Journal of Clinical and Experimental Neuropsychology

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ncen20

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Available online: 24 Mar 2010

To cite this article: Silke Paulmann & Marc D. Pell (2010): Dynamic emotion processing in Parkinson's disease as a function of channel availability, Journal of Clinical and Experimental Neuropsychology, 32:8, 822-835

To link to this article: http://dx.doi.org/10.1080/13803391003596371

JOURNAL OF CLINICAL AND EXPERIMENTAL NEUROPSYCHOLOGY
2010, 32 (8), 822–835

Psychology Press
Taylor & Francis Group

Dynamic emotion processing in Parkinson's disease as a function of channel availability

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Parkinson's disease (PD) is linked to impairments for recognizing emotional expressions, although the extent and nature of these communication deficits are uncertain. Here, we compared how adults with and without PD recognize dynamic expressions of emotion in three channels, involving lexical–semantic, prosody, and/or facial cues (each channel was investigated individually and in combination). Results indicated that while emotion recognition increased with channel availability in the PD group, patients performed significantly worse than healthy participants in all conditions. Difficulties processing dynamic emotional stimuli in PD could be linked to striatal dysfunction, which reduces efficient binding of sequential information in the disease.

Keywords: Visual; Auditory; Emotion; Parkinson's disease; Basal ganglia; Audiovisual speech.

INTRODUCTION

Over the last years, an increasing literature has revealed that Parkinson's disease (PD)—a neurodegenerative disorder characterized by a loss of dopamine projections to the striatum—not only has a negative impact on motor skills (e.g., bradykinesia, muscle rigidity), but can seriously affect cognition and communication skills, including emotional language comprehension (see Zgaljardic, Borod, Foldi, Mattis, 2003; or Pell & Monetta, 2008, for an overview). It is well established that the basal ganglia form part of an interconnected system of circuits that link areas of the striatum to other critical brain regions, such as the cortex and the thalamus (e.g., Tisch, Silberstein, Limousin-Dowsey, & Jahanshahi, 2004). As these circuits convey information concerning movement, cognition, language, and emotion, it is not surprising that the clinical presentation of PD often includes difficulties in several of these areas simultaneously, which emerge in a complex manner as the disease progresses. The specific manner in which PD leads to impairments in emotion and language processing remains unclear in many ways. The goal of the present study was to further investigate the impact of PD on emotional communication, in this case on the ability to comprehend emotions from audiovisual speech stimuli, which vary in their informational content and emotional redundancy.

Effects of PD on nonverbal emotion processing

During social communication, we make use of not only verbal cues, or what someone says, but also nonverbal cues that accompany the verbal message (e.g., facial expression, speech prosody, gesture). To date, much of the research on nonverbal emotion processing in PD has focused on the ability to discriminate or recognize static facial expressions (Adolphs, Schul, & Tranel, 1998; Blonder, Gur, & Gur, 1989; Breitenstein, Daum, & Ackermann, 1998; Dujardin et al., 2004; Kan, Kawamura, Hasegewa, Mochizuki, & Nakamura, 2002; Lawrence, Goerendt, & Brooks, 2007; Pell & Leonard, 2005; Sprengelmeyer et al., 2003; Suzuki, Hoshino, Shigemasu, & Kawamura, 2006; Yip, Lee, Ho, Tsang, & Li, 2003). As a whole, this literature suggests that PD can impact negatively on facial expression processing, although a number of discrepant and ambiguous results have been reported. For instance, Jacobs and colleagues (Jacobs, Shuren, Bowers, &

The authors wish to thank Alla Sorokin for help with data acquisition, Stephen Hopkins for help with stimulus preparation, and Catherine Knowles for help with preparing figures and tables. This research was financed by a grant from the Canadian Institutes of Health Research, Institute of Aging (to M.D.P.). The support of the German Academic Exchange Service (DAAD) to the first author and the Fonds de la Recherche en Santé du Québec to the second author is gratefully acknowledged.

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http://www.psypress.com/jcen DOI: 10.1080/13803391003596371

Heilman, 1995) compared PD patients and healthy controls on tasks of emotional face perception and imagery, as well as object imagery (imagery tasks required the participant to answer questions about the physical attributes of an imagined facial expression or object). They found that the PD patients were only impaired on tasks involving emotional face (and not object) processing, suggesting that basal ganglia damage in PD interrupts specific procedures related to emotional face processing. Along similar lines, Sprengelmeyer et al. (2003) reported impairments of emotional face recognition in unmedicated patients in the early stages of PD, although medicated PD patients at later stages of the disease were not impaired. In contrast, Pell and Leonard (2005) tested a group of medicated patients in the early stages of PD on a range of emotional and nonemotional face-processing tasks (discrimination, identification, feature rating) and found that these abilities were largely intact in PD (see Adolphs et al., 1998, for similar findings). However, the PD patients appeared to exhibit selective difficulties recognizing expressions of disgust from facial expressions (Pell & Leonard, 2005).

In fact, within the framework that emotion recognition revolves around "basic" or discrete emotions (e.g., Ekman & Friesen, 1971), several researchers have tried to specify whether the recognition of specific emotions is selectively impaired in the context of PD. Again, the evidence is still inconclusive. For instance, Suzuki and colleagues (2006) reported a selective impairment to recognize faces of disgust in PD (similar to Pell & Leonard, 2005), whereas a more recent study implies that PD patients are selectively impaired to recognize faces of anger (Clark, Neargarder, & Cronin-Golomb, 2008). Several additional studies have concluded that PD leads to poor recognition of more than one of the negatively valenced, basic emotions when processing facial expressions; the emotions reported are: fear and disgust (Kan et al., 2002); anger, disgust, and sadness (Dujardin et al., 2004); and anger, fear, disgust, and sadness (Sprengelmeyer et al., 2003). The presence of emotion-specific deficits in PD could further vary according to whether patients exhibit unilateral versus bilateral motor signs according to some data (Yip et al., 2003). This survey emphasizes that, while there is evidence that PD frequently influences the ability to process emotional faces, the nature of this impairment and the factors involved are subject to further study.

Another nonverbal channel for communicating emotions is speech prosody. Prosody conveys emotional meaning via relative changes in the pitch, loudness, and temporal properties of speech (among other cues). There are two dominant approaches to investigate how emotional prosody is recognized independent of verbal (i.e., lexical–semantic) cues, which are typically processed in tandem with prosodic information in speech. The first approach is to present semantically neutral sentences to listeners, which are intoned to convey different emotions. A second approach tries to eliminate any effects of semantic information (whether neutral or not) by presenting emotionally intoned pseudosentences—that is, sentences that are phono-syntactically legal but semantically anomalous (e.g., for English: *"He nestered the flugs"*). Using these approaches, many studies demonstrate that adults with PD perform more poorly than control participants on tasks of recognizing emotions from a speaker's voice (Blonder et al., 1989; Borod et al., 1990; Breitenstein et al., 1998; Breitenstein, Lancker, Daum, & Waters, 2001; Dara, Monetta, & Pell, 2008; Pell, 1996; Pell & Leonard, 2003; Scott, Caird, & Williams, 1984; Yip et al., 2003), although there are some counterfindings (Caekebeke, Jennekens-Schinkel, van der Linden, Buruma, & Roos, 1991; Kan et al., 2002; Mitchell & Boucas, 2008). The notion that specific emotions conveyed by prosody are selectively impaired by PD has also been raised, although again, a coherent pattern has not yet emerged (e.g., see Breitenstein et al., 1998; Pell & Leonard, 2003; Yip et al., 2003).

One of the unique issues raised in the prosody literature is the possibility that the basal ganglia are directly engaged in the sequencing of auditory affective information (Meyer, Steinhauer, Alter, Friederici, von Cramon, 2004; Pell & Leonard, 2003). According to this argument, PD patients exhibit a reduced capability to encode emotionality from affective cue sequences (e.g., pitch and intensity variations during an emotional utterance) as part of a broader deficit for binding meaningful relations among sequential events (see Monetta, Cheang, & Pell, 2008; Pell & Leonard, 2003, for details). Given the inherent temporal characteristics of vocal emotion expressions, an underlying deficit in cue sequencing in PD would frequently manifest as difficulties understanding the emotional significance of speech prosody, although this idea implies that other dynamic signals that convey emotion in a sequential manner could be similarly compromised in PD (Pell & Leonard, 2003). Moreover, PD may negatively impact on other nonemotional functions such as syntactic processing, which rely on temporal sequencing (Kotz, Schwartze, & Schmidt-Kassow, 2009). These arguments provide a firm basis for investigating how dynamic expressions of emotion conveyed in different communication channels are processed and understood by patients with PD.

Effects of PD on verbal (lexical–semantic) emotion processing

In contrast to nonverbal cues, much less work has concentrated on how verbal information about emotions is processed in PD. In a unique study, Kan and colleagues (2002) compared the recognition of emotions from facial, prosodic, and lexical stimuli in 16 medicated PD patients (symptoms of patients were reported to fall into Hoehn & Yahr Stages 2 and 3; Hoehn & Yahr, 1967) and healthy control participants. Interestingly, while the authors report that facial expression recognition was adversely affected in the PD sample (with specific impairments for fear and disgust), their patients displayed no impairment to recognize emotions from prosody or written verbal stimuli. Similarly, other researchers have noted that PD patients successfully use lexical–semantic information about emotions in a manner resembling healthy participants (e.g., Dara et al., 2008;

Mitchell & Boucas, 2008; Pell, 1996). Recently, a study by Hillier and colleagues (Hillier, Beversdorf, Raymer, Williamson, & Heilman, 2007) investigated whether PD patients suffer from an emotional conceptual deficit, by requiring participants to rate the emotional connotation of words (for their positive/negative valence and arousal). The ratings pertaining to emotional, but not nonemotional, words were found to be "blunted" in a group of PD patients when compared to healthy controls; the authors proposed that these differences could be due to a degeneration of the emotional conceptual–semantic system in PD patients. These findings are partially mirrored in a study by Castner and colleagues (2007), who observed differences in controlled lexical–semantic processing in PD patients who had undergone deep brain stimulation surgery, although this was true only when the patients were not receiving stimulation. Specifically, PD patients on stimulation and controls showed slower reaction times for negative than for neutral targets in a lexical decision task, while no such effect was observed for patients off stimulation. This result may imply a critical functional role of the subthalamic nucleus (STN) during emotional semantic processing.

Given the sparse literature that has looked at emotional semantic processing in PD, it is informative to consult related evidence from patients with focal basal ganglia lesions, as a disruption of the basal ganglia–thalamocortical circuits plays an important role in PD. Several notable studies argue that the basal ganglia are involved during semantic processing (e.g., Cappa & Abutalebi, 1999; Kotz, Cappa, von Cramon, & Friederici, 2002; Kotz, Frisch, von Cramon, & Friederici, 2003; Lieberman, 2001), including emotional semantic processing (Kotz, Paulmann, & Raettig, 2006). In particular, Paulmann, Pell, and Kotz (2009b) studied the combined processing of emotional semantic and emotional prosodic information in patients with focal basal ganglia lesions by recording event-related brain potentials (ERPs). The data suggested that basal ganglia damage is associated with a deficit in the online integration of emotional semantic and emotional prosodic features (i.e., an altered capacity to combine different sources of (emotional) information present in the speech signal), which could lead to recognition difficulties at later stages of emotional processing. However, given the above evidence that basal ganglia dysfunction does not always hamper the ability of PD patients to use semantic information about emotions in offline behavioral tasks (Dara et al., 2008; Kan et al., 2002; Pell, 1996; Pell & Leonard, 2003), there is no direct evidence that difficulties integrating verbal cues to emotion with other emotion-related cues manifest in patients with PD. The current study is a first step, which addresses the question of how PD patients use emotion-related cues in isolation and in an interactive manner to make decisions about a speaker's emotion.

THE PRESENT INVESTIGATION

As summarized above, there is mounting evidence that PD can negatively impact on the comprehension of cues in several emotional information channels (face, voice, content), although many issues remain unresolved. As can be seen, current studies in this literature have tested PD patients with very different characteristics—differing in disease severity, cognitive and medication status, the presence of accompanying emotional disorders such as depression, and so on—and these variables are likely obscuring what we know about the effects of PD on the processing of emotion across communication channels (see Assogna, Pontieri, Caltagirone, & Spaletta, 2008, for related comments). Some of the controversies raised may also reflect inherent differences in the nature of each information channel and the way that emotional cues are naturally decoded (and therefore studied) in PD patients; for example, prosodic expressions of emotion are inherently dynamic, whereas both facial and semantic expressions are typically investigated in a static manner. It is possible that cognitive demands unrelated to emotion, but rather to the stimuli or task, are contributing to what we know about emotion processing in PD when compared across channels. As well, there are considerable differences across studies in the number of emotions and the number of emotional channels investigated, which limits their comparability (most studies have investigated only one or two isolated emotional channels where unimodal emotional stimuli were presented in separate tasks).

As a consequence, there is currently little information on how PD patients process facial, vocal, and verbal expressions of emotion in a comparative manner, a situation that is most common in human interactions although the availability of cues varies depending on the communicative setting (e.g., face-to-face interactions, telephone conversations, e-mail, or text messages). One possibility, raised by Kan et al.'s (2002) finding that PD patients are impaired for facial expressions of emotion but not prosody or written verbal stimuli, is that emotion recognition in many PD patients will benefit when bimodal or multimodal cues are present (i.e., patients may be able to compensate by using cues in unaffected channels). Surprisingly, it is rare to find investigations that present unimodal versus multimodal emotional stimuli in nonconflict situations (that is, when emotional information is congruent in all channels displayed). Still, we have general evidence that emotion recognition tends to increase with channel availability in healthy adults (e.g., de Gelder & Vroomen, 2000; Kreifelts, Ethofer, Grodd, Erb, & Wildgruber, 2007), and a similar pattern is likely to occur to some degree in adults with PD, although this experiment has not yet been performed.

The aim of the current study was to directly compare how PD influences the processing of emotional expressions in the three major communication channels—face, prosody, semantics—in isolation and in various combinations (involving unimodal, bimodal, and multimodal emotion cues). This approach allowed us to evaluate whether the type and/or the amount of emotional information presented to PD patients influences their recognition abilities, possibly in a facilitative manner in certain conditions. To correct for previous methodological differences and to enhance the ecological validity of

our stimuli, we presented only dynamic emotional stimuli in each channel (short sentences), which always conveyed one of five basic emotions (anger, disgust, sad, happiness, pleasant surprise) or neutral affect. Through stepwise manipulation of the three major communication channels, we could explore whether PD leads to differential impairment of only certain communication channels, or only certain emotions (across channels), and whether increasing emotional "redundancy" by presenting congruent information in more than one channel promotes better recognition of emotions for PD patients (by comparing accuracy across uni-, bi-, and multimodal conditions).

Based on the literature, we hypothesized that emotion recognition deficits in PD would affect processing of all three emotion channels (face, voice, semantics) to some extent, although specific predictions could not be made with certainty. Moreover, we expected that emotion recognition would generally improve for all participants when attending to bi- and multimodal emotion stimuli (versus unimodal stimuli), although it is simultaneously possible that PD patients would display certain abnormalities (as reflected in reduced emotion recognition accuracy scores) in the ability to compare and integrate emotion-related cues from dynamic stimuli in the bi- or multimodal conditions (Paulmann et al., 2009b; Pell & Leonard, 2003). The possibility that specific emotions would be selectively impaired in PD patients was monitored but could not be predicted in a confident manner.

METHOD

Participants

The participants were 11 native English-speaking adults with idiopathic Parkinson's disease (5 female, 1 left-handed), with a mean age of 68.0 years (SD = 10.8) and a mean education of 15.5 years (SD = 3.3). All patients were recruited from the Montreal community through movement disorder clinics and support groups for individuals living with Parkinson's disease. Diagnosis of idiopathic PD was confirmed by a neurologist for each participant based on accepted motor criteria (e.g., Calne, Snow, & Lee, 1992); the average duration of PD (postdiagnosis) in the group was 10.3 years (SD = 3.2, range = 4–15). The relative severity of motor signs in the group could be characterized as mild–moderate; all patients fit Hoehn and Yahr Stages II to IV criteria (mode = Stage III), with a mean Unified Parkinson's Disease Rating Scale (UPDRS) motor score of 28.5 (SD = 9.9). All patients were being treated with dopaminergic replacement therapy and were optimally medicated for PD at time of testing. None of the patients was receiving antidepressants or had coexisting neurological or psychiatric conditions that might independently influence their cognitive functioning.

For comparison purposes, 11 healthy adults (4 female) were selected from a volunteer database to serve as a control group; healthy control (HC) participants averaged 69.4 years in age (SD = 7.5) and 15.2 years of formal education (SD = 3.1). All PD and HC participants had normal or corrected-to-normal vision, and an audiometric screening performed at study onset established that all participants had acceptable hearing to engage in an auditory experiment (minimum 35 dB HL at 0.5, 1, and 2 kHz). All participants completed the Dementia Rating Scale (DRS; Mattis, 1988) to exclude participants with possible dementia; all participants performed very well on this test, and there were no significant differences in the mental status of the two groups. The two groups also did not differ in depression scores according to the Hamilton Depression Inventory (HDI; 1 PD and 1 HC participant were classified as mildly depressed). Finally, as summarized in Table 1, all participants completed a battery of standardized neuropsychological tests to provide information on their perceptual, memory, and cognitive functions—for example, Forward

TABLE 1
Mean results from Parkinson's disease patients and healthy controls on standardized neuropsychological testing

	PD (n = 11)		*HC (n = 11)*		
Test type	*Mean*	*SD*	*Mean*	*SD*	*t test*
Mattis Dementia Rating Scale (/144)	139.55	2.58	140.91	2.17	*ns*
Hamilton Depression Inventory-SF (/33)	4.20	3.47	2.40	2.50	*ns*
Benton Phoneme Discrimination (/30)	27.09	1.97	27.91	1.14	*ns*
Benton Face Recognition (/54)	41.00	5.69	47.64	4.50	$p = .0066$
Warrington Recognition Memory Word (/50)	45.18	5.36	47.64	2.73	*ns*
Warrington Recognition Memory Face (/50)	39.36	4.39	41.45	6.07	*ns*
Auditory digit span, forward (/9)	7.18	0.75	7.55	1.92	*ns*
Working memory/listening span (correct words recalled, /42)	28.27	7.21	37.90	3.84	$p = .0013$
Tower of London (total score)	108.55	20.71	110.2	20.08	*ns*
Verbal fluency task: animals	15.82	3.74	16.64	5.70	*ns*
Identify emotions from static faces (%)	83.76	9.62	85.34	11.19	*ns*

Note. PD = Parkinson's disease patients. HC = healthy controls. SF = Short Form. Except for the results scored on the Benton Face Recognition Test and the working memory test, none of the comparisons reached significance.

Digit Span; a listening span/verbal working memory task (Tompkins, Bloise, Timko, & Baumgaertner, 1994); Color Trail-Making test, verbal fluency; Tower of London; Warrington Recognition Memory Test for faces and words (Warrington, 1984); Benton Phoneme Discrimination and Face Recognition subtests. Significant group differences on these measures were restricted to static facial identity processing (Benton task), $t(20) = 3.03$, $p < .01$, and verbal working memory capacity, $t(19) = 3.76$, $p = .001$, which were both significantly lower in the PD group. All participants gave informed consent before completing the study, which was ethically approved by the McGill Faculty of Medicine Institutional Review Board.

Stimulus and task construction

The base stimulus materials were short sentences produced by six English speakers to convey one of five basic emotions (anger, disgust, sad, happiness, pleasant surprise) and neutral affect (six emotion types in total). We concentrated on five basic emotions, which included emotions with both a positive and a negative valence, to correspond with the emotional categories studied by Pell and Leonard (2003, 2005). To allow prosodic information to be isolated in certain conditions, there were two distinct sentence types: "lexical," or well-formed English sentences with emotional semantic content (e.g., *I didn't make the team* to convey sadness); and pseudosentences, which were semantically anomalous (e.g, *Someone migged the pazing*). Five unique lexical sentences were constructed to convey each emotion type (5 items × 6 emotion types = 30 total), whereas the same five pseudosentences could be emotionally inflected by speakers to convey the six emotion types strictly through prosody. Emotional portrayals were elicited from six native English speakers (three male) who had amateur experience in acting (see Pell, 2002, for details). Each actor was recorded continuously by a digital camcorder connected to a high-quality microphone. During the recording session, the emotion conditions were blocked, and the actors were provided cues (e.g., descriptions of emotional situations, pictures) to help induce thoughts of the target emotion; the actors then produced each of the five lexical sentences to convey the intended target emotion, followed by the five pseudosentences to convey the same emotion. This process was repeated to establish a set of audiovisual recordings of each actor expressing the six target emotions, which were digitally transferred and edited on a computer in Adobe Premiere (as .avi movies). The actors were instructed to express the emotions in a way that was natural for them, and at no time were they provided a model of how they should pose the target emotion by the examiner.

The audiovisual recordings were then systematically altered to construct seven unique conditions, defined by the type and number of emotional channels present for recognizing the emotion target. These manipulations were performed on all acceptable recordings that did not contain auditory or movement artifacts (approximately 1,000 tokens), which were then judged for their emotional meaning by a group of 20 young participants in a validation study. There were three unimodal conditions where only one communication channel was available (face, prosody, semantics), three bimodal conditions where two channels were available (face + prosody, face + semantics, prosody + semantics), and one multimodal condition, which presented cues in all three information channels (face + prosody + semantics).

Unimodal stimuli

The unimodal face stimuli were created by extracting the video track of the base stimuli when the actors were producing lexically meaningful sentences,[1] whereas the unimodal prosody condition was constructed by extracting the audio track of videos of the same actors producing emotionally intoned pseudosentences. Since semantic information can be processed in the auditory or visual modality (i.e., through written text), and the effects of semantic and prosodic cues are often confounded in speech, the unimodal semantics condition was achieved by presenting the lexical sentences as scrolling (i.e., dynamic) text. In the semantics condition, the speed with which each sentence was scrolled on the computer screen was carefully matched with the speech rate of the original spoken sentence in the corresponding base stimulus.

Bimodal stimuli

The face + prosody stimuli were created by presenting the (unaltered) videos where the actors produced emotionally intoned pseudosentences. The face + semantics stimuli were created by presenting the silent videos from the unimodal face condition (i.e., lexical sentences), accompanied by scrolling text of the same lexical sentence as it is produced by the actor, matched for timing. Finally, the prosody + semantics stimuli were created by extracting the audio track of videos where the actors produced emotionally inflected, lexically meaningful speech. Note that the modality for presenting semantic information differed between the prosody + semantics condition (auditory presentation) and the face + semantics condition (visual presentation); as argued in the section describing the unimodal stimuli, this approach was necessary to restrict emotional cues to the specific channels of interest in each experimental condition, which required semantic cues to be presented in the visual modality whenever experimental conditions were meant to exclude prosodic information.

Multimodal stimuli

For the multimodal condition (face + prosody + semantics), the base stimuli where actors produced lexically meaningful sentences were presented in their unaltered format.

[1]As our validation study showed no difference in the recognition of emotions from silent, unimodal face stimuli when actors were producing lexical versus pseudosentences, lexical sentences are presented here whenever possible because they are more ecologically valid.

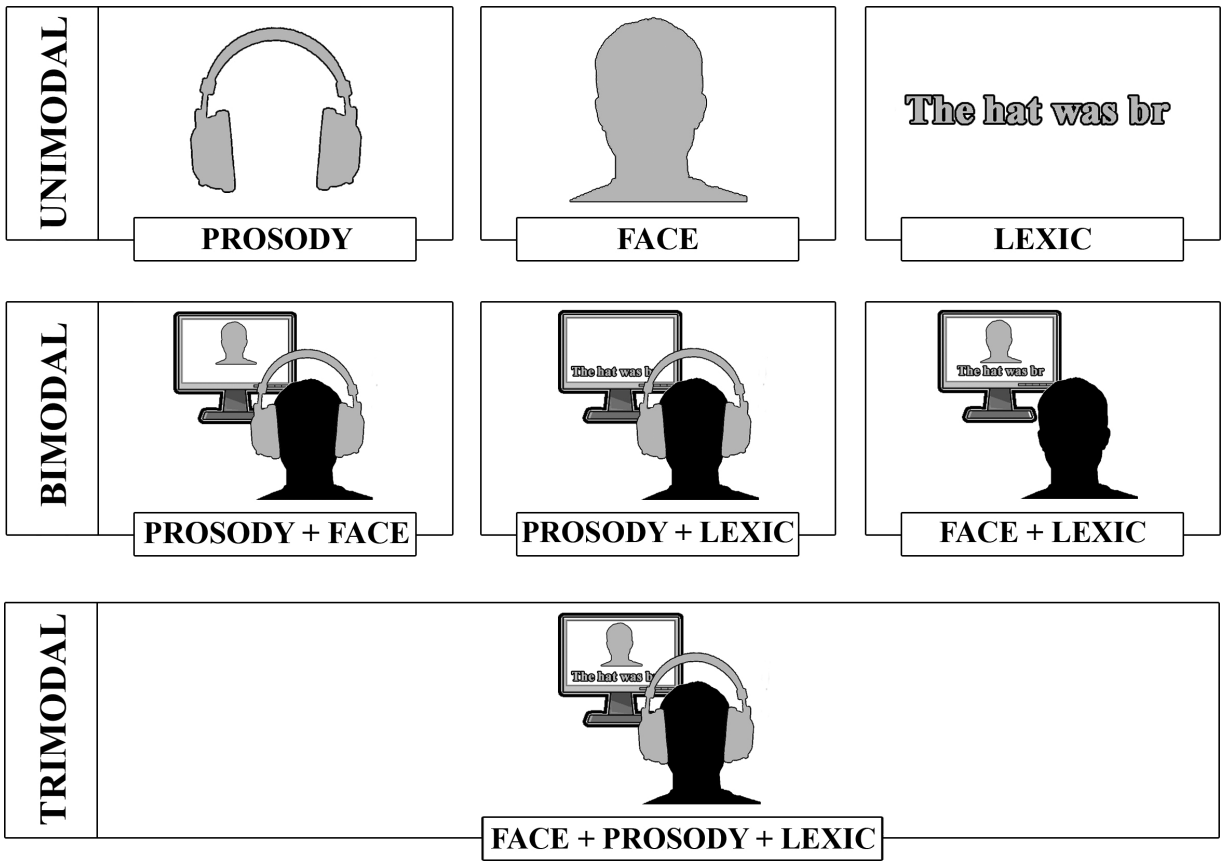

Figure 1. The figure shows how the different channels were combined in each of the seven presented experimental conditions.

Figure 1 provides an illustration of how the channels were combined in each of the seven experimental conditions. Based on data from our validation study, 48 stimuli were selected for presentation in each condition (8 sentences × 6 emotions), with the exception of the unimodal semantics condition where there were only 30 possible stimuli (i.e., 5 lexical sentences × 6 emotions). Stimuli selected in each condition were highly representative of the target emotion and were balanced across conditions for the presence of different speakers and items. Table 2 lists the emotion recognition rates from the validation study for stimuli presented in each condition of the current study, separately by emotion.

Procedure

Participants were tested individually, either at their home (PD patients) or in a quiet laboratory at McGill University (HC participants). Participants were seated at

TABLE 2
Mean recognition rates achieved in the rating study for the stimulus material presented in the current study

	Emotion target recognition						
Channel	*Anger*	*Disgust*	*Sadness*	*Neutral*	*Happiness*	*Surprise*	*All emotions (marginal means)*
Face	84.4	80.6	81.9	84.8	92.5	70.6	82.5
Prosody	77.5	66.9	92.5	88.1	74.4	75.6	79.2
Lexical	76.0	67.0	70.0	99.0	91.0	38.0	73.5
Face + prosody	84.4	85.6	92.5	82.5	85.0	76.3	84.4
Face + lexical	81.8	78.8	83.1	85.0	91.3	70.6	81.8
Prosody + lexical	91.3	90.0	95.6	81.3	83.8	76.3	86.4
Face + prosody + lexical	93.1	95.6	93.1	86.9	95.0	80.0	90.6
All channels (marg. means)	84.1	80.6	87.0	86.8	87.6	69.6	

Note. Recognition rates for each channel tested as well as the mean for the combined material are given in percentages.

a comfortable viewing distance in front of a computer monitor, and the experiment was run using Superlab 4.0 software (Cedrus, USA). Each participant judged all of the stimuli, which were presented in seven separate blocks (corresponding to the seven experimental conditions), randomized for presentation order across participants. Stimuli in each block were fully randomized. The run-time of the experiment was approximately 75 min. Visual stimuli (videos or text) were always presented in the center of the computer screen, whereas auditory stimuli were presented over headphones at a comfortable hearing level (accompanied by a black screen). After presentation of each stimulus, participants viewed a screen, which presented six emotion labels (anger, disgust, sadness, happiness, pleasant surprise, neutral), and they were instructed to choose which of the six emotions was conveyed by the stimulus. Emotion labels were varied in their position on the screen across participants to mitigate response bias. Participants responded by clicking on the appropriate response label on the computer screen, which was recorded by the computer. Time limitations on responses were never imposed, as these would systematically vary for participants with and without PD for reasons unrelated to emotion processing. Each condition of the experiment always started with a set of practice trials to familiarize the participant with the nature of the stimuli that would be presented in each block. Participants received a nominal fee for taking part in the study ($20 CDN).

RESULTS

Emotional target hit rates (in percentages correct) were analyzed with a repeated measures analysis of variance (ANOVA), followed by post hoc contrasts ($p < .05$), which used a modified Bonferroni correction for multiple comparisons when appropriate.[2] To test whether emotion recognition differed as a function of which cues were available in the stimulus, responses were first analyzed in a mixed ANOVA that included channel (face, prosody, semantics, face + prosody, face + semantics, prosody + semantics, face + prosody + semantics) and emotion (anger, disgust, sad, happiness, pleasant surprise, neutral) as repeated measurement factors, with group (PD, HC) as the between-subjects factor. We then carried out exploratory analyses of each group separately to assess whether the patients differed from control participants in their use of information in specific channel groupings (e.g., in conditions when facial cues were present or absent) and to examine whether our measures of emotion processing were associated with neuropsychological features of the PD group.

Channel analysis

Table 3 furnishes complete accuracy data on the recognition of emotions in each of the seven channel conditions, separately by group. A 7 (channel) × 6 (emotion) × 2 (group) ANOVA performed on these data yielded significant main effects for emotion, $F(5, 100) = 10.97$, $p < .0001$, and for channel, $F(6, 120) = 12.89$, $p < .0001$. Post hoc contrasts revealed that sad and pleasant surprise stimuli were

[2]The modified alpha value is obtained by the following formula: alpha multiplied by the degrees of freedom associated with the conditions tested, divided by the number of comparisons (Keppel, 1991). For significant effects involving the emotion factor, with alpha set at .05, there were 15 contrasts with a corrected $p = .017$. Elaboration of significant effects involving the channel variable included 6 contrasts resulting in a corrected $p = .05$.

TABLE 3
Emotion recognition rates for healthy controls and Parkinson's patients for all channels and emotions

			Emotion target recognition						
Group	*N*	*Channel*	*Anger*	*Disgust*	*Sadness*	*Neutral*	*Happiness*	*Surprise*	*Marg. means*
HC	11	Face	75 (20)	69 (23)	50 (13)	81 (21)	92 (8)	68 (20)	73 (13)
		Prosody	68 (16)	58 (29)	80 (17)	76 (16)	72 (25)	66 (20)	70 (7)
		Lexical	85 (20)	85 (25)	71 (10)	93 (24)	91 (19)	42 (23)	78 (18)
		Face + prosody	76 (14)	86 (16)	80 (18)	75 (18)	88 (30)	68 (19)	79 (7)
		Face + lexical	86 (18)	75 (14)	73 (15)	86 (16)	88 (16)	67 (28)	79 (8)
		Prosody + lexical	86 (19)	88 (15)	78 (20)	93 (9)	84 (19)	77 (17)	84 (6)
		Face + prosody + lexical	91 (16)	95 (8)	91 (16)	90 (13)	93 (12)	68 (20)	88 (9)
		Marginal means	81 (8)	79 (13)	75 (13)	85 (8)	87 (7)	65 (11)	
PD	11	Face	59 (21)	48 (31)	33 (28)	64 (26)	80 (23)	49 (29)	56 (16)
		Prosody	53 (18)	45 (20)	36 (23)	72 (35)	50 (29)	61 (21)	53 (13)
		Lexical	67 (21)	75 (24)	65 (20)	76 (34)	75 (24)	27 (24)	64 (19)
		Face + prosody	68 (24)	68 (29)	65 (32)	70 (36)	73 (22)	63 (17)	68 (4)
		Face + lexical	67 (23)	74 (19)	65 (25)	76 (32)	82 (20)	64 (10)	71 (7)
		Prosody + lexical	67 (26)	68 (19)	63 (36)	68 (33)	63 (26)	57 (20)	64 (4)
		Face + prosody + lexical	85 (13)	85 (18)	86 (13)	75 (34)	76 (13)	61 (27)	78 (10)
		Marginal means	67 (10)	66 (15)	59 (19)	72 (5)	71 (11)	55 (13)	

Note. Emotion recognition rates in percentages, standard deviations in parentheses. HC = healthy controls; PD = Parkinsonis disease patients. In addition, marginal means are provided.

recognized less successfully than all other emotions overall. Independently, there was evidence that recognizing emotions from unimodal prosody stimuli was least accurate overall (61%), followed by unimodal face stimuli (64%), unimodal semantics (71%), face + prosody (73%), prosody + semantics (74%), face + semantics (75%), and then multimodal stimuli, which were recognized most accurately (83%). These patterns appear to affirm that increasing the number of available channels in our stimuli promoted more accurate emotion recognition overall.[3]

The main effects were informed by a significant interaction of emotion and channel, $F(30, 600) = 6.66$, $p < .0001$, indicating that some emotions were recognized better in specific communication channels. Post hoc comparisons among the three unimodal channels revealed that all emotions could be recognized best from semantic cues, with the exception of happiness, which was recognized more accurately from the facial channel. After semantic information, the facial channel always yielded more accurate recognition of emotions than prosody, with the exception of sadness, which could be detected significantly better from prosody than from the face. For pleasant surprise stimuli, the prosodic and facial channels were more informative than the lexical channel. As for the bimodal channels, the pattern observed for the unimodal stimuli was continued, as most emotions were better recognized among those bimodal channels that contained lexical information than those that did not. In general, all emotional categories were best recognized from the multimodal channel, except for the neutral category; neutral affect was recognized well from all channels/channel combinations and was not influenced by the channel variable.

Finally, the ANOVA on these data revealed a significant main effect of group, $F(1, 20) = 7.42$, $p = .01$, $r = .52$. When viewed overall, recognition of emotions was more accurate for the healthy control participants than for the PD patients (79% vs. 65%). There was no evidence that group interacted with either emotion or channel in the form of significant two- or three-way interactions (all Fs < 1.22, ps > .30). The impact of group on the recognition of uni-, bi-, and multimodal stimuli is presented graphically in Figure 2.

Use of specific channel information by PD patients and healthy controls

To explore whether PD and HC participants may have demonstrated more subtle differences in their use of specific channel information when processing emotions, we carried out a series of planned comparisons for each group where channel was redefined and then reentered as a repeated measurement factor in the analysis. Specifically, for each group we compared accuracy in the combined uni- and bimodal conditions where the stimuli contained: (a) facial cues or not; (b) semantic cues or not; and (c) prosodic cues or not. These analyses averaged data for the six emotion types since our initial analyses provided no indication that group interacted with emotion category. For the healthy control group,

[3]To confirm the advantage of multimodal stimuli over uni- and bimodal stimuli, we carried out a second ANOVA with condition (uni, bi, or multimodal stimuli) as a repeated measurement factor. This analysis yielded a significant condition main effect, $F(2, 40) = 42.81$, $p < .0001$. Planned comparisons confirmed that recognition of both bimodal, $F(1, 20) = 22.78$, $p < .0001$, and multimodal, $F(1, 20) = 83.53$, $p < .0001$, stimuli exceeded unimodal stimuli and also that multimodal stimuli were recognized significantly better than bimodal stimuli, $F(1, 20) = 20.69$, $p < .001$.

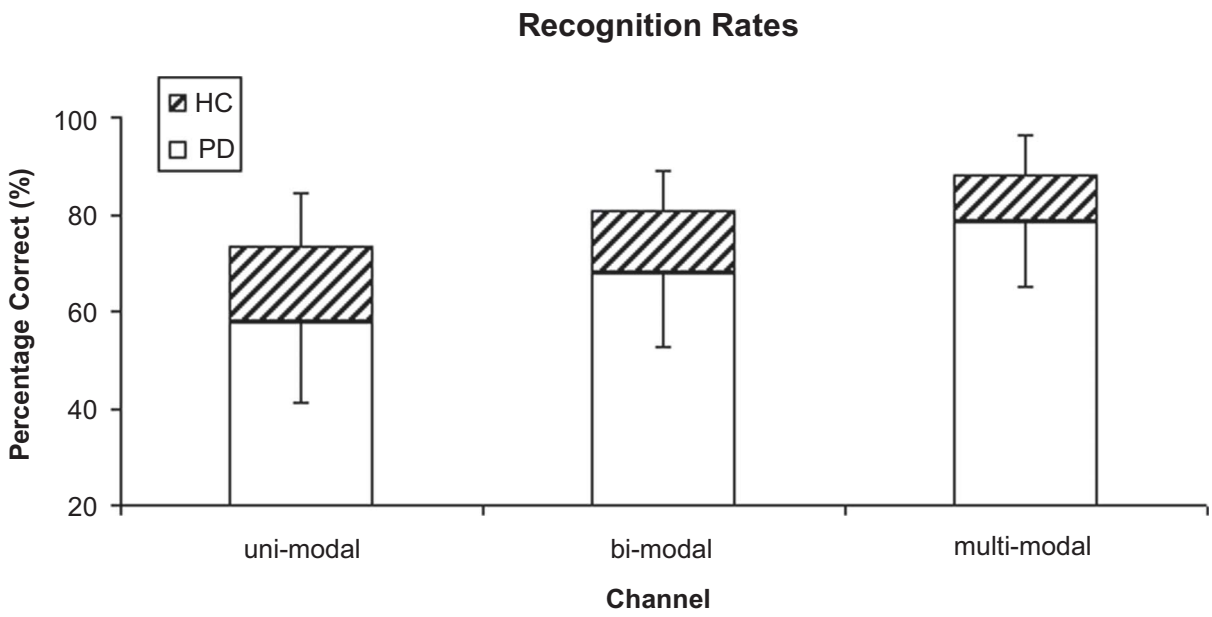

Figure 2. Recognition rates for uni-, bi-, and multimodal stimuli for both healthy controls (HC) and Parkinson patients (PD) are displayed. Error bars show the standard deviations for the HC (positive direction) and PD (negative direction) group.

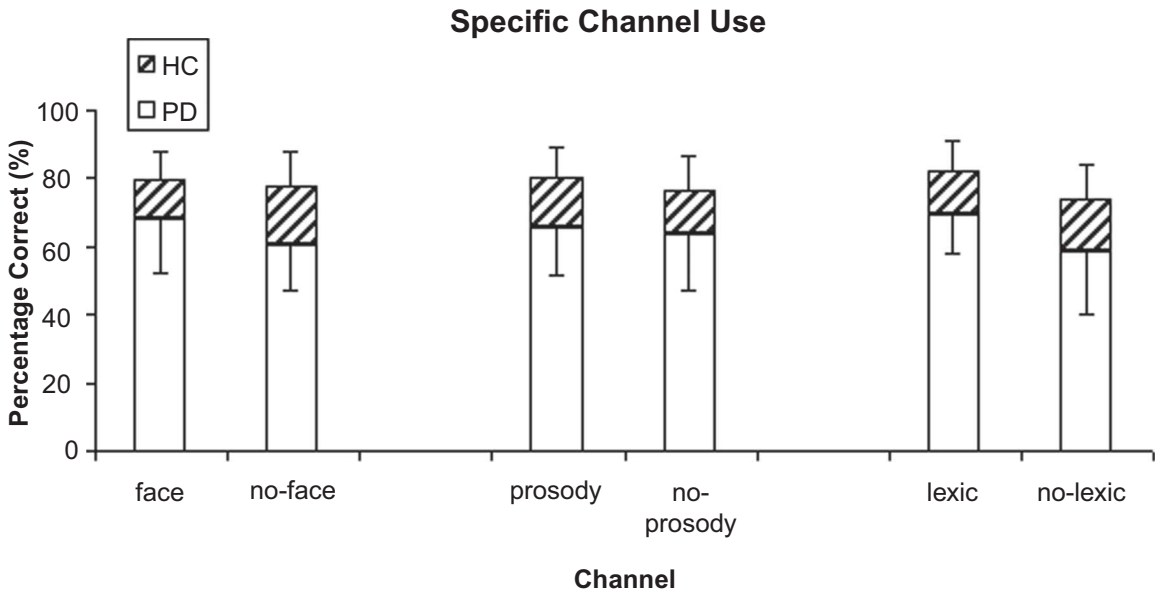

Figure 3. Different accuracy scores obtained in the analysis that looked at specific channel usage are illustrated. In particular, recognition rates for stimulus material that either contained or lacked face, prosodic, or lexical information are shown. Bars show results (in percentages) obtained from patients and controls. Error bars show the standard deviations for the healthy control (HC; positive direction) and Parkinson's disease patient (PD; negative direction) group.

there was no evidence that recognition of emotions was systematically improved when facial cues were present than when they were absent ($p > .1$; 80% correct vs. 77% correct, respectively). However, healthy controls profited significantly in conditions when prosodic information was present (80% correct) than absent (76% correct), $F(1, 10) = 6.97$, $p < .05$. Most notably, control participants performed much more accurately when semantic cues could be used to categorize emotions (82%) than when semantic cues were unavailable (73%), $F(1, 10) = 29.96$, $p < .001$.

When the PD group was examined, the picture looked somewhat different. The patients recognized emotions more accurately in combined conditions when facial information was present (68% correct) than when facial cues were unavailable (60% correct), $F(1, 10) = 7.41$, $p < .05$. The patients also benefited from the presence of semantic information about emotions when compared to conditions that lacked semantic cues (69% vs. 59% correct, respectively), $F(1, 10) = 12.86$, $p < .01$. However, there was no evidence that conditions that contained prosodic cues about emotion modulated the recognition of emotions in the PD group (66% vs. 64% correct), $F(1, 10) = 0.45$, $p > .5$. These relationships are displayed in Figure 3.

Correlation with background variables

Finally, to determine whether emotion recognition abilities in PD were related to key background variables of these participants identified by previous studies of PD, a global measure of the patients' accuracy in the combined unimodal, bimodal, and multimodal conditions was compared to measures of education (years), performance in Tower of London test, motor impairment (UPDRS motor score), mental status (Mattis DRS full score), depression (HDI score), Benton face recognition score, and verbal working memory span (words recalled). Pearson correlation computed among these variables did not show evidence of a significant relationship that predicted the performance of PD patients in the unimodal, bimodal, or multimodal channel conditions (all ps > .08). Correlation matrices are displayed in Table 4.

TABLE 4
Comparison of a global measure of the patients' emotion recognition accuracy with measures of education and with results on various tasks

	Emotion recognition	
	Pearson correlation	*p value*
Education	–.427	.191
Task		
Tower of London	.25	.458
UPDRS	–.498	.143
Mattis DRS	.073	.83
Hamilton Depression Inventory-SF	.409	.24
Benton Face Recognition	.307	.358
Working memory/listening span	.424	.19

Note. SF = Short Form. "Frontal lobe task": Tower of London total score; motor impairment: UPDRS (Unified Parkinson's Disease Rating Scale) motor score; mental status: Mattis DRS (Dementia Rating Scale) full score; depression: HDI (Hamilton Depression Inventory) score; Benton Face Recognition score; verbal working memory span. None of the variables showed a significant correlation.

DISCUSSION

For the first time, this study compared how PD affects the processing of emotional cues as a function of channel availability, using a controlled set of stimuli, which were always presented in dynamic format in each of our channel conditions. As anticipated, our findings demonstrate that emotion recognition tends to increase with channel availability (e.g., de Gelder & Vroomen, 2000; Kreifelts et al., 2007), an observation that was true for both healthy aging adults and patients with idiopathic PD. At the same time, our results clearly indicate that healthy controls are better at recognizing emotions from communicative displays than are PD patients overall, and certain analyses implied that PD patients differ from healthy controls in the use of emotional cues in specific communication channels (although not for specific emotions). These issues are discussed in the context of the literature in the sections that follow.

Emotional deficits in PD: General or specific?

As summarized earlier, there are separate findings that demonstrate that PD patients are impaired at recognizing emotions conveyed via facial expressions (Blonder et al., 1989; Breitenstein et al., 1998; Kan et al., 2002; Lawrence et al., 2007; Sprengelmeyer et al., 2003; Suzuki et al., 2006; Yip et al., 2003) and by speech prosody (Benke, Bosch, & Andree, 1998; Breitenstein et al., 2001; Dara et al., 2008; Pell & Leonard, 2003). In addition, some data imply that lexical–semantic processing of emotional information is disturbed to some extent in PD (e.g., Castner et al., 2007; Hillier et al., 2007). In general, our findings support these claims by demonstrating that PD patients were significantly less successful than healthy adults at recognizing emotions from the face, voice, and lexical–semantic cues, irrespective of which cues were presented or how these cues were combined to promote recognition (i.e., a significant group main effect was observed). Given that our study is one of the few to evaluate emotion recognition from several channels presented at the same time, our data provide a strong case for arguing that PD is associated with a relatively broad-based impairment in the processing of dynamic emotion expressions, which could manifest in a variety of communicative settings involving different types of cues in daily life.

It is well known that cognitive impairments, including deficits in executive functioning, occur on a frequent basis even in the early stages of PD (Lewis, Dove, Robbins, Barker, & Owen, 2003; Monchi, Petrides, Mejia-Constain, & Strafella, 2007; Owen, 2004). There are current opinions that some of the communication and language-processing difficulties faced by individuals with PD, such as impairments in complex sentence processing and nonliteral language comprehension, are directly tied to deficits in executive control in the disease, such as reductions of working memory or attention (Lee, Grossman, Morris, Stern, & Hurtig, 2003; Pell & Monetta, 2008). It has also been proposed that emotion-processing deficits in PD are predicted in large part by executive impairments, or are otherwise "mental state dependent" (e.g., Benke et al., 1998; Breitenstein et al., 2001; Mitchell & Boucas, 2008). However, given that the PD patients tested here were cognitively high functioning, that they performed well on several traditional "frontal lobe" tasks (e.g., Tower of London, Trail-Making Test, verbal fluency), and that none of the background measurements correlated significantly with their emotion recognition abilities, we consider it unlikely that our results are due to underlying executive problems in this patient sample.

The fact that PD patients exhibited a rather generalized impairment in the processing of dynamic emotion cues across channels does not simply indicate that all emotions, or all emotional channels, are recognized equally well during communication. Rather, consistent with the normal behavioral literature (e.g., Paulmann, Pell, & Kotz, 2008; Scherer, 1991), some emotions in our stimuli were recognized less reliably than others (especially pleasant surprise), and this pattern varied significantly as a function of the channel presented. The lexical–semantic channel seemed to provide especially strong cues for recognizing emotions when compared to the face, followed by prosody, except for "happiness," which could be identified significantly better from the face, and "sadness" and "pleasant surprise," which could be detected relatively better from prosody. It has been argued that the physical properties that encode emotions in the face (e.g., upturned vs. downturned mouth) and through prosody (e.g., high vs. low pitch) vary in their perceptual complexity, which acts as a determinant of how certain emotions are recognized in each channel (see Borod et al., 2000). Here, there was no evidence that PD patients were less sensitive to these natural variations in how specific emotions are detected from their perceptual and communicative features, as group status did not interact with differences in emotion and/or channel for any of our analyses.

This suggests that pathophysiological changes in PD do not fundamentally alter the system for perceiving and recognizing emotions from cues in different communication channels, although PD patients tend to perform more poorly than controls overall. Another conclusion that can be drawn from these data is that PD does not necessarily lead to emotion-specific impairments, despite a sizable (albeit inconsistent) literature on this topic (e.g., Kan et al., 2002; Sprengelmeyer et al., 2003). However, as performance on forced-choice tasks is influenced by the number and type of emotional response alternatives allowed, and this factor varies considerably among studies in the PD literature, it is also possible that our measures were not sensitive to emotion-specific difficulties frequently observed in PD (such as difficulties with negative emotions, e.g., Dara et al., 2008).

One reason that emotion recognition abilities may decline in a generalized manner in PD is that verbal and nonverbal emotional cues recruit similar neural pathways, which become functionally compromised in the disease. While this study was not designed to specify neuroanatomical components of the emotion-processing network in any detail, other research shows that processing emotions from verbal and nonverbal cues recruits a

complex brain network, which includes both cortical and subcortical brain structures (see Adolphs, 2002; Schirmer & Kotz, 2006, for details). Importantly, there is evidence that this network includes the basal ganglia/fronto-striatal pathways (e.g., Cancelliere & Kertesz, 1990; Pell & Leonard, 2003; Weddell, 1994). It is therefore possible that functional degeneration of the striatum and/or cortical-striatal pathways in PD leads to a relatively general emotional recognition deficit that affects processing of multiple channels (e.g., Blonder et al., 1989), rather than a channel-specific or emotion-specific deficit as implied by many previous investigations.

The fact that we observed a more general emotional recognition deficit is also in line with the assumption that emotional information is first treated independently by individual sensory modality systems, but that at a later point the information is processed by a "general affective processor" (Borod et al., 2000). There is now compelling evidence that cortical mechanisms of the right hemisphere, especially superior temporal and inferior frontal regions, assume a privileged role in the processing and recognition of emotional meanings (e.g., Schirmer & Kotz, 2006). Arguably, this places the seat of a general affective processor in the right perisylvian cortex (Borod et al., 1998; Bowers, Bauer, & Heilman, 1993). However, accepting arguments that the intact basal ganglia/fronto-striatal circuitry are essential to provide input to (right-sided) cortical regions that assign emotional significance to communicative displays (Pell, 1996; Pell & Leonard, 2003), it is not surprising that our PD patients had consistent difficulties identifying dynamic expressions of emotion, since critical subcortical mechanisms that contribute to the network for emotion processing were functionally compromised in our patients. Whether or not a general affective processor is truly modulated by the basal ganglia, or whether the basal ganglia are simply a critical part of the pathway leading to such a processor, cannot be properly investigated in the context of PD and should be explored through other approaches.

Interestingly, our background measures imply that the PD patients were not impaired on all types of emotion recognition tasks, since the patients could accurately identify emotions from static faces in one of our neuropsychological subtests (see Table 1). At present, the literature on whether PD influences the ability to recognize emotions from static facial expressions has led to mixed claims, with reports that these abilities are spared in PD patients (Adolphs et al., 1998; Borod et al., 1990; Pell & Leonard, 2005) or impaired (Jacobs et al., 1995; Lawrence et al., 2007; Sprengelmeyer et al., 2003). Conflicting results in this literature could revolve around methodological differences in the medication status of PD patients, disease severity, and whether the ability to structurally encode faces is intact in the participants evaluated (see Pell & Monetta, 2008, for a recent analysis). Although the present investigation focused primarily on dynamic emotion processing and included only a brief evaluation of static face recognition, our findings imply that there is a discrepancy in how PD patients recognize emotions from static versus dynamic emotion expressions, at least for the present patient sample. This observation could provide meaningful information about the nature of emotion-processing deficits in many individuals with PD, as elaborated below.

Emotional processing deficits in PD: Impairments in stimulus binding?

Our data suggest that PD patients were qualitatively similar to healthy adults in their sensitivity to dynamic expressions of emotion in our different conditions, and this conclusion was confirmed by visual inspection of confusion matrices for both groups, which indicated that there was no group-specific emotional response bias in the experiment. Nonetheless, supplementary analyses hinted at subtle differences in how the two groups processed information in specific channels. While the performance of both groups clearly improved when semantic cues were present than when they were absent (Dara et al., 2008; Kan et al., 2002), the PD patients did not seem to benefit from prosodic information in the same way that controls did. Interestingly, the reverse pattern was found for the face—that is, the PD patients significantly improved their emotional recognition for stimuli that contain facial information, in contrast to the controls who did not differ in conditions when facial cues were present or absent. These patterns, which imply differences in how adults with and without PD use information in the prosody and face channels, must be interpreted cautiously if we restrict our view to the present data. However, there are several existing reports that PD patients are relatively more successful at using facial cues than prosody to infer emotions when these two channels are directly compared (Blonder et al., 1989; Borod et al., 1990; Kan et al., 2002; Pell & Leonard, 2003, 2005). Moreover, consistent with our findings, the ability to process prosodic information—both emotional and nonemotional—is frequently cited as an area of difficulty in PD (McNamara & Durso, 2003; Pell & Monetta, 2008), allowing some brief commentary on these patterns.

Based on past findings, it has been proposed that many PD patients have difficulties related to prosody (rather than static facial expressions, for example) because meaningful processing of vocal emotion requires listeners to monitor and analyze a number of acoustic parameters that unfold in the speech stream over time (e.g., changes in pitch, tempo, intensity, voice quality, etc.). According to this view, the striatum, which is functionally altered in PD, is necessary at an intermediary stage to successfully detect meaningful relations among prosodic cue sequences by means of a binding mechanism, which then enables emotion recognition at a later stage in dedicated cortical regions (see Meyer et al., 2004; Pell, 2006; Pell & Leonard, 2003, for details). If true, it is likely that efficient binding of cue relations is necessary for other types of dynamic emotional stimuli, and this mechanism would be operational when making decisions about emotion based on a comparative analysis of bimodal and multimodal displays of emotion (see Lieberman, 2001, for a general discussion). Indeed, there

is preliminary evidence that the basal ganglia are involved during simultaneous, online processing of emotional semantic and prosodic information and that these abilities are impaired in patients with focal basal ganglia lesions (Paulmann et al., 2009b). Thus, it can be argued that one of the difficulties faced by our PD patients in each of our task conditions involved the comparative processing and binding of emotional cue relations, which promote efficient recognition of a speaker's emotion, yielding a relatively generalized impairment in our data since all of our stimuli were dynamic in nature.

The fact that our PD patients appeared to be less sensitive to prosody and relied somewhat more on semantic and facial cues may have reflected different strategies that can be adopted to process emotions in each channel. Although prosody cannot be understood without sensitivity to sequencing relationships, it may have been possible for the PD patients to successfully extract the physical features of emotional facial expressions at specific time intervals without further monitoring changes in these expressions. Similarly, despite the fact that we presented the lexical–semantic information as scrolling written text, PD participants could have waited for whole words to unfold before making a decision, thereby ignoring the dynamic features of the stimuli to some extent. These strategies may have allowed the PD patients to correctly infer the speaker's emotion in certain instances without a full appreciation of the relational properties of the stimuli (within or between channels), although these heuristics would not compensate entirely for the patients' processing difficulties leading to emotion impairments in most conditions. This proposal could be tested by evaluating PD patients using both offline and online measures of emotion processing in different communicative channels and by comparing sequencing abilities simultaneously in both emotional and other cognitive domains.

Facilitating emotion recognition in PD: The impact of channel availability

Finally, one of the unique contributions of this report is to show that PD patients benefit significantly not only from the presence of lexical–semantic information, but more generally from increased channel availability when required to infer a speaker's emotion state. Consistent with previous work on multimodal emotion processing in (young) healthy adults (e.g., Collignon et al., 2008; de Gelder & Vroomen, 2000; Massaro & Egan, 1996; Paulmann, Jessen, & Kotz, 2009a), we report that emotion recognition is facilitated in healthy older adults, as well as individuals with PD, when emotions are conveyed via multiple channels, in contrast to unimodal channel presentation. Current models suggest that the advantage for recognizing multimodal stimuli is related to the processes underlying (emotional) information processing: Encountering a multimodal stimulus first activates populations of neurons in modality-specific input systems (e.g., auditory, visual, affective). While these systems can each act independently, they may also be highly interconnected allowing for information alliance—that is, allowing for a fusion of information (e.g., Niedenthal, 2007).

When emotional displays are processed, it is presumed that emotion nodes or concepts are activated through interconnected or "allied" input systems (for details on "affective activation" see Hermans, de Houwer, & Eelen, 2001; or Spruyt, Hermans, de Houwer, Vandromme, & Eelen, 2007).[4] Of clinical importance to PD, the current results suggest that the activation of emotional representations or concepts associated with different types of communicative signals is generally intact in PD, since the patients benefited normally from increased redundancy/channel availability in our stimuli (information binding hypothetically occurs at the stage immediately following the automatic activation of representations by the perceptual input, see Oberauer & Lange, 2009). If our data can be generalized to natural communicative situations encountered in daily life, one can predict that providing more cues about a speaker's emotion should help many PD patients to overcome their difficulties in recognizing the emotional intentions of others, although not completely. Quite possibly, this emphasizes a potential clinical benefit of face-to-face interactions, which typically provide congruent emotion cues in the three major communicative channels, as a compensatory measure to facilitate efficient communication for individuals living with PD.

Original manuscript received 13 February 2009
Revised manuscript accepted 14 December 2009
First published online 24 March 2010

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[4]In fact, one may argue that the input system would be activated more strongly when bimodal or multimodal stimuli are encountered than when the stimuli are unimodal, explaining the advantage for multimodal emotion recognition (cf., e.g., Paulmann et al., 2009a).

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