all participants (they were composed for experimental purposes, not taken from the classic repertoire). This primary problem in the recognition of positive emotion categories in music may be related to the dysfunction in basal ganglia and dopaminergic pathways. PD can affect other brain systems during the course of the disease, such as the brainstem, thalamus, entorhinal cortex, cingulate cortex, cortical association areas, and amygdala (e.g., Braak, Ghebremedhin, Rüb, Bratzke, & Tredici, 2004; Braak et al., 2003), and these neuropathological changes correlate with cognitive impairment (e.g., Kövari et al., 2003).

However, they are likely to have played a less important role here because the sampled patients were in relatively early stages of the disease, performed normally in most of the domain-general cognitive measures, and were nondepressed. Additionally, neuropsychological studies on patients with extrabasal ganglia pathology, namely in the amygdala, have found a pattern of results different from ours. Using the same music stimuli as those that we used here, Gosselin et al. (Gosselin, Peretz, Johnsen, & Adolphs, 2007; Gosselin et al., 2005) found impaired recognition of fear and sadness in patients with amygdala damage, with relatively spared recognition of happiness and peacefulness. The hypothesis that basal ganglia are involved in the processing of positive musical emotions would be coherent with fMRI evidence. Koelsch, Fritz, Cramon, Müller, and Friederici (2006) showed that pleasant consonant music activates the ventral striatum, and Mitterschiffthaler, Fu, Dalton, Andrew, and Williams (2007) reported activations in the ventral and dorsal striatum for happy music (see also Trost, Ethofer, Zentner, & Vuilleumier, 2012). In their study on how PD affects the recognition of musical emotions, Tricht et al. (2010) found that responses were normal for happy music. However, this was probably due to a ceiling effect, as all but two participants obtained the maximum score possible for this emotion. On the other hand, they found impaired recognition of fear, while we did not. A straightforward explanation for the discrepancy is lacking, but it is possible that their patients had more extrabasal ganglia neuropathology than ours, including in the amygdala, which could explain difficulties for fear. Indeed, their patients had longer disease duration than ours (12 vs. 8 years, on average), and they also had more severe motor symptoms, as indicated by the higher score in the motor scale of the UPDRS (26 vs. 18).

Reward and motor functions of basal ganglia might underlie the selective impairment for positive musical emotions. Human and nonhuman studies link dopaminergic activity in basal ganglia with reward-related responses (e.g., Graybiel, 2005; Nambu, 2008), and these are altered in PD (e.g., Schott et al., 2007), both in patients undertaking dopaminergic replacement therapy and in those not medicated (Rowe et al., 2008). Patients might have experienced abnormal reward responses to the positive music stimuli due to their dopaminergic dysfunction. Recent evidence that the activation of the striatum by pleasurable music reflects the modulation of dopaminergic activity lends support to this notion (Koelsch, 2010; Salimpoor et al., 2011). Negative musical emotions, particularly sadness, may also evoke pleasurable

and rewarding responses (e.g., Salimpoor, Benovoy, Longo, Cooperstock, & Zatorre, 2009). However, the negative excerpts that we used, sad and scary ones, were at least relatively more unpleasant than positive excerpts: An independent sample of 32 listeners (mean age = 33.3 years; SD = 12.2; range = 18–56) judged happy and peaceful music as similarly pleasant in a 10-point valence scale (z-transformed ratings, 0.5 and 0.3, respectively; p = .3), and sad and scary excerpts were considered unpleasant (–0.14 and –0.66, respectively; fear was considered more unpleasant than sadness, p < .01). Thus, the impaired emotions were those that were more pleasurable. The basal ganglia, particularly the striatum and substantia nigra, are also involved in the interface between motivational responses and motor functions (Mitterschiffthaler et al., 2007; Utter & Basso, 2008). It has been suggested that these structures support the activation of (pre)motor representations during the perception of pleasant auditory stimuli (Koelsch et al., 2006). The dysfunction of reward and motor circuits might culminate in altered outputs for the cortical regions where higher order integrative processes take place.

PD and emotion recognition in speech prosody

With respect to speech prosody, the patients tested here had a global impairment, which was only marginally significant. Some prior studies found more pronounced defects (e.g., Dara, Monetta, & Pell, 2008; Gray & Tickle-Degnen, 2010; Paulmann & Pell, 2010; Pell & Leonard, 2003; Yip et al., 2003), but others found no defects at all (Caekebeke, Jennekens-Schinkel, Linden, Buruma, & Roos, 1991; Garrido-Vásquez et al., 2012; Kan, Kawamura, Hasegawa, Mochizuki, & Nakamura, 2002; Mitchell & Bouças, 2009). Therefore, our study adds to the point that the severity of prosodic impairments is highly variable across PD samples (Gray & Tickle-Degnen, 2010). Importantly, we provide for the first time direct evidence of the mediating role of executive abilities in the prosodic difficulties of PD patients: A mediation analysis revealed that executive control, as measured by the Stroop task, has a specific and unique contribution to explain the effects of PD on emotion recognition in prosody. The patients' general executive problems, which are highly frequent in PD (e.g., Kehagia et al., 2010), appear to have been the primary origin of difficulties in processing prosody. Accordingly, other studies have also found that in PD executive function correlates

with the recognition of emotional prosody (e.g., Breitenstein, Lancker, Daum, & Waters, 2001; Pell & Leonard, 2003). Furthermore, it has been suggested that some subgroups of patients show normal processing of prosody because the impairment is detected only when the executive and working memory impairments are prominent (Benke et al., 1998; Caekebeke et al., 1991; Garrido-Vásquez et al., 2012; Mitchell & Bouças, 2009). It might be that basal ganglia pathways are chiefly involved in later stages of emotion recognition in prosody, where executive processes are preponderant. Indeed, patients with focal lesions in the basal ganglia, despite being impaired in the explicit recognition of emotions in prosody, display normal event-related potential (ERP) responses (Paulmann et al., 2011; Paulmann et al., 2008); specifically, they do not differ from controls in the P200 component, which reflects emotional salience detection, nor in the following negative-going brain wave, associated with meaning-related processes, nor in a right lateralized positive component that indexes emotional prosody expectancy violations. This pattern suggests that basal ganglia pathways may not be critical during early online prosodic processes, but only during explicit offline judgments, which rely on executive and working memory operations. A recent ERP study on PD patients by Garrido-Vásquez et al. (2012) provided evidence for a relatively early effect (P200 component) when prosody was examined alone—that is, with no congruent lexical information—but only for patients with left-sided symptoms and for disgust; all the other emotions were unaltered (anger, fear, happiness, plus neutrality) in online and offline measures. In the measure of derived accuracy, our patients also had some differences in the pattern of misclassifications: They categorized happy sentences as surprised less often than controls did, and surprised sentences as happy more often than controls did. These differences remained unaltered when executive dysfunction was controlled for, and so they could point to a more specific origin for prosodic difficulties in PD. However, such an inference cannot be made with certainty from the current results because we were unable to detect any effects for these emotions either in the intended accuracy rates after correcting for response bias, or in the correlation measure, which is a sensitive index of the entire range of emotions perceived in a given stimulus. Future studies manipulating the executive demands of the task will better specify whether PD patients' problem concerning emotional prosody is exclusively attentional/executive, or whether it is also a low-level and early one, more fundamentally related to prosody.

Dissociation between musical and prosodic emotions: A room for functional specificities?

A possible cause for the dissociation between musical and prosodic emotions lies in the functional specificities of the two domains. With respect to music, we listen to it typically because it is a rewarding experience. Music is most adept at communicating and inducing positive emotions (e.g., Zentner, Grandjean, & Scherer, 2008), and it can evoke intensely pleasurable responses (Blood & Zatorre, 2001; Salimpoor et al., 2011). Furthermore, there is evidence that it may engage reward and emotion systems more readily than speech prosody: Ilie and Thompson (2006) observed that listeners provide higher ratings of valence and energetic arousal for music than for speech. Music may also be more effective than speech in recruiting motor systems: Brain motor regions are activated during passive music listening (Chen, Penhune, & Zatorre, 2008), and children as young as 5–24 months of age initiate rhythmic movement in response to music more than in response to speech (Zentner & Eerola, 2010). Indeed, music is frequently used for movement coordination and dancing in social contexts (e.g., Koelsch, 2010). On the basis of these findings, we can speculate that the integrity of emotion, reward, and motor systems is relatively more important for emotion recognition in music than in speech. This would explain why we found a primary impairment for positive emotions in music, but not in speech. Speech prosody is used primarily for communicative/pragmatic purposes. In natural communicative situations encountered during daily life, prosodic information is always integrated with co-occurring processes related to lexico-semantic information in order to make sense out of the interlocutor's spoken utterances (Schirmer & Kotz, 2006). Hence, processing prosody usually requires integrative and selection processes to a greater extent than music does—that is, executive functions could be more preponderant for prosody than for music. This would explain why executive functions were linked to prosodic, but not musical, difficulties. Other findings indicate that processing emotional prosody is highly dependent on attention. For instance, Schirmer, Kotz, and Friederici (2002, 2005) found sex differences in a prosodic priming task only when the participants had not been instructed to direct their attention to prosodic information; when they were (thus under directed attention), the sex differences disappeared.

A drawback of this study is that, although three of the emotion categories were identical for music and speech prosody (sadness, fear, and happiness),

the other one was not: peacefulness was examined in music, and surprise in speech (peacefulness is frequently reported in response to music but not to speech prosody, and surprise is frequently reported in response to speech prosody but not to music; Zentner et al., 2008). Apart from happiness, it was difficult to find non-negative emotion categories that could be similarly well expressed in the two domains, and our priority was to avoid an unbalanced number of negative and positive emotions. Future studies will need to include a greater number of equivalent emotions across domains. Notwithstanding, this does not compromise the conclusion that PD affects differently music and prosody. Another issue regarding comparability across domains should be discussed. Stimuli were longer in music than in speech, and so one could argue that it is difficult to tease apart domain-related from duration-related effects. However, care was taken to guarantee that music and speech stimuli were comparable in perceptual dimensions: They were pretested and selected so as to be perceived with similar recognition accuracy and intensity across emotion domains. Moreover, we did not find any association between how long participants listened to the stimuli and their performance on emotion recognition (see correlations between RTs and emotion recognition performance in the Results section). In other words, the duration of the stimuli did not impact on performance.

Dissociating music perception and emotion recognition in music

The present study also revealed that music perception is dissociated from emotion recognition in music. Patients were as good as controls in detecting out-of-key tones, rhythmic changes, and differences in meter, as assessed by three tests of the MBEA. This observation indicates that PD does not compromise these abilities. Yet, patients had impaired recognition of musical emotions, as discussed above. These results extend those by Gosselin and colleagues (2005), who reported that patients with temporal medial resection have no problem in detecting timing errors in music, but are impaired in the perception of emotions in music. A dissociation in the opposite direction was found by Peretz and colleagues (1998): The brain-damaged patient I.R. had severe impairments in music perception and relatively spared emotional judgments (see also Omar, Hailstone, Warren, Crutch, & Warren, 2010). Such a double dissociation is evidence that the neurocognitive mechanisms allocated for music perception

are distinct from those allocated for musical emotions. Additionally, we observed that performance in music perception tests did not correlate with emotion recognition in music. The exception was the Scale test (task: to detect out-of-key tones), which correlated with the recognition of fear. This suggests that achieving better tonal encoding of pitch facilitates emotion recognition when out-of-key tones are an important emotion cue, as was the case of scary excerpts (Vieillard et al., 2008). Hence, albeit music perception and emotion recognition appear to be neurally autonomous systems, they might interact in some circumstances. This interaction might contribute to explain why individuals with amusia show abnormal emotional responses to music (McDonald & Stewart, 2008).

CONCLUSION

In this study we uncovered a neuropsychological dissociation between emotion recognition in music and in speech prosody in PD. Patients had a selective impairment for positive emotions in music, which was not explained by general perceptual and cognitive factors, whereas for prosody they had a small global impairment, which was mediated by executive dysfunction. From a clinical perspective, the present findings corroborate and add to previous studies showing that even cognitively well-preserved and nondepressed PD patients may experience difficulties in perceiving emotions, particularly in the auditory domain. While these difficulties may go unnoticed by clinicians and family, it is possible that they contribute to interpersonal distress in communicative settings, reducing the quality of social interactions. From a basic science perspective, the dissociation between music and speech is evidence that the mechanisms underlying emotion processing in the two domains do not fully overlap—that is, specific mechanisms are engaged.

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