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Impaired Perception of Vocal Emotions in Parkinson's Disease: Influence of Speech Time Processing and Executive Functioning

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Little is known about the underlying dimensions of impaired recognition of emotional prosody that is frequently observed in patients with Parkinson's disease (PD). Because patients with PD also suffer from working memory deficits and impaired time perception, the present study examined the contribution of (a) working memory (frontal executive functioning) and (b) processing of the acoustic parameter speech rate to the perception of emotional prosody in PD. Two acoustic parameters known to be important for emotional classifications (speech duration and pitch variability) were systematically varied in prosodic utterances. Twenty patients with PD and 16 healthy controls (matched for age, sex, and IQ) participated in the study. The findings imply that (1) working memory dysfunctions and perception of emotional prosody are not independent in PD, (2) PD and healthy control subjects perceived vocal emotions categorically along two acoustic manipulation continua, and (3) patients with PD show impairments in processing of speech rate information. © 2001 Academic Press

Key Words: Parkinson's disease; emotional prosody; working memory; speech synthesis; acoustic processing; time perception.

INTRODUCTION

For many decades, Parkinson's disease (PD) has been associated with flat emotional and nonemotional speech (Caekebeke, Jennekens-Schinkel, van der Linden et al., 1991; Darkins, Fromkin, & Benson, 1988; Flint, Black, Campbell-Taylor et al., 1992; Monrad-Krohn, 1947; Pitcairn, Clemie, Gray et al., 1990; Scott & Caird, 1983; Scott, Caird, & Williams, 1984). The previously well accepted view of dysprosody

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in PD as essentially attributable to a motor disorder (Critchley, 1981; Duffy, 1995) has been challenged by recent independent findings of impaired perception of emotional prosody in PD patients with bilateral motor symptoms in more advanced stages of the disease (Benke, Bösch, & Andree, 1998; Borod, Welkowitz, Alpert et al.,1990; Breitenstein, Daum, & Ackermann, 1998; Lloyd, 1999; Pell, 1996). Patients in the earliest stage of the disease showed a dissociation between performance in perceptive (preserved) and expressive (impaired) tasks (Blonder, Gur, & Gur, 1989). Additionally, the role of fronto-striatal circuits in identifiable neurobehavioral syndromes (cf. Cummings, 1993, 1998; Masterman & Cummings, 1997), which include emotional dysprosody (Bhatia & Marsden, 1994), has become generally known. Studies of persons with focal hemispheric damage also show that patients who had additional damage to the basal ganglia presented the most pronounced deficits in processing of vocal emotions, independent of lesion side (e.g., Cancelliere & Kertesz, 1990; Starkstein, Federoff, Price et al., 1994; Weddell, 1994). The mounting evidence for a significant association of basal ganglia (and amygdala) damage with impaired emotional perception and production as well as a failure to consistently find differences between patient groups presenting with focal right- versus left-sided brain damage (Bradvik, Dravins, Holtas et al., 1990; Breitenstein et al., 1998; Cancelliere & Kertesz, 1990; House, Rowe, & Standen, 1987; Lalande, Braun, Charlebois et al., 1992; Pell, 1998; Pell & Baum, 1997a, 1997b; Ryalls, 1988; Schlanger, Schlanger, & Gerstman, 1976; Trauner, Ballantyne, Friedland et al., 1996; Van Lancker & Sidtis, 1992, 1993; for reviews, see Baum & Pell, 1999, as well as Van Lancker & Breitenstein, 2000) have been weakening the previous claim of a right-hemispheric dominance for emotional prosodic processing (Blonder, Bowers, & Heilman, 1991; Borod, 1992, 1993; Borod et al., 1990; Borod, Cicero, Obler et al., 1998; Bowers, Coslett, Bauer et al., 1987; Gorelick & Ross, 1987; Heilman, Bowers, Speedie et al., 1984; Heilman, Scholes, & Watson, 1975; Ross, 1981; Ross, Anderson, & Morgan-Fisher, 1989; Ross, Edmondson, Seibert et al., 1988; Ross & Mesulam, 1979; Schmitt, Hartje, & Willmes, 1997; Tucker, Watson, & Heilman, 1977). As for emotional prosodic perception, both hemispheres seem to contribute to the recognition of emotional prosody, but it is unclear ''how functional attributes of prosodic stimuli are related to hemispheric differences in processing capacity'' (Pell, 1998, p. 702; see also: Baum & Pell, 1999; Berthier, Fernandez, Celdran et al., 1996; Peper & Irle, 1997; Ross, Thompson, & Yenkosky, 1997; Tompkins & Flowers, 1985).

The question follows: Why are patients with PD impaired in the perception of emotional prosody? There are at least two possible explanations.

One possibility is that the prosodic impairment is part of a more *general cognitive deficit* because patients with PD frequently present with selective dysfunctions of the central executive component of Baddeley's (1992, 1996, 1998) working memory model. A second possibility is that there is an *acoustic processing deficit.* It may be that one or more of the acoustic parameters important for prosodic classifications (fundamental frequency [F0] variation perceived as pitch, duration/speech rate, and amplitude perceived as intensity) are processed inefficiently, e.g., patients with PD are not using acoustic cues appropriately. It has also been proposed that different neural systems may be involved in processing pitch (right-sided cerebral dominance) and temporal (left-sided dominance) stimulus aspects (Baum & Pell, 1997; Baum & Pell, 1999; Belin, Zilbovicius, Crozier et al., 1998; Johnsrude, Zatorre, Milner et al., 1997; Ouellette & Baum, 1993; Pell, 1998; Robin, Tranel, & Damasio, 1990; Sidtis & Volpe, 1988; Van Lancker & Sidtis, 1992; Zatorre, 1988; Zatorre, Evans, & Meyer, 1994; Zatorre, Evans, Meyer et al., 1992; Zatorre, Halpern, Perry et al., 1996; but see also Pell & Baum, 1997b, who failed to replicate the findings by Van Lancker & Sidtis, 1992). A recently published finding (Dykstra, Gandour, & Stark, 1995; see also Grela & Gandour, 1998) inconsistent with the acoustic lateralization theory (preserved pitch and impaired timing and intensity processing following damage to the right frontal lobe) is difficult to interpret because the patient had been suffering from epilepsy since early childhood and underwent a commissurotomy at age 16. Considerable neuronal reorganization following brain injury and functional shifts in the brains of epilepsy patients make an interpretation of lateralized functions difficult, if not impossible (cf. Kroll, Markowitsch, Knight et al., 1997). We explore both the acoustic and the cognitive assumptions in greater detail below.

Frontal Executive Deficit

Distribution of attentional resources may play an important role in judging emotional prosody in spoken sentences (Bowers et al., 1987; Lalande et al., 1992). The prosodic stimulus must be held in a short-term (or working) memory buffer. Giving the correct response involves focusing on the prosodic meaning while disregarding, or inhibiting, the task-irrelevant semantic meaning of the sentence. For example, listening to the sentence ''I am going to the movies'' spoken with an angry tone of voice requires subjects to ignore the neutral (or, often, happy/pleasant) semantic meaning and respond as ''angry.'' This is a process also known as selective attention or response inhibition; both aspects are associated with the central executive component of working memory (Baddeley, 1996, 1998). It is possible that patients with PD have difficulties in recognizing emotional prosody in spoken sentences because task-irrelevant stimulus attributes (i.e., semantic meaning) are not as effectively inhibited as in elderly control subjects, as has been shown for patients with focal right-hemisphere damage (cf. Bowers et al., 1987; Ross, 1996; Ross et al., 1997; Tompkins, Baumgaertner, Lehman et al., 1997). A significant association of working memory capacity and the ability to resolve conflicting information in spoken discourse comprehension ($r = -.67$) has been reported for patients with focal right hemisphere damage (Tompkins, Bloise, Timko et al., 1994). It is therefore likely that brain structures involved in working memory contribute to the recognition of emotional prosody under distracting task demands.

It is now widely accepted that nondemented patients with PD present with a specific pattern of cognitive deficits, and different labels have been used to describe the observations: a limitation in the Supervisory Attentional System (Brown & Marsden, 1988, 1990), central executive dysfunction (Dalrymple-Alford, Kalders, Jones et al., 1994; Taylor & Saint-Cyr, 1995; Taylor, Saint-Cyr, & Lang, 1990), or reduced working memory capacity associated with deficits in strategic memory (Gabrieli, 1996, 1998; Gabrieli, Singh, Stebbins, & Goetz, 1996; Pillon, Deweer, Vidailhet et al., 1998). One of the common mechanisms seems to be that PD patients have difficulty focusing on the salient features of a stimulus while ignoring distracting, or task-irrelevant, aspects. Cognitive impairments in PD have also been observed in skill learning (or other nondeclarative memory) tasks (cf. Gabrieli, 1995). Furthermore, impaired declarative memory in nondemented PD has recently been associated with hippocampal atrophy in only a subgroup of patients in advanced stages of the disease (Riekkinen, Kejonen, Laakso et al., 1998). The findings on declarative and nondeclarative memory deficits in PD are of minor relevance to the present investigation and are therefore not reviewed.

It is well known that frontal executive functioning is dependent on prefrontal cortex (neuroimaging studies: Barch, Braver, Nystrom et al., 1997; Berman, Ostrem, Randolph et al., 1995; Cabeza & Nyberg, 1997; Cohen, Perlstein, Braver et al., 1997; D'Esposito, Aguirre, Zahran et al., 1998; D'Esposito, Detre, Alsop et al., 1995; Klingberg, 1998; Manoach, Schlaug, Siewert et al., 1997; Smith & Jonides, 1997;

findings in patients with selective lesions to the prefrontal cortex: Baddeley, Della Salla, Papagno et al., 1997; Eslinger & Grattan, 1993; Rogers, Sahakian, Hodges et al., 1998; Stuss, Alexander, Hamer et al., 1998). The connections from the basal ganglia (in particular from the caudate nucleus) to the prefrontal cortex have been described as serving to increase the ''salience of selected stimuli, facilitating attentional processes under frontal cortical control'' (Knoke, Taylor, & Saint-Cyr, 1998, p. 272; see also Beiser, Hua, & Houk, 1997).

Because fronto-striatal circuitry (cf. Alexander, Crutcher, & DeLong, 1990) is compromised in PD without dementia, executive functioning is expected to be impaired (Bondi, Kaszniak, Bayles et al., 1993; Brown, Schneider, & Lidsky, 1997; Cooper, Sagar, Doherty et al., 1992; Dubois, Malapani, Verin et al., 1994; Dubois & Pillon, 1997; Hornykiewicz & Kish, 1986; Jagust, Reed, Martin et al., 1992; Lieberman, Kako, Friedman et al., 1992; Owen, Doyon, Dagher et al., 1998; Riekkinen et al., 1998). Patients with PD are particularly prone to interference when previously irrelevant stimulus dimensions are suddenly task relevant, as observed in tasks like the Wisconsin Card Sorting Test (Gotham, Brown, & Marsden, 1988) or tasks requiring the ability to switch sets, e.g., in ''alternating'' verbal fluency tasks or the ''odd man out test'' (Downes, Roberts, Sahakian et al., 1989; Downes, Sharp, Costall et al., 1993; Flowers & Robertson, 1985; Gotham et al., 1988; Gurd & Ward, 1989; Hanley, Dewick, Davies et al., 1990; Hayes, Davidson, Keele et al., 1998; Owen, James, Leigh et al., 1992; Owen, Roberts, Hodges et al., 1993; Raskin, Sliwinski, & Borod, 1992; Sharpe, 1990, 1992; Van Spaendonck, Berger, Horstink et al., 1996).

Hypotheses. As outlined above, tasks designed to evaluate perception of emotional prosody and working memory tests share a process known as selective attention or response inhibition. We therefore hypothesized that patients with PD *are significantly impaired* in the perception of emotional prosody when prosodic and semantic meaning are inconsistent and that performance in emotional prosody recognition could be *predicted by scores in tasks tapping central executive functioning.* Because of the observation that ''. . . if observers are confronted with contradictory information, they will rely most on the source that is most explicitly overlearned, namely speech content'' (Ekman, Friesen, O'Sullivan, & Scherer, 1980, p. 277), and because patients with PD are distractable by irrelevant stimulus aspects, we also assumed that PD patients will *rely to a greater degree on the concomitant semantic meaning* than control subjects when judging emotional prosody. It has to be kept in mind, though, that behavior observed in laboratory prosody studies may differ from behavior in everyday life: Prosody is generally not subject to conscious awareness in social interactions and prosodic skills are exercised implicitly (Hird & Kirsner, 1998), e.g., by triggering automatic emotional responses in the listener (cf. Hietanen, Surakka, & Linnankoski, 1998).

To additionally explore the *effect of symptom severity* on performance in perception of vocal emotions, we compared medicated PD patients (with moderate symptom severity) with PD patients who were not yet receiving dopaminergic replacement therapy.

Acoustic Processing Deficit

Perception of emotional prosody requires the implicit processing of temporal information (Ivry & Hazeltine, 1995) because speech rate is considered to be among the most potent cues in subjects' classifications of vocal emotions (Scherer, 1986). Time perception and temporal control parameters (''time production'') have traditionally been considered as a specific function of the cerebellum (Ivry & Keele, 1989).

Recently, however, impaired time perception in Parkinson's disease has been supported by several independent research groups. Artieda and coworkers (Artieda, Pastor, Lacruz et al., 1992; Pastor, Artieda, Jahanshahi et al., 1992) found increased temporal discrimination thresholds and underestimation of time interval durations in PD patients as compared to healthy control subjects. Because neither study controlled for the effect of practice, the validity of the findings is limited (Harrington, Haaland, & Hermanowicz, 1998a). Using a different time perception procedure (judging the relative duration of two tone pairs), Harrington et al. (1998a) showed a dissociation between the discrimination of temporal (impaired) and pitch (preserved) stimuli in patients with PD. Additionally, administering the same experimental design to patients with focal damage to the right or the left hemisphere provided evidence for the involvement of a right-sided prefrontal-parietal network in temporal discrimination tasks (Harrington, Haaland, & Knight, 1998b). Furthermore, performance in duration perception was correlated with performance in a working memory task (attention switching) for patients with right-sided lesions, implying that the prefrontal-parietal network may support timing functions indirectly by sustaining attention (i.e., working memory). In contrast to the patients with PD, both right- and left-hemisphere-damaged groups additionally presented with impaired pitch perception compared to their respective control group and pitch and duration perception scores were significantly correlated in both groups. This implies a more generalized deficit in processing acoustic stimuli in both cortically damaged groups. The high cognitive demand of the task may account for inconsistencies with previous findings in the domain of temporal processing (Robin et al., 1990; Van Lancker & Sidtis, 1992). An involvement of the dorsolateral prefrontal cortex or basal ganglia structures in allocating attentional resources to time perception is also supported by a variety of other animal and human studies (for summaries, see Jueptner, Rijntes, Weiller et al., 1995; Malapani, Rakitin, Levy et al., 1998; Maquet, Lejeune, Pouthas et al., 1996; Meck, 1996; Rammsayer, 1994, 1997; Zakay & Block, 1996).

Furthermore, it has been suggested that perceptual and productive timing share common neural mechanisms (Keele, Pokorny, Corcos et al., 1985) and that ''principles underlying the coordination of speech movements are the same principles that underly the coordination of all movements'' (Smith, McFarland, & Weber, 1986, p. 480). Temporal abnormalities in the production of speech (Darkins et al., 1988; Darley, Aronson, & Brown, 1975; Duffy, 1995; Flint et al., 1992; Volkmann, Hefter, Lange et al., 1992) and in nonspeech motor tasks (e.g., O'Boyle, Freeman, & Cody, 1996) are among the core clinical symptoms of PD. It is therefore likely that a timing deficit will also be observed in the *perception* of durational aspects of speech in patients suffering from PD.

Hypotheses. Systematic manipulation (see below) of two major acoustic cues underlying emotional prosodic stimuli, speech rate, and F0 variability was employed to examine a selective deficit for duration perception in patients with PD. The systematic variation of pitch cues was included to control for a general impairment in processing of complex acoustic stimuli. The prosodic stimuli were spoken in a foreign language to greatly reduce semantic processing of the stimuli.

METHODS

Subjects

Twenty outpatients with PD, recruited from the Movement Disorders Clinic at the University of Southern California Hospital, and 16 neurologically intact healthy control (HC) subjects took part in the experiment. All subjects were right-handed and had normal hearing (as assessed with a brief audiometric screening procedure, testing frequencies from 500 to 4000 Hz at 30 dB), and the groups were matched for age and educational level. The diagnosis of idiopathic PD without dementia [all PD patients scored higher or at 27 on the Mini-Mental State Examination (MMSE); Folstein, Folstein, & McHugh, 1975] was made by an experienced neurologist (C. H. Waters) who also provided the score on the motor section of the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn, Elton et al., 1987) and the Hoehn and Yahr (HY) (Hoehn & Yahr, 1967) severity measure (stages I to V) for each patient. The motor assessment was carried out during the ''on'' rather than the ''off'' phase if patients experienced fluctuations with respect to the medication. All but one patient (HY IV) were classified as HY stage II (moderate, bilateral involvement); the motor UPDRS scores are presented in Table 1. Only patients with a disease onset after age 55 were included because recent evidence suggests the existence of a late-onset ''malignant'' and an early-onset ''benign'' form of PD with respect to cognitive decline (Birkmayer, Riederer, & Youdim, 1979; Caparros-Lefebvre, Pecheux, Petit et al., 1995; Dubois & Pillon, 1995; Hietanen & Teräväinen, 1988; Katzen, Levin, & Llabre, 1998; Lieberman, Dziatolowski, Kupersmith et al., 1979; Portin & Rinne, 1986; Reid, Broe, Hely et al., 1989; Schrag, Ben-Shlomo, Brown et al., 1998).

Fourteen PD patients (MODERATE-PD group) were on dopaminergic replacement therapy (all 14 were taking levodopa plus carbidopa; 7 patients additionally took a d2-agonist and/or a MAO-B-inhibitor). None of the patients were taking anticholinergics or amantadine at the time of testing or had undergone neurosurgical operation for PD. All patients were tested during their optimally medicated (''on'') state. The remaining 6 PD patients were taking part in an ongoing placebo-controlled clinical trial study (two different dosages and one placebo condition) for a novel MAO-B-inhibitor (rasagiline mesylate). Because previous randomized double-blind clinical studies for MAO-B-inhibitors (e.g., selegiline) have not shown specific cognitive effects in PD (Hietanen, 1991) and none of the patients in this study reported any pharmacological effects, we considered these patients as the early PD group not yet receiving dopaminergic replacement therapy (EARLY-PD). None of the PD patients presented with severe dyskinesias or resting tremors that could have interfered with testing.

The healthy control group ($n = 16$) was recruited by advertisements or personal contact. None of the control subjects had a history of neurological or psychiatric disease or were taking medication affecting the central nervous system.

Because one of the prosodic tasks (see below) used stimuli in the German language, only subjects who were not fluent in the German language were included. Three male subjects each in the HC and the PD group had spent a short period of army service time in Germany, but none of the subjects had learned to speak German during that period.

Materials

Background Information

Information regarding age, years and field of education, language abilities (number of languages spoken fluently, time spent in a German-speaking country, and years of residence in California), and years of musical training were assessed for each subject.

TABLE 1
Demographic and Clinical Data for the Patients with PD and the HC Group

Variable	Group		
	EARLY-PD	MODERATE-PD	HC
Sample size (*n*)	6	14	16
Female/male	2/4	5/9	8/8
Age in years	68.3 ± 5.1	72.6 ± 6.9	68.6 ± 8.9
Motor UPDRS score[a]			
Mean and *SD*	17.5 ± 5.1	27.5 ± 13.5	N/A
Range	11.5–26	4–56	
Duration of disease (in months)			
Mean and *SD*	16.2 ± 7.8	59.1 ± 58.3	N/A
Age at disease onset			
Mean and *SD*	67.0 ± 5.5	67.7 ± 7.1	N/A
Levodopa in mg (per day)			
Mean and *SD*	N/A	562 ± 294	N/A

[a] max. score: 137; EARLY-PD = patients with Parkinson's disease not receiving dopamine supplement therapy; MODERATE-PD = patients with Parkinson's disease receiving dopamine supplement therapy; HC = healthy control subjects; *SD* = standard deviation.

Nonverbal Auditory Perception/Amusia

Neurological patients may have difficulty discriminating sounds even when the hearing test yields normal results (Lezak, 1995), and this deficit may interfere with the perception of prosodic information. Therefore, a control task of nonverbal auditory perception of nonspeech acoustic stimuli was included. All subjects were administered 20 tape-recorded pairs of tones, presented via headphones. For 10 of the pairs, subjects had to decide whether the two tones sounded the same or different with respect to *pitch;* for 10 pairs, subjects were required to make same/different judgments with respect to duration of the tones. It was taken care that the stimuli reflected characteristic properties of the acoustic differences between emotional prosodic categories and that duration differences were above the general discrimination threshold of about 30 ms. More detailed information on the stimuli is presented in Appendix A.

Neuropsychological Test Battery

A short battery of neuropsychological tests was administered to all subjects.

General intellectual functioning. Visuospatial processing was assessed using the Picture Completion subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) because it does not involve a motor component; the WAIS-R subtest Vocabulary was used to evaluate semantic verbal memory. The MMSE (Folstein et al., 1975) served as a screening procedure for the presence of dementia (maximum score = 30); as indicated above, all scores were within the normal range (≥27).

Immediate memory. As a measure of *attention* (or verbal short-term memory), subjects were administered the Digit Span subtest (forward and backward spans) of the WAIS-R (Wechsler, 1981).

Assessment of central executive frontal lobe functions. *Verbal fluency* tasks involved a semantic category (animals) and a further subtest which required the subject to name men's first names and vegetables in alternation (e.g., Paul–artichoke). Subjects were instructed to produce as many items as possible in a time interval of 1 min. The Wisconsin Card Sorting Test (WCST) was administered in the modified version by Nelson (Nelson, 1976). The numbers of categories achieved, number of random errors, and number of perseverative errors served as measures. Another task of central executive or working memory functioning was the Listening Span Test (Daneman & Carpenter, 1980; modified for testing neurological patients by Small, Andersen, & Kempler, 1997; for psychometric properties, see Lehman & Tompkins, 1998). This procedure has been shown to be sensitive to verbal working memory deficits in early, untreated PD patients (Gabrieli et al., 1996). In this test, subjects listen to short tape-recorded sentences and are required to carry out two tasks in parallel: (a) immediately answer the question ''True or false?'' about each sentence (e.g., ''A triangle has four sides. True or false?'') and (b) keep the last word of each sentence (in this example ''sides'') in mind for later recall at the end of the given trial. In the first step (level one), only one sentence is presented on a given trial. If the subject correctly recalls the last word of each sentence in three or more of five trials, the next step (level two) is presented. At level two, two sentences are presented with an interstimulus interval of 1.5 s on a given trial. Again, if both words were correctly recalled in three or more of five trials, the next level (level three, with three sentences on a given trial) is presented, which if successfully completed leads to the presentation of the highest level (level four; with four sentences on a given trial). All sentences were spoken by a male adult speaker and recorded using a digital tape player (Sony TCD-D8, connected to a Sony ECM-MS957 microphone). Stimuli were then digitized using speech analysis software (Computerized Speechlab 4300, Kay Elemetrics Corp., U.S.A.). Three different measures are derived: (a) The *listening span* is equal to the highest span level at which three of five final words were correctly recalled (maximum = 4; half a point is given if two of the five trials are correct); (b) *number of trials* refers to the total number of trials in which all final words were correctly recalled (maximum = 20); and (c) *number of words* refers to the total number of correctly recalled final words (maximum = 50). Two practice trials (span level one = one final word to be recalled) were presented to all subjects.

Depression. All subjects were administered the Beck Depression Inventory (BDI-II; Beck, 1996), which has been shown to be a reliable and valid measure of depression in PD, including the somatic items (Levin, Llabre, & Weiner, 1988).

Prosody Perception

Two different prosody tasks were used to study two different hypotheses: A prosody tape in the English language was administered to examine the contribution of working memory (distraction by content meaning of the prosodic stimuli). In order to minimize any effect of working memory, prosodic stimuli in the German language were used for the systematic variation of duration and pitch cues.

''Conflicting emotional prosody'' (prosody in the English language). Subtest 8b of the Florida Affect Battery (Bowers, Blonder, & Heilman, 1991; Bowers et al., 1987) was used to study the effect of distraction by semantic meaning on perception of emotional prosody. The tests consists of 32 emotional prosodic stimuli, spoken by a female voice. Half of the sentences convey the same emotional meaning in both semantic content and emotional prosody (e.g., ''The couple beamed at their brand new grandson,'' spoken in a happy tone of voice). These are the so-called *congruent* stimuli. On the remaining 16 trials, the emotional prosody is inconsistent with the emotional content of the sentence. These *incongruent* trials are further divided according to the degree of discrepant information expressed by the prosodic and semantic message. The first type is referred to as *''conflicting''* because in these 8 stimuli, the emotional prosody is directly in conflict with the emotional semantic meaning of the sentence (e.g., ''The couple beamed at their brand new grandson'' said in an angry tone of voice). The second type of incongruent stimuli comprised 8 stimuli in which a neutral semantic meaning was paired with an emotional prosodic message or vice versa (e.g., ''The chairs are made of wood,'' spoken in a sad tone of voice, or ''The man held his dying son,'' spoken in a neutral tone of voice). These were the so-called *''conflicting-neutral''* stimuli. A total prosody score is calculated as well as separate scores for the congruent and incongruent (conflicting and conflicting-neutral) conditions. Subjects were given the instruction to listen to the emotional tone of voice while disregarding what the speaker said. Subjects were asked to respond verbally or by pointing to a response card with the printed emotion labels (to reduce fatigue effect in the PD patients with speech problems).

Systematic variation of duration and pitch cues (prosody tape in the German language). Twenty sentences from a standardized set of emotional prosodic utterances (Breitenstein, Daum, Ackermann, Luetgehetmann, & Mueller, 1996) were selected. The sentences were all in German (to minimize distraction effects by semantic meaning of the sentences) and neutral in propositional content, but differed in their meaning (four different meanings) and their emotional tone of voice (five categories: happy, sad, angry, frightened, and neutral). All sentences had identical grammatical structures (subject, verb, and object). The inclusion of a neutral category was considered methodologically crucial as a control category because previous research has shown that confusion errors do not occur with the same likelihood across all emotional categories. With the inclusion of a neutral category, subjects are less likely to use exclusion rules which may result in artificially high recognition rates (cf. Scherer, 1986). Scherer (1986) recommends the inclusion of a large number of emotional categories to prevent this artifact. We chose the inclusion of a neutral category instead because increasing attentional demands by adding forced-choice alternatives may have detrimental effects on performance in brain-damaged populations (Tompkins & Flowers, 1985). All sentences were recorded (in the German language) by a professional German actress in a sound-attenuated room using a portable digital tape player (SONY TCD-D7) and a microphone (SONY ECM-959A) placed at a mouth distance of 30 cm. The actress was instructed not to use additional vocal sounds, such as laughs or sobs, for the portrayal of vocal emotions. Previous research indicated that effects for acoustic variables are speaker-independent and generalizable across different speakers (Ladd, Silverman, Tolkmitt et al., 1985).

Speech signals were originally digitized at a sampling rate of 25 kHz (after low-pass filtering at 9 kHz) and 16-bit quantization using speech-analysis software (Computerized Speechlab 4300, Kay Elemetrics Corp.). The speech-synthesis software (see below) required a sampling rate of 10 kHz (or less). For that reason, all sentences were downsampled at 10 kHz prior to setting of pitch markers. The F0 was determined using a pitch frame length of 20 ms and a pitch frame advance of 10 ms. The maximum frequency of F0 was limited to 350 Hz, the minimum to 50 Hz. The F0 data were stored in a data file and also displayed visually on the computer screen so that stray data points arising from microphone artifacts, voice break-ups, and errors due to digital analysis could be removed. The acoustic data for the original sentences are presented in Appendix B. Following the visual correction of artifacts in the intonation contour, the data underwent systematic variation of two acoustic parameters (standard deviation of F0 and speech rate) using LPC Parameter Manipulation/Synthesis (Kay Elemetrics Corp.). The choice of these two acoustic parameters was based on prior studies indicating the crucial role of pitch variation and temporal aspects in real vocal emotions (Williams & Stevens, 1972) and in judgments of vocal emotions portrayed by actors (Banse & Scherer, 1996; Bergmann, Goldbeck, & Scherer, 1988; Ellgring & Scherer, 1996). Furthermore, pitch and speech rate are considered to exert independent, i.e. additive, effects on raters' judgments (Apple, Streeter, & Krauss, 1979). Mean F0 was not selected for the acoustic manipulation because global changes in mean F0, independent of F0 variation, produce voice quality differences which do not constitute clear emotional prosodic cues (cf. Bergmann et al., 1988).

For each acoustic parameter (speech rate and F0 variation), 10 sentences were resynthesized from each of the 20 original sentences (tokens): For half of the sentences, the values for the parameter of interest were *decreased* (to 90, 80, 70, 60, and 50). For the other half, the values were *increased* (to 110, 120, 130, 140, and 150%). Following the recommendations by Bergmann et al. (1988), to ensure that the stimuli sounded as natural as possible and the acoustic features remained within the normal range of a female voice, the new values for F0 (after the multiplication) were corrected by addition or subtraction of a constant so that the speaker's baseline F0 of 120 Hz (which was the lowest F0 data point occurring in any of the 20 tokens) remained constant. For speech rate manipulation, both consonant and vowel information were linearly expanded or compressed. In natural speech, vowel duration is usually slightly more affected by changes in speech rate than is the duration of the consonants. Because (a) the exact ratio of vowel-to-consonant lengthening or shortening is unknown, (b) a correlation of $r = .87$ has been reported between duration of articulation with duration of voiced segments (Banse & Scherer, 1996), and (c) alteration of total speech rate yielded stronger effects on emotion attributions compared to alteration of stressed syllables (Bergmann et al., 1988), we decided to linearly expand and compress each utterance. The manipulation resulted in a very natural-sounding speech quality. Altogether, 400 stimuli (5 emotional categories $\times$ 4 different meanings $\times$ 2 acoustic parameters $\times$ 10 factor levels) were resynthesized. All 400 stimuli were recorded in random order on a digital tape with an ISI of 4 s (the trial number was announced by a male voice in English). These are the ''rate-'' and ''pitch-altered'' stimuli. To explore the suitability of the synthesized German sentences, a pilot study with eight American subjects was conducted with all 400 stimuli. The effects were very stable across subjects and the speech rate and pitch variation manipulations resulted in linear or quadratic trends with respect to accuracy of emotion perception across the 10 manipulation levels. For economic reasons, a reduced set of 240 stimuli, using only 6 instead of 10 manipulation levels (50%, 70%, 90%, 110%, 130%, and 150%), presented in two parts with a short break after 120 trials, was administered to 30 American and 35 German students. Besides judging which of five possible emotions they had perceived, subjects were also asked to rate each item on a 5-point scale: (a) *''How certain are you about the choice of that emotion?''* and (b) *''How active or passive did the utterance sound?''* Complete data for the cross-cultural comparison in acoustic cue utilization are presented elsewhere (Breitenstein, Van Lancker, & Daum, 2001). Briefly, performance of German and American students was very similar with slight differences in arousal-related emotions (angry and happy), indicating that the use of speech rate and pitch information in prosody perception is largely culturally invariant. The rating scales (certainty and activity) explained only a small fraction of the variance (less than 25%) and were therefore not included in the present study. Furthermore, the total number of stimuli was reduced to 180 (with a short break after 90 trials) by excluding one of the four sentence content types, which overall achieved the lowest item–whole correlations in the cross-cultural experiment. For all subjects, the experimenter recorded the response given by the subject on a testing sheet (which did not indicate the correct answer so that the experimenter was unaware of the subject's performance during the task).

Procedure

The procedures were kept very similar for all subjects. After subjects gave written informed consent, they were asked a standardized set of demographic questions (years and field of education, their foreign language abilities, time spent living abroad, and years of musical training). Subjects were tested individually, and all stimuli were presented on a portable digital tape recorder (SONY TCD-D7) and headphones (beyerdynamic DT211). Headphones were chosen instead of loudspeakers to minimize distraction effects. The subjects were told to adjust the volume to a comfortable setting. They were also informed that they could stop the tape at any time and listen to a sentence again if they wished to. All instructions were read to the subjects to optimize standardization. All subjects were given an English translation of the German sentences before performing the listening task to prevent subjects from trying to figure out what was said. For the 180 synthesized German stimuli (rate- and pitch-altered tape) and the tape with the 32 prosodic sentences in the English language, the participants were instructed to pick the appropriate emotional category from a sheet which contained the four (English tape) or five (German tape) emotion labels.

For the synthesized stimuli in the German language, six practice trials (taken from the set of stimuli that were excluded after the pilot phase) were presented on tape before the main task started. Practice trials were included to ensure acquaintance with the speaker's idiosyncratic pattern of vocal emotions (Cosmides, 1983; but see also Frick, 1985) and the slightly distorted sound quality of the synthesized stimuli. Subjects were given feedback on these practice trials, but not at any other point during the experiment.

To control for effects of experience, fatigue, and carryover, the sequence of the tasks (synthesized stimuli in the German language, prosodic stimuli in the English language, and neuropsychological tests) was counterbalanced across subjects. For the synthesized stimuli, the sequences of part 1 (trials 1–90) and part 2 (trials 91–180) were counterbalanced for the same reasons.

The session lasted about 120 min, and all subjects were given a nominal reimbursement for their participation ($10).

Data Analysis

Group differences were analyzed using one-way analyses of variance (ANOVAs) or Kruskal–Wallis tests, where appropriate. If higher order interactions were significant, lower order interactions or main effects will not be interpreted. Post hoc paired comparisons were explored with Tukey's HSD tests or, when only two groups were compared, by unpaired *t* test or (Mann–Whitney) *U* tests respectively. Pearson or Spearman correlation coefficients with Bonferroni-corrected probability levels were used to compare performance in the different variables (prosody, memory). A link between prosody task and cognitive measures was also explored by means of stepwise multiple regression analyses (forward entry; criterion: $p < .05$).

RESULTS

Background Variables

Information on subjects' demographic data and patients' clinical data are presented in Table 1. The PD and HC groups did not differ significantly with respect to age, years of education, years of musical training, years of residence in California, number of self-reported languages spoken (all *p*'s $> .31$), or the distribution of sex [$\chi^2(1) = .62$, $p = .43$]. The MODERATE-PD and EARLY-PD patients were not significantly different from each other with respect to all of the above listed demographic variables as well as age at onset of disease (all *p*'s $> .14$). As expected, the group difference on the mean motor UPDRS score approached significance (*U* test, $p = .05$) with EARLY-PD patients scoring lower (lower number of motor symptoms) than the MODERATE-PD group. The MODERATE-PD patients also had a significantly longer disease duration than the EARLY-PD patients (*U* test, $p = .043$).

Test or Item Sequence

Neither the sequence of the tasks (prosodic stimuli in the English language, rate- or pitch-altered prosodic stimuli in the German language, and neuropsychological tests) nor the sequence of items within the speech-manipulated prosodic stimuli yielded an effect on the groups' overall scores (all *p*'s $> .25$). Therefore, the data were pooled across sequence conditions for all analyses.

Nonverbal Auditory Perception/Amusia

An ANOVA with the between-group factor *group* (EARLY-PD, MODERATE-PD, and HC) and the within-factor parameter (duration and pitch) yielded a significant interaction of group × parameter [$F(2, 30) = 9.04$, $p = .001$]. Subsequent analyses showed that groups differed significantly only in the duration discrimination task [$F(2, 30) = 7.24$, $p < .01$), which was due to the MODERATE-PD group scoring significantly lower than the HC group (Tukey: $p = .002$). The EARLY-PD patients were not significantly different from the HC subjects or the MODERATE-PD group. Errors occurred most often for stimulus pair number five (400 and 600 ms), followed by stimulus pair number two (400 and 200 ms), which were incorrectly judged as sounding the ''same.'' No group effect was observed for the discrimination of *pitch* stimuli [$F(2, 30) = 0.61$, n.s.].

Neuropsychological Data

General Intellectual Functioning

The three groups did not differ significantly with respect to the MMSE score (Kruskal–Wallis: $p > .10$) and the Vocabulary or Picture Completion IQ scores (Kruskal–Wallis: both *p*'s $> .05$).

Immediate Memory

No group differences emerged for digit spans forward or backward (Kruskal–Wallis: both p's $> .22$).

Assessment of Central Executive Frontal Lobe Functions

The three groups were significantly different with respect to number of achieved categories (Kruskal–Wallis: $p = .02$) and number of non perseverative errors [$F(2, 31) = 3.69$, $p = .037$] in the WCST, with MODERATE-PD patients achieving a lower number of categories and committing more errors than the HC group (both p's $< .03$). Significant group differences also emerged for performance in the switching condition of the verbal fluency task [$F(2, 31) = 4.26$, $p = .02$] in that MODERATE-PD patients produced fewer pairs in the verbal fluency switching condition compared to the HC group ($p < .02$). The EARLY-PD group did not differ from either the MODERATE-PD group or the HC group. Main effects of group also emerged for the three different measures of the listening span task[1] [listening span: Kruskal–Wallis, $p = .003$; number of trials and total words recalled: both F's$(2, 31) \geq 6.30$, p's $\leq .005$]. Post hoc comparisons revealed that the MODERATE-PD group scored significantly lower than HC controls on all three measures of the Listening Span Test (all p's $\leq .02$; see Table 2). Furthermore, the group difference between EARLY-PD patients and HC subjects for the listening span approached significance.

No group differences were observed for number of perseverative errors in the WCST (Kruskal–Wallis: $p = .16$) and performance in the semantic fluency task [$F(2, 31) = 2.34$, $p = .11$].

Depression

BDI depression scores were not different between groups (Kruskal–Wallis: $p = .30$).

Prosody Perception

''Conflicting Emotional Prosody'' (Prosody in the English Language)[2]

Percentage correct scores. Comparisons were made with the emotional prosodic task in the English language, which consisted of 32 sentences spoken with four emotional intonations (happy, sad, angry, and neutral) using different propositional content types.

Using the total prosody score as a dependent variable, a main effect of group emerged [$F(2, 30) = 6.60$, $p = .004$]. Post hoc analyses (Tukey) showed a significantly lower total percentage correct score of the MODERATE-PD as compared to the HC group ($p < .01$); the EARLY-PD group did not differ significantly from either the HC or the MODERATE-PD group.

To explore the effect of stimulus condition, an ANOVA with the between-group factor group (EARLY-PD, MODERATE-PD, HC) and the within-factor stimulus condition (congruent, incongruent) yielded a significant main effect of group as well as a significant interaction of group $\times$ stimulus condition [$F(2, 30) = 4.36$, $p = .02$]. To examine the interaction, the two stimulus conditions were analyzed separately,

[1] True/false errors were very infrequent and were therefore not analyzed.

[2] One MODERATE-PD patient and 2 HC subjects were unable to perform the complete test battery because of time constraints and did not take this test. Data analyses were thus performed with 19 PD patients and 14 HC subjects.

TABLE 2
Neuropsychological Data (Mean and SD) for the Patients with PD and the HC Group

Variable	Group		
	EARLY-PD (n = 6)	MODERATE-PD (n = 14)	HC (n = 16)
Nonverbal auditory perception			
Pitch (max = 10)	10.0 ± 0	9.7 ± 0.9	9.9 ± 0.4
Duration (max = 10)	9.2 ± 0.8	8.4 ± 1.3	9.7 ± 0.5
MMSE (max = 30)	29.5 ± 0.5	28.9 ± 1.0	29.6 ± 0.6
Intelligence (PR)			
Vocabulary	83.7 ± 12.8	66.7 ± 17.4	78.4 ± 12.8
Picture completion	73.5 ± 20.8	58.6 ± 20.9	74.6 ± 18.6
Digit span			
Forward	7.3 ± 1.5	6.4 ± 0.8	6.6 ± 1.2
Backward	5.0 ± 1.3	4.2 ± 1.3	4.8 ± 1.1
WCST (Nelson-Version)			
Categories (max = 6)	6 ± 0	5.4 ± 1.0	6 ± 0
Number of errors	4.7 ± 2.1	6.8 ± 4.7	3.3 ± 2.4
Number of perseverations	0	0.2 ± 0.4	0
Verbal fluency			
Semantic (1 min)	20.2 ± 5.1	19.5 ± 6.8	24.8 ± 7.0
Switching (1 min)	7.2 ± 2.1	6.3 ± 1.7	8.1 ± 1.2
Listening Span Test			
Span (max = 4)	2.6 ± 0.5	2.4 ± 0.5	3.1 ± 0.6
Number of trials (max = 20)	12.7 ± 2.6	11.3 ± 2.7	14.6 ± 2.2
Total words (max = 50)	32.0 ± 9.4	25.9 ± 9.0	38.4 ± 7.1
Depression Score (BDI)	5.2 ± 4.3	8.6 ± 7.3	4.9 ± 3.6

Note. EARLY-PD = patients with Parkinson's disease not receiving dopamine supplement therapy; MODERATE-PD = patients with Parkinson's disease receiving dopamine supplement therapy; HC = healthy control subjects; *SD* = standard deviation; max = maximum; WCST = Wisconsin Card Sorting Test; BDI = Beck Depression Inventory.

which resulted in significant group differences for the incongruent [main effect *group:* $F(2, 30) = 6.94$, $p = .003$], but not the congruent stimulus condition (see Fig. 1). Post hoc comparisons (Tukey) yielded significantly lower scores of the MODERATE-PD group compared to the HC ($p = .004$) and the EARLY-PD ($p = .04$) groups.

To assess whether the MODERATE-PD group was more distracted than the other two groups by the incongruent semantic content, we used the percentage of reduction in accuracy from congruent to incongruent trials as a dependent variable. The following formula was used: (''congruent'' score − ''incongruent'' score)/''congruent score'' (cf. Bowers et al., 1987). The analysis yielded a main effect of group [$F(2, 30) = 4.18$, $p = .03$]. Post hoc comparisons showed that the decrement in the MODERATE-PD group (39% reduction) was significantly greater than in the HC group (15% reduction; Tukey: $p = .03$; see Fig. 2).

To examine the effect of increasing the degree of conflict between prosodic and semantic meaning of the stimuli on accuracy scores in the incongruent condition, an additional ANOVA with the within-factor stimulus type (conflicting and conflicting-neutral) and the between-factor group was conducted. The analysis yielded a signifi-

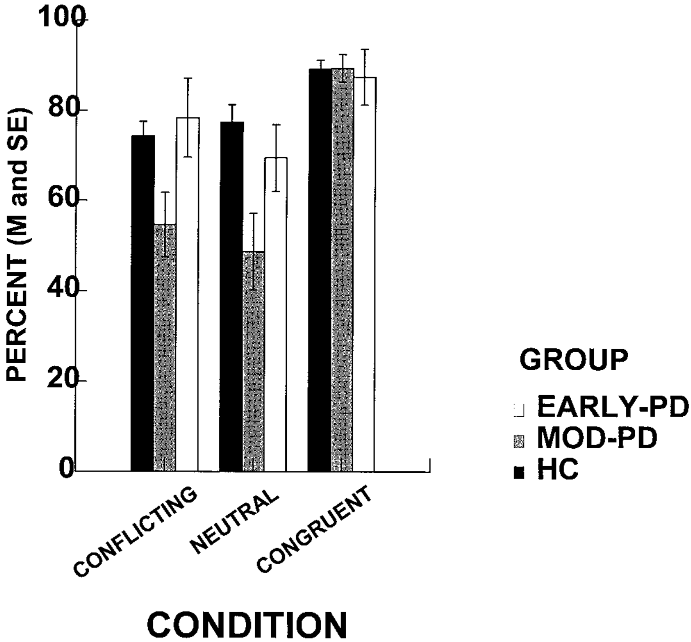

FIG. 1. Percentage correct (mean and standard error) for the three conditions (conflicting, conflicting-neutral, and congruent) in the English prosody task (EARLY-PD, MODERATE-PD, and HC groups).

cant main effect of group [$F(2, 30) = 6.94$, $p = .003$]; the main effect stimulus condition and the two-way interaction of group and stimulus condition were not significant. This indicates that increasing the degree of contrast between the vocal and linguistic channel in the incongruent condition did not significantly affect subjects' performance (see Fig. 1).

Error analysis. Additional analyses were conducted to determine whether the confusion errors made by the MODERATE-PD group compared to the other two groups in the two incongruent conditions were to a greater degree based on the semantic content of the prosodic stimuli. Using stimulus condition (conflicting and conflict-

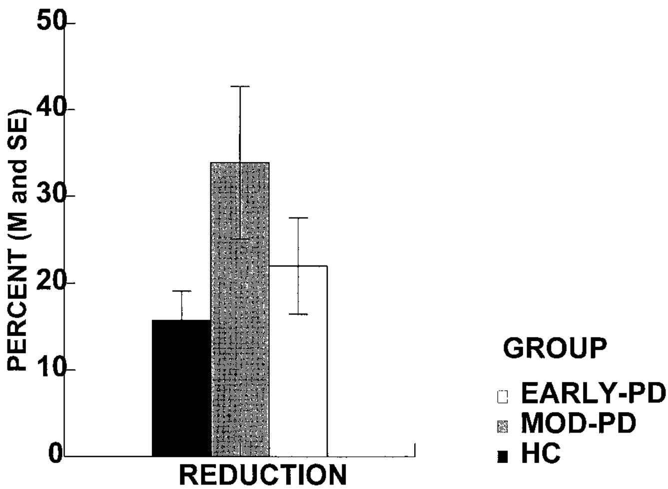

FIG. 2. Percentage reduction (mean and standard error) in accuracy between congruent and incongruent stimuli (English prosody task) for the three groups (EARLY-PD, MODERATE-PD, and HC).

ing-neutral) and error type (content error versus random error) as within-group factors and subject group as a between-group factor yielded a significant three-way interaction [condition × error type × group: $F(2, 30) = 5.34$, $p = .01$]. To explain the three-way interaction, separate analyses were conducted for the two stimulus conditions (see Fig. 3). For the conflicting-neutral condition, a significant interaction of error type by group emerged [$F(2, 30) = 5.24$, $p = .01$], with groups differing on semantic error scores [$F(2, 30) = 6.23$, $p = .005$], but not on random error scores ($p = .86$). Post hoc comparisons revealed significantly more (about 3 times as many) semantic errors for the MODERATE-PD group as compared to the HC group (Tukey: $p = .004$). The EARLY-PD group did not differ from either group. The finding implies that the MODERATE-PD group used the semantic meaning of the content to a significantly greater degree than the control group.

For the conflicting condition, a main effect of group was observed [$F(2, 30) = 4.80$, $p = .02$], which could be explained by an overall higher error rate of the MODERATE-PD group compared to both the EARLY-PD and HC groups (Tukey: both p's $< .05$). All groups committed a comparable proportion of content-based versus random errors.

Summary. The data provide evidence that the MODERATE-PD group based responses more often on sentence content, especially when the prosodic and the semantic meanings of the stimulus differed only slightly such that the contrast between the prosodic and semantic channels of meaning was less stark (e.g., ''They slit all the tires on my car,'' spoken with a neutral tone of voice). This occurred despite the instruction to disregard the semantic channel. Verbal reports of several of the PD patients during the test session indicated that they experienced considerable difficulties in focusing on the intonation only while ignoring the sentence content.

Single emotional categories. To examine group differences with respect to single emotional categories, data were pooled across content types (due to the small number of items for each emotional category in each of the three content types). The two-way interaction of group × emotional category was not significant, but Fig. 4 indicates a particularly pronounced impairment of the MODERATE-PD group compared to the HC and the EARLY-PD groups in classifying happy intonations. For all groups, correct identification rates were lowest for angry and happy and highest for sad utterances.

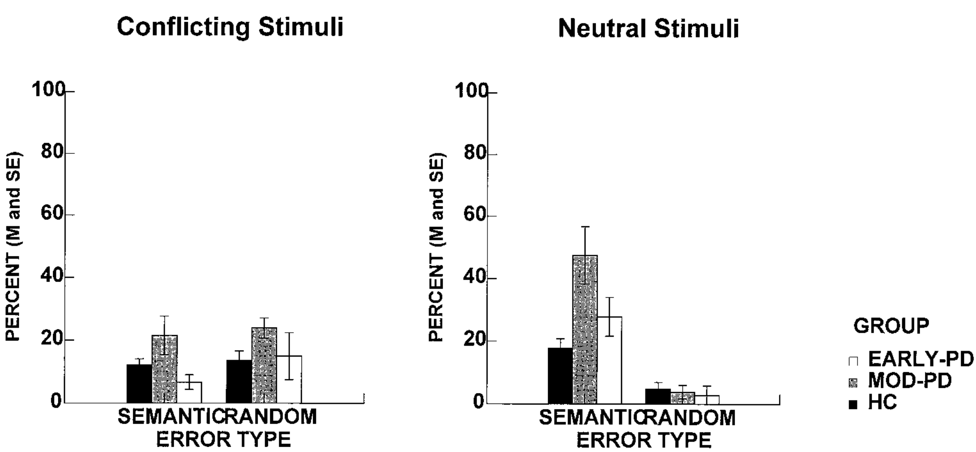

FIG. 3. Content versus random errors (mean and standard error) in the conflicting and conflicting-neutral conditions (English prosody task) for the three groups (EARLY-PD, MODERATE-PD, and HC).

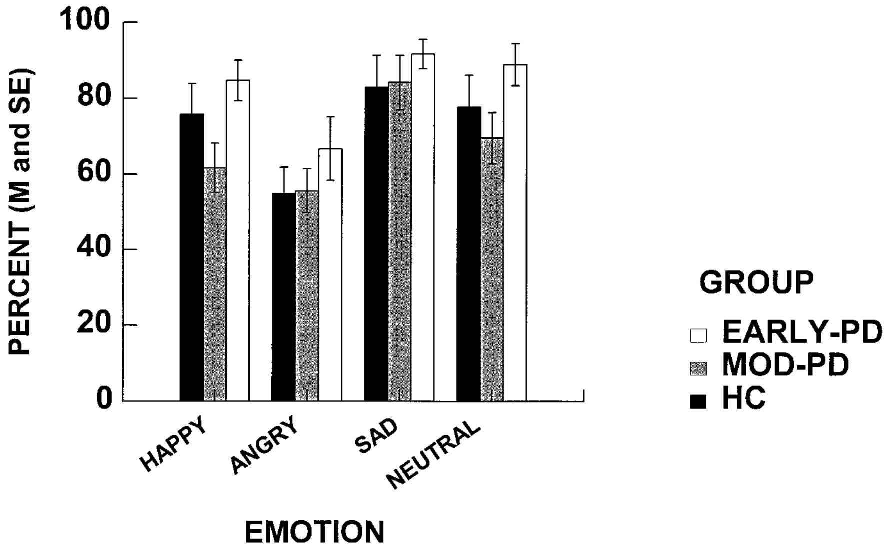

FIG. 4. Percentage correct (mean and standard error) for the five emotional categories (pooled across the conditions conflicting, conflicting-neutral, and congruent) in the English prosody task (EARLY-PD, MODERATE-PD, and HC groups).

Correlations with demographic and clinical variables. For clarity of presentation, results for the total score on the prosody task are presented because correlational analyses were very similar for the two incongruent conditions (conflicting and neutral) and performance was at ceiling for all groups in the congruent condition. For none of the three groups was performance in the emotional prosody task in the English language significantly correlated with age, years of education, sex, number of languages spoken fluently, years of residence in California, duration of musical training, the motor UPDRS score, duration of disease, age at onset of disease, or daily dose of levodopa drug regimen (all p's $> .56$).

Correlations with neuropsychological measures. To examine the relationship between emotional prosody and cognitive variables, a composite central executive functioning score was derived. The calculation of this composite score was based on the observation that three measures of central executive function were highly intercorrelated.[3] For each of these measures (total number of words recalled in the Listening Span Test,[4] number of pairs produced in the alternating condition of the verbal fluency task, and number of random errors in the WCST), the raw scores were transformed into Z scores by using the control group's mean and standard deviation. Furthermore, the pitch and rate discrimination scores of the nonverbal auditory perception task were highly intercorrelated in the PD group ($r = .70$, $p = .001$; HC: $r = .19$, $p = .51$); for the PD group, the two scores were therefore combined to a single score by simple addition.

Stepwise multiple regression analyses (forward entry; criterion: $p < .05$) were then conducted separately for each group (PD and HC) using the total prosody score as

[3] Intercorrelations between tasks tapping frontal lobe functions are frequent (Della Salla, Gray, Spinnler et al., 1998).

[4] All three measures (span, number of trials, and number of recalled words) of the Listening Span Test were highly intercorrelated. We selected number of recalled words for calculation of the composite working memory score because of a higher range of scores than span or number of trials.

the dependent variable and the neuropsychological measures (general intellectual functioning, immediate memory, frontal executive functioning, and depression) as predictor variables. Because MODERATE-PD and EARLY-PD patients did not significantly differ from one another on the total prosody score, they were combined to a single group in order to increase the sample size for the stepwise multiple-regression analysis. For the combined group of PD patients, the composite central executive functioning score predicted 45% of the variance in the emotional prosody task (multiple $r = .67$, $F = 12.07$, $\beta = 4.66$; see Fig. 5). The only other variable incorporated into the model was nonverbal auditory perception, predicting an additional 13% of the variance (multiple $r = .76$, $F = 4.87$, $\beta = 4.51$). In summary, the optimal regression formula which was identified explained 58% of the variance in the total prosody score and included only frontal executive functioning and nonverbal auditory perception. Using the subscores (incongruent and congruent) as dependent variables resulted in a very similar pattern of results: the composite working memory score predicted 25% of the incongruent (multiple $r = .50$, $F = 5.32$, $\beta = 8.13$) and 9% of the congruent ($r = .30$, n.s.) scores, but none of the other predictor variables contributed substantially. For none of the dependent variables (total, congruent, and incongruent scores) were significant contributions found for measures of general intellectual functioning (Vocabulary, Picture Completion, and MMSE), immediate memory (digit span forward and backward), semantic verbal fluency, number of categories achieved in the WCST, number of perseverative errors in the WCST, or depression (BDI).

For the HC group, none of the cognitive predictor variables accounted for a significant proportion of the variance in the total prosody score or the congruent score (all F's < 2.3, all p's $> .15$). When using the incongruent score as dependent variable, however, the depression score (BDI) predicted 54% of the variance (multiple $r = -.73$, $F = 13.91$, $\beta = -1.840$). This findings implies that HC subjects with a lower depression score performed better on the incongruent trials than HC subjects with a higher depression score. None of the subjects had a depression score of clinical relevance.

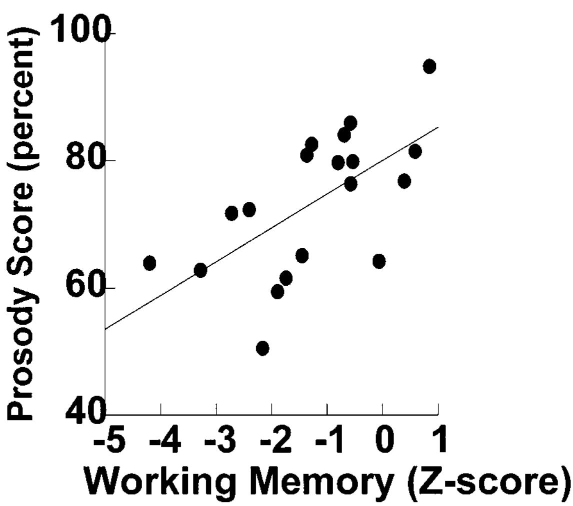

FIG. 5. Correlation (Pearson coefficient) between the composite working memory score and the total English prosody score for the PD group.

Systematic Variation of Duration and Pitch Cues (Prosody Tape in the German Language)[5]

The second set of prosodic stimuli consisted of the duration-altered and pitch variation-altered sentences. For the synthesized stimuli in the German language, repeated-measures analyses of variance (ANOVAs) were performed to test group differences in scores across emotions and to describe response trends (linear, quadratic) across the six manipulation factors. From our previous experience with the stimulus material (Breitenstein et al., 2001), it was predicted that the effects of the acoustic manipulations (decrease and increase of speech rate/pitch variation as compared to the original prosodic stimulus parameters) could be described as linear or quadratic trends.

Overall, subjects (pooled across groups) received higher accuracy scores when pitch variation (mean = 60.4% correct) was manipulated than when speech rate (mean = 49.9% correct) was altered [main effect of acoustic parameter: $F(1, 31) = 57.2$, $p < .001$]. Furthermore, the HC group achieved higher scores than the PD patients in both manipulation conditions [main effect group: $F(1, 31) = 10.4$, $p = .003$]. A significant four-way interaction of group (PD and HC) $\times$ acoustic parameter (speech rate and pitch variation) $\times$ emotion (happy, angry, sad, frightened, and neutral) $\times$ manipulation factor (50%, 70%, 90%, 110%, 130%, and 150%) was best described by a quadratic trend [$F(1, 31) = 6.63$, $p = .015$]. A difference in the quadratic trends indicates that the two groups were differentially affected by manipulation factors of specific emotions for the two acoustic parameters (duration and pitch variation). To explain the complex interaction and to achieve better clarity of presentation, more detailed analyses are presented separately for the alteration of speech rate and pitch variation. Because MODERATE-PD and EARLY-PD patients did not significantly differ in their performance in any of the below reported analyses and our previous experience demonstrated that large sample sizes are required to achieve smooth trends across manipulation factors, data were pooled across both PD groups.

Rate-Altered Stimuli

Percent correct responses. To examine the effect of degree of manipulation, an ANOVA with the between-group factor group and the within-factors emotional category and manipulation factor was performed, yielding a significant interaction of the three factors [linear trend: $F(1, 31) = 4.89$, $p = .035$]; none of the two-way interactions involving group achieved significance. To explain the three-way interaction, group differences of trends were analyzed separately across manipulation factors for each of the five emotional categories (see Fig. 6). Results show significantly different trends of the two groups for happy intonations [linear trend: $F(1, 31) = 8.62$, $p = .006$] and a trend toward significance for sad stimuli [quadratic trend[6]: $F(1, 31) = 3.39$, $p = .075$].

For *happy* utterances, the main effect of manipulation factor yielded significance for the HC group [linear trend: $F(1, 14) = 21.49$, $p < .001$] but not the PD group, indicating that PD patients were benefiting less by the gradual increase in speech duration than the HC subjects. Group differences were mainly observed for a decrease in speech duration (faster stimuli). As presented in Fig. 6, both groups gradually increased their performance with an increase in speech duration (from manipulation

[5] Two MODERATE-PD patients and 1 HC subject were unable to perform the complete test battery and did not take this test. Data analyses were therefore performed with 18 PD patients and 15 HC subjects.

[6] A quadratic rather than a linear trend was expected because of a ceiling effect in both groups at the slowest manipulation factors.

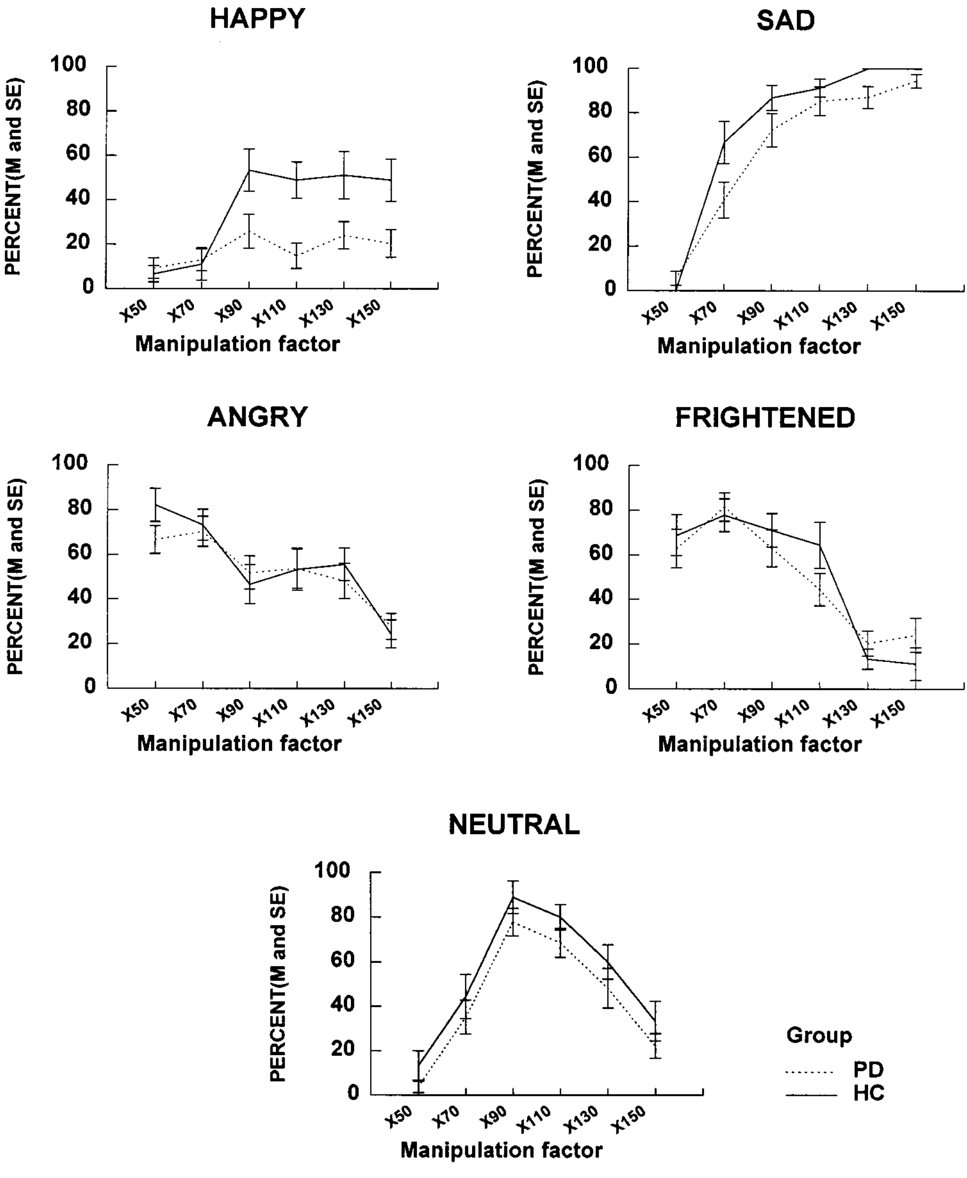

FIG. 6. Percentage correct scores (mean and standard error) for speech rate manipulation (German task) across the six manipulation factors for the five different emotional categories in the PD and HC groups (50% to 150% = 50 to 150% of original stimulus duration).

factors 50 to 90%), but this linear trend was significantly steeper in the HC compared to the PD group [group × manipulation factor (50%, 70%, and 90%): linear trend $F(1, 31) = 5.69$, $p = .02$]. For factor levels 110 to 150%, a significant main effect group [$F(1, 31) = 11.40$, $p = .002$], but no interaction of group × manipulation factor (110%, 130%, and 150%), was observed. Furthermore, the PD group performed at chance level (=20%) for happy stimuli at all factor levels, whereas the HC group performed significantly better than chance for manipulation factors 90% to 150% (Bonferroni-adjusted one-sample t tests: all p's $< .05$). The findings imply that the HC group was utilizing the temporal dimension (longer speech duration as a cue for happy classifications) to a greater degree than the PD group. It might be argued that this effect is due to a higher number of subjects in the PD group who performed at chance level in the happy category. Six of the PD patients and three of the HC subjects performed at chance across all manipulation factors in both acoustic manipulation conditions (speech rate and pitch variation). Excluding these subjects from statistical analyses resulted in an almost identical picture: The linear trend for the HC group yielded significance from factor levels 50% to 90% [linear trend: $F(1, 11) = 17.47$, $p = .002$]; the trend for the PD patients was not significant. The latter group did not differ from chance level (20%) at any of the manipulation factors (Bonferroni-adjusted one-sample *t* tests).

With respect to sad stimuli, both groups showed a significant linear increase across all manipulation factors from 50% to 150% [manipulation factor: linear trend; HC: $F(1, 14) = 126.47$, $p < .001$; PD: $F(1, 17) = 23.90$, $p < .001$]. As indicated by the above reported trend toward significance for the interaction of manipulation factor × group and as presented in Fig. 6, faster speech duration had a greater detrimental effect on the PD group as compared to the HC subjects. Performance of the PD group was not significantly different from chance at manipulation factors 50% and 70%; the HC group performed at chance level at manipulation factor 50% only (Bonferroni-adjusted one-sample *t* tests: all p's $> .10$).

There were no significant group differences for the trends of angry, frightened, or neutral stimuli. As displayed in Fig. 6, for both groups (PD and HC) and the three emotional categories (angry, frightened, and neutral), the linear and/or quadratic trends across manipulation factors (50% to 150%) were highly significant (all p's $<$ .01). This indicates that subjects' classifications of emotional categories were overall strongly influenced by temporal changes in the prosodic stimuli.

Confusion errors. Data for the confusion errors are presented in Table 3. Filled-in areas reveal correct responses, while directional arrows have been placed where the particular acoustic manipulation increased or decreased the percentage of perceived emotional category choices by more than chance level (20%). Double boxes highlight the response category most frequently chosen for the respective correct emotion. Overall, *decreasing* speech duration (i.e., speeding up the utterance) was associated with lowest identification of happy and sad intonations, but scarcely affected the correct classification of angry or frightened utterances. At factor levels 50% and 70% (i.e., faster speech rate), both groups misperceived sad utterances most frequently as expressing frightened or angry emotional states. *Increasing* speech duration resulted in misclassifications of frightened and neutral for sad in both groups. Consistent with the a priori hypothesis, an increase in speech duration (resulting in longer utterances) was related to high correct classification rates of sad utterances.

Several interesting group differences were observed. For *happy* productions, the majority of HC subjects misclassified fast happy stimuli (manipulation factors 50 and 70%) as angry, whereas PD patients tended to (incorrectly) label these stimuli frightened. Furthermore, HC subjects shifted their (incorrect) judgments from angry (correctly) to happy at factor levels 90% and higher ($>$50% of responses); the majority of PD patients shifted from frightened/angry to neutral. A very similar pattern of confusion errors for the two groups occurred for sad stimuli, but as Table 3 indicates, the HC group benefited to a higher degree from the gradually increasing speech duration across manipulation factors (50% to 150%). Whereas both groups misjudged sad for frightened most often at manipulation factor 50%, the majority of HC subjects shifted their judgment (correctly) to sad at factor 70%. This categorical shift did not occur until manipulation factor 90% in the PD group, indicating a different cue utilization of acoustic timing information. With respect to frightened stimuli, PD patients misclassified a bigger proportion of frightened stimuli as happy in comparison to the control group, particularly at the manipulation factors closest to the original

TABLE 3
Confusion Errors (Percentage of Possible Responses) for Manipulation of Speech Rate[a]

Correct emotion	Perceived emotion: HC Group (n = 15) H	S	A	F	N	PD Group (n = 18) H	S	A	F	N
Happy										
0.5 (fast)	7	0	60	29	4	9	2	37	48	4
0.7	11	0	56	22	11	13	4	37	33	13
0.9	53	2	11	13	20	26	7	13	11	43
1.1	49	0	11	0	40	15	4	19	4	59
1.3	51	7	13	0	29	24	9	24	4	39
1.5 (slow)	49	9	9	0	33	20	22	11	6	41
Sad										
0.5 (fast)	0	0	24	53	22	4	6	30	52	9
0.7	2	67	2	9	20	6	41	4	26	24
0.9	0	87	0	4	9	9	72	0	7	11
1.1	2	91	0	4	2	4	85	0	2	9
1.3	0	100	0	0	0	2	87	4	4	4
1.5 (slow)	0	100	0	0	0	2	94	0	4	0
Angry										
0.5 (fast)	0	0	82	18	0	2	2	67	28	2
0.7	11	0	73	7	9	7	0	70	7	15
0.9	2	4	47	2	44	2	7	50	4	37
1.1	7	4	53	2	33	9	0	54	4	33
1.3	11	4	56	2	27	13	9	48	7	22
1.5 (slow)	2	20	24	0	53	6	26	28	7	33
Fright										
0.5 (fast)	2	0	22	69	7	11	2	24	63	0
0.7	9	0	11	78	2	4	0	11	82	4
0.9	9	7	9	71	4	22	2	11	63	2
1.1	4	9	11	64	11	15	19	7	44	15
1.3	4	71	2	13	9	6	50	2	20	22
1.5 (slow)	2	87	0	11	0	9	63	0	24	4
Neutral										
0.5 (fast)	4	2	44	36	13	4	6	41	46	4
0.7	11	2	24	18	44	11	2	30	22	35
0.9	4	7	0	0	89	11	4	7	0	78
1.1	7	7	7	0	80	13	13	4	0	70
1.3	16	22	2	0	60	7	41	2	2	48
1.5 (slow)	11	51	4	0	33	13	56	6	4	22
Total	11	25	22	18	24	10	25	21	21	23

[a] Total responses for each emotional category: n = 45 for the HC group; n = 54 for the PD group; H = happy, S = sad, A = angry, F = frightened, N = neutral. Arrows indicate that selection of the category increased or decreased >20%.

stimulus duration (90% and 110%). Both groups used the category happy least frequently, and the HC group scarcely confused any of the other emotional categories (except neutral) with happy. For all but the neutral category, the PD patients misclassified slow stimuli (manipulation factors 130% and 150%), independent of the emotional category, more frequently as frightened than the control group. This provides more evidence for a disturbed processing of speech timing information in PD.

Pitch-Altered Stimuli

Percentage correct responses. ANOVAs revealed a trend toward significance for the three-way interaction of group × emotional category × manipulation factor [quadratic trend: $F(1, 31) = 3.33$, $p = .07$; see Fig. 7] and a significant main effect of *group* [$F(1, 31) = 9.52$, $p = .004$] with HC subjects scoring overall higher (66.2% ± 11.7%) than the PD group (55.5% ± 8.5%). None of the two-way interactions involving group yielded significance. The HC group performed above chance on all emotional categories, except at manipulation factor 90% for happy; the PD

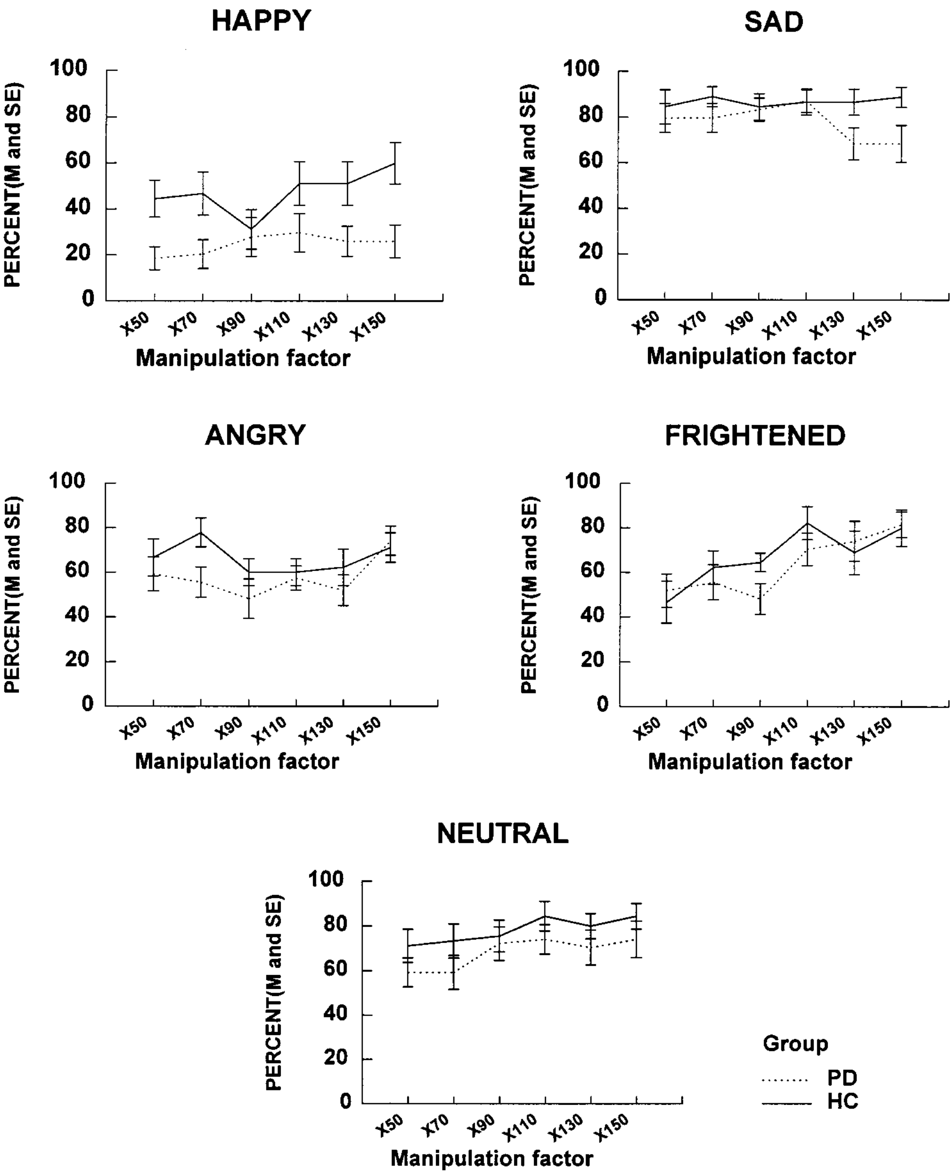

FIG. 7. Percentage correct scores (mean and standard error) for pitch variation manipulation (German task) across the six manipulation factors for the five different emotional categories in the PD and HC groups (50% to 150% = 50 to 150% of original pitch variation; all resulting F0 values were corrected to the speaker's baseline).

patients scored at chance level for all manipulation factors (50% to 150%) for happy stimuli. As for manipulation of speech rate, exclusion of the subjects who performed at chance level across all manipulation factors in both acoustic manipulation conditions (speech rate and pitch variation) did not change the pattern of results.

Finally, a significant interaction of emotional category × manipulation factor [linear trend: $F(1, 31) = 5.79$, $p = .02$] could be explained with significant gradual increases in correct classifications across manipulation factors for the categories frightened and neutral [linear trends: both F's$(1, 32) > 9.12$, p's $< .001$], indicating that both groups achieved higher scores the greater the pitch variation in these stimuli. The linear trend for happy approached significance ($p = .065$), which indicates that both groups benefited (although statistically nonsignificantly) from an increase in pitch variation across manipulation levels. The emotional categories sad and angry were less affected by the manipulation of pitch variation (see Fig. 7).

Confusion errors. In Table 4, as in Table 3, filled-in boxes indicate correct responses and directional arrows have been placed where the acoustic manipulation influenced the percentage of perceived emotional category choices by more than 20% of responses. Misclassifications occurred most frequently at factor levels 50% and 70% for both groups and were most pronounced for happy, angry, and frightened productions. Happy utterances were mistaken for neutral most often in both groups. Interestingly, the PD group misclassified substantially more happy stimuli as angry compared to the HC subjects when pitch variation was increased. This could be seen as evidence that the PD patients associated an increase in pitch variation with the emotional category anger, whereas the HC subjects relied to a lesser degree on pitch variation information in judging emotional prosody. This is also supported by the finding that PD patients improved their performance to a slightly greater degree when pitch variation in angry and frightened stimuli was increased (from manipulation factor 130% to 150% for angry stimuli and from factor 90% to 110% in frightened stimuli). For sad stimuli, PD patients were more affected when pitch variation was increased (manipulation factor 130% and 150%) and misclassified these sad stimuli as frightened or neutral. The control group, however, was not affected by variation of pitch information in sad stimuli. Finally, both groups misclassified neutral intonations most often as happy, but the effect was slightly more pronounced in the PD group. ''Neutral'' was the response given most frequently in both groups (30% and 31% respectively), which was mainly due to misclassifications of happy and angry stimuli. In summary, it appears that the PD group based their judgments to a higher degree than the control group on the available pitch variation information.

Correlations with demographic and clinical variables. No significant correlations (all p's $> .21$) were observed between the speech rate- or pitch-altered prosody scores and any of the clinical and demographic variables (age, years of education, sex, number of languages spoken fluently, years of residence in California, years of musical training, motor UPDRS score, disease duration, age at onset, and levodopa dose).

Correlations with neuropsychological measures. As outlined above, a composite central executive functioning score as well as an overall nonverbal auditory perception score were used. Stepwise multiple-regression analyses (forward entry; criterion: $p < .05$) were then conducted separately for each group and each acoustic parameter using either the total percentage correct score for rate-altered stimuli or the score for pitch-altered stimuli as the dependent variable and the neuropsychological measures (general intellectual functioning, immediate memory, frontal executive functioning, and depression) as predictor variables. For neither dependent variable (rate- or pitch-altered score) or group (PD and HC) were any of the predictor variables incorporated

TABLE 4
Confusion Errors (Percentage of Possible Responses) for Manipulation of Speech Rate[a]

Correct emotion	Perceived emotion: HC Group (n = 15) H	S	A	F	N	PD Group (n = 18) H	S	A	F	N
Happy										
0.5 (at)	44	4	7	2	42	19	7	9	13	52
0.7	47	2	2	2	47	20	4	17	6	54
0.9	31	0	4	11	53	28	2	20	2	48
1.1	51	0	7	0	42	30	2	19	4	46
1.3	51	0	11	9	29	26	0	28	7	39
1.5 (variable)	60	0	11	4	24	26	2	32	7	33
Sad										
0.5 (at)	0	84	0	4	11	7	80	2	4	7
0.7	0	89	0	7	4	2	80	0	6	13
0.9	0	84	0	7	9	0	83	0	2	15
1.1	0	87	0	4	9	0	87	0	4	9
1.3	0	87	2	7	4	9	69	2	11	9
1.5 (variable)	0	89	0	4	7	7	69	2	13	9
Angry										
0.5 (at)	0	7	67	4	22	6	7	59	0	28
0.7	2	7	78	4	7	9	4	56	11	20
0.9	11	4	60	4	20	15	6	48	11	20
1.1	9	7	60	0	24	4	9	57	4	26
1.3	9	0	62	0	29	9	4	52 ↓	6	30
1.5 (variable)	9	7	71	4	9	6	2	74	6	13
Fright										
0.5 (at)	11	11	18	47	13	6	7	24	52	11
0.7	4	13	11	62	9	13	11	9	56	11
0.9	7	7	7	64	16	20	2	13	48 ↓	17
1.1	11	2	2	82	2	9	6	2	70	13
1.3	11	7	13	69	0	11	4	7	74	4
1.5 (variable)	0	7	7	80	2	4	2	13	82	0
Neutral										
0.5 (at)	16	9	7	0	69	17	9	9	6	59
0.7	16	7	4	0	73	24	11	4	2	59
0.9	11	7	2	2	76	15	6	4	4	72
1.1	13	2	0	0	84	15	6	4	2	74
1.3	9	2	7	2	80	19	0	9	2	70
1.5 (variable)	13	2	0	0	84	15	7	2	2	74
Total	15	21	17	16	30	13	20	19	17	31

[a] Total responses for each emotional category: n = 45 for the HC group; n = 54 for the PD group; H = happy, S = sad, A = angry, F = frightened, N = neutral. Arrows indicate that selection of the category increased or decreased >20%.

into the model. In summary, no significant contributions were found for cognitive measures or depression scores on perception of prosodic stimuli in a foreign language.

Correlations between prosodic stimuli in the English and the German languages. Significant correlations between the total score and the incongruent score in the English prosody task with the pitch-altered German stimuli were observed for the PD patients only (total score: $r = .59$, $p = .04$; incongruent score: $r = .81$, $p = .001$). The correlation between the English prosody task and rate-altered German stimuli was not significant for neither the PD nor the HC group. Interestingly, for the HC group, correlations (albeit non significant) between the English prosody tape and the rate-altered stimuli ($r = .38$) were higher than the correlation between the English prosody tape and the pitch-altered stimuli ($r = .25$). This observation provides further evidence that unlike HC subjects, PD patients preferred pitch over duration cues.

DISCUSSION

The purpose of the present investigation was to examine which factors contribute to the impaired perception of emotional prosody in PD. As outlined in the Introduction, there are at least two possible explanations.

Frontal Executive Deficit

One possibility is that there is a *cognitive* deficit, e.g., the central executive component of working memory may play a role in judging emotional prosody in spoken sentences. To study this assumption, we administered a standardized set of emotional prosodic stimuli spoken in the English language to all subjects. We hypothesized that patients with PD would not only score significantly lower than HC subjects, but also show greater distraction by the concomitant semantic content of the stimuli. Both assumptions were generally supported by our findings. According to Bowers et al. (1987), scores on the conflicting and conflicting-neutral trials should not significantly differ if patients adopt a compensatory strategy of always attending only to the semantic content. In contrast, if the main difficulty for PD patients involves focusing on the task, then patients should perform more poorly on conflicting than conflicting-neutral trials because of the greater conflict between emotional and semantic meanings. The latter pattern of performance has been shown for right-hemisphere-damaged patients (Bowers et al., 1987). According to this model of the cognitive difficulty underlying the performance, the MODERATE-PD patients in the present study showed clear evidence for a compensatory strategy of attending to the semantic content (rather than greater ''distraction'' by trials with greater conflict between semantic and prosodic meanings) because their scores on the conflicting and conflicting-neutral conditions did not differ. This was also supported by the direct finding (see error analysis) that patients with MODERATE-PD based their responses to a greater degree on sentence content than the HC subjects. EARLY-PD patients performed within the range of the HC subjects, but showed a slight decrement in accuracy scores on the conflicting-neutral trials compared to the HC group (see Fig. 1).

The present data also demonstrate that patients with PD are not impaired in comprehending verbal emotional descriptions (or lexical emotions), as indicated by their response bias for the semantic content. A similar finding has been reported by St. Clair, Borod, Sliwinski et al. (1998) in PD patients with lateralized motor symptoms. This implies that PD patients, unlike patients with right-hemisphere damage (Bowers et al., 1987), do not suffer from a generalized emotional processing deficit; if present at all, it is limited to the nonverbal emotional domain. A clinical implication is that addition of congruent lexical emotional content may help patients with PD understand the prosodic message; the opposite has been proposed for aphasic patients who are unable to comprehend verbal emotional messages but may retain relatively intact prosodic perception of emotions (Heilman & Gilmore, 1998).

With respect to cognitive functioning, MODERATE-PD but not EARLY-PD patients were significantly impaired in tasks sensitive to central executive functions: Compared to HC subjects, they recalled fewer final words in the Listening Span task, made more random errors in the WCST,[7] and produced fewer pairs in the switching condition of the verbal fluency task. Performance of the EARLY-PD group did not significantly differ from either the control group or the MODERATE-PD group. Group differences between the MODERATE-PD and the HC group were also observed for the duration discrimination part of the nonverbal auditory perception task. The MODERATE-/EARLY-PD and HC groups did not differ with respect to the score in the MMSE, intelligence measures, digit span forward and backward, semantic condition of the verbal fluency task,[8] or the level of depression. To examine the hypothesis of a correlation between emotional prosody and working memory (central executive functioning) performance, a composite working memory score was derived (see above). As predicted, for the PD group, performance on the English-language emotional prosody task was highly correlated with the composite working memory score and was highly significant. A link between emotional prosody perception scores and central executive functioning in the PD group was also confirmed using stepwise multiple-regression analyses: The composite working memory score predicted 45% of the variance in the total prosody task in the English language and performance in the nonverbal auditory perception task explained an additional 13% of the variance in the PD group; none of the remaining cognitive measures nor the depression score contributed significantly. For the HC group, the correlations between prosody and cognitive performance did not approach significance, but mood as measured by a depression scale was negatively correlated with performance on the incongruent trials.

Finally, impaired perception of emotional prosody has also been reported in another dopamine-related disorder, namely schizophrenia (e.g., Kee, Kern, Barringer et al., 1998; Kerr & Neale, 1993; Leentjens, Wielaert, van Harskamp et al., 1998; Murphy & Cutting, 1990). It has recently been shown that schizophrenic patients treated with risperidone, an atypical neuroleptic with affinity to dopamine (d2) and serotonin receptors, were significantly superior in the perception of vocal emotions than patients treated with haloperidol (Kee et al., 1998). The same patients were reported to reveal a greater beneficial effect on verbal working memory when treated with risperidone as compared to haloperidol (Green, Marshall, Wirshing et al., 1997). These observations suggest that ''risperidone may influence perception of emotion indirectly through its effect on basic neurocognition'' (Kee et al., 1998; p. 163). Unfortunately, the authors do not provide data on a possible correlation between prosodic and cognitive measures in their patient groups (see also Kerr & Neale, 1993).

In summary, the impaired performance of patients with MODERATE-PD in the perception of emotional prosody could be due either to a failure in the response inhibition system (inability to suppress the semantic content or to selectively focus on the prosodic channel) or to an insufficient activation of the parallel pathway (reinforcement of the prosodic meaning). Because patients with PD utilized semantic content of the sentence significantly more frequently than HC subjects (and did not choose emotional categories randomly when making the wrong choice), a difficulty in inhibiting a system that processes semantic content seems more likely.

Acoustic Processing Deficit

Another possibility is that there is an *acoustic* problem. It may be that one or more of the acoustic parameters important for prosodic classifications are processed

[7] Number of perseverative errors in the WCST is frequently a less sensitive measure than number of nonperseverative errors in PD (Owen et al., 1993).

[8] PD patients are usually unimpaired in semantic or phonemic verbal fluency tasks without a shifting component (Goldman, Baty, Buckles et al., 1998).

inefficiently, e.g., patients with PD are not using information about speech rate or pitch appropriately. To investigate this assumption, we systematically varied two primary acoustic parameters known to be important for prosodic classifications in a common set of base stimuli: F0 variability and duration. Based on previous findings in the literature, we expected that patients with PD would present with a selective disadvantage when duration aspects of the prosodic stimuli were manipulated. All stimuli were neutral in semantic content and all subjects knew the linguistic meaning of the German sentences. Performance data from the EARLY- and MODERATE-PD groups were combined because preliminary analyses did not indicate differences between groups and a larger sample size was required to achieve smooth trends across the six acoustic manipulation steps (50, 70, 90, 110, 130, and 150% of the original stimulus).

Duration manipulation. Group differences were noted across manipulation factors for happy and sad utterances. The increase in accuracy across the six manipulation factors was steeper for the HC compared to the PD group in both emotional categories, indicating that the HC group benefited more from the utilization of the increasingly available duration cues. The differences in the steepness of the trends are, however, rather subtle. Additionally, the low accuracy score of the PD group on happy utterances is difficult to interpret. On the one hand, a relatively low accuracy score for happy as compared to the other emotions is consistent with previous findings. And inclusion of a neutral category decreased the likelihood of giving a correct response by simply applying exclusion and probability rules (cf. Banse & Scherer, 1996) because ‘‘happy’’ is most frequently confused with ‘‘neutral.’’ Furthermore, as indicated by the confusion errors (see Table 3), the happy category was chosen least frequently by both groups. Thus, the increased task difficulty of recognizing happy emotions may account for the observed group differences between PD and HC groups. The confusion errors, however, point to qualitative differences in group performance. Whereas the HC group most frequently misclassified fast (50% and 70% of original duration) happy stimuli as angry, the PD patients tended to categorize these utterances as frightened. And unlike the HC subjects, patients with PD did not use the increasingly available timing information across manipulation factors (90% to 150% of original duration) to give the correct response. Interestingly, the PD group also judged fast neutral intonations more frequently as frightened, whereas the HC subjects labeled those most often ‘‘angry.’’ For all but the neutral category, the PD patient misclassified slow stimuli (manipulation factors 130% and 150%), independent of the emotional category, more frequently as frightened than the control group. This pattern of performance points to deficient differentiation between emotional categories at fast and slow speech rates in the PD group, classifying all fast and slow emotional stimuli with a greater likelihood than the HC subjects as ‘‘frightened.’’ Furthermore, the HC group benefited to a greater degree from the gradually increasing speech duration across manipulation factors (50% to 150%) for sad intonations. Our findings for the duration discrimination task also pointed to a specific deficit in the PD group, in contrast to their performance to a like pitch discrimination task. Overall, these observations agree with reports by other groups that processing of short time intervals is impaired in PD (Rammsayer & Classen, 1990).

Harrington et al. (1998a) pointed out that dopaminergic replacement therapy does not completely restore dopamine-dependent functions of the brain (particularly in the basal ganglia) and disease severity may be an important factor in the study of temporal perception in PD (see Artieda et al., 1992; Pastor & Artieda, 1996; Ivry & Keele, 1989, did not provide information on disease severity of their PD group). However, performance of PD patients in our speech time processing task did not correlate with clinical ratings of disease severity, nor with disease duration. The lack of correlation may at least partially be due to the greater homogeneity in our PD group compared to previous studies because of the stringent inclusion criteria.

In summary, in both PD and HC groups, duration changes affected the perceptual labeling of prosodic stimuli in a categorical manner, with some qualitative differences. PD patients were less efficient in utilizing temporal changes as a cue to vocal emotion. Our findings point to a deficit in speech time processing in PD, particularly as evidenced for the two emotions ''happy'' and ''sad,'' both of which are associated with longer speech durations in our speaker (see Appendix B) as well as in other reports (see, Banse & Scherer, 1996, for the acoustic correlates of happiness as compared to joy, whereby joy is associated with faster speech).

Manipulation of pitch variation. Overall, manipulation of pitch variation had a weaker effect with respect to influencing the perception of vocal emotions. This is consistent with our cross-cultural findings of acoustic cue utilization using the same design (Breitenstein et al., 2001). For the pitch-varied stimuli, the two groups were not differentially affected across the manipulation factors for specific emotions. Overall, the HC group scored significantly higher in accuracy than the PD group. Confusion errors were similar in both groups with some evidence for a greater reliance on pitch cues in the PD as compared to the HC group. This was also supported by a significant correlation between the prosody task in the English-language and the overall score in the pitch-altered condition for patients with PD, but not the HC subjects. Performance for happy utterances was at chance at all manipulation factors for the PD group. We cannot extrapolate a particular meaning from this result, as the prosodic cues for happy have been found insufficient for performance in other studies using speech synthesis. Happy was the least recognized by American and German subjects listening to the German prosody tape (Breitenstein et al., 2001). Recently, using a similar experimental design, Pell (1998) reported that perception of happy prosody was at or below chance level for both the HC and the patient groups with focal cortical damage when pitch cues were manipulated in emotional prosodic stimuli.

The relatively impaired perceptual utilization of durational cues as compared with pitch cues in the PD subjects reported is consistent with clinical observations of speech in patients with PD, which is unique in its rate disturbance. It is well known that among dysarthrias, increased rate (festination and tachyphemia) is seen only in speech of patients with PD (Canter, 1965; Darley et al., 1975; Weismer, 1997). Therefore, an association of temporal output control with basal ganglia function has long been known. Recent findings by Harrington et al. (1998a) using a nonspeech temporal discrimination task in PD suggest that also in perception, the temporal disturbance transcends speech processes. Impaired durational perception observed in speech tasks in our study and nonspeech tasks both in our and in the Harrington et al. study (1998a) suggest the possibility of a common neural processor in the basal ganglia for production and perception of temporal information. Furthermore, the present data support the assumption of independent processors for pitch and temporal aspects of speech, as has been observed in patients with unilateral focal cortical damage (Baum & Pell, 1997; Ouellette & Baum, 1993; Pell, 1998; Robin et al., 1990; Sidtis & Volpe, 1988; Van Lancker & Sidtis, 1992; Zatorre, 1988).

In another study utilizing synthesized speech (Pell, 1998), across the different emotional categories, the HC group scored on average 45% correct (chance level of 25%) when pitch cues were rendered ''neutral'' (i.e., pitch was not indicative of the target emotion) and on average 65% correct (chance level 25%) when durational aspects of the stimuli were rendered ''neutral'' (i.e., duration was not indicative of the target emotion). Our manipulation procedure resulted in the opposite pattern of performance: HC subjects in the present investigation scored higher in accuracy when pitch as compared to duration was altered (66% versus 55%, respectively), and a comparable pattern was observed in the PD patients. Differences in experimental procedures (''neutralization'' of pitch and duration cues versus systematic variation of these acoustic parameters) may explain the discrepant findings between the studies, and it remains unclear which procedure has higher ecological validity.

Finally, there is recent evidence for a role of specific emotions with respect to amygdala function (fear and anger; see also LeDoux, 1995) in patients with selective bilateral damage to the amygdala [Adolphs, Tranel, Damasio et al., 1994; Adolphs, Tranel, Damasio et al., 1995; Adolphs, Damasio, Tranel et al., 1996; Calder, Young, Rowland et al., 1996; Scott, Young, Calder et al., 1997 (but see Adolphs & Tranel, 1999); Young, Hellawell, Van de Wal et al., 1996; but see also Hamann, Stefanacci, Squire et al., 1996] as well as from recent PET (Morris, Frith, Perrett et al., 1996) and fMRI (Phillips, Young, Senior et al., 1997) studies in normal control subjects. Additionally, there are preliminary reports of especially severe deficits in the recognition of facial and vocal disgust (and to a lesser extent fear) in patients with Huntington's disease (Gray, Young, Barker et al., 1997; Sprengelmeyer, Young, Calder et al., 1996). However, for neither the prosody task in the English nor the German language were emotion-specific impairments incidentally observed in patients with PD in this study. This is in line with previous observations in PD (e.g., Breitenstein et al., 1998; Pell, 1996).

In conclusion, using a structured design, the present study replicated previous reports of impaired perception of emotional prosody in PD (Benke et al., 1998; Borod et al., 1990; Breitenstein et al., 1998; Pell, 1996; Scott et al., 1984). In this study, patients with PD were significantly more distracted by the linguistic meaning of the utterances than the HC group and central executive functioning was significantly correlated with prosodic performance in PD patients. An association of cognitive status and prosody performance was also observed in the study by Benke et al. (1998), who compared PD patients with and without verbal memory impairment. The cognitively impaired group scored significantly lower than the cognitively intact PD group on a test of emotional prosody perception. We propose that cognitive function and perception of emotional prosody are not independent. It could very well be that different cognitive factors contribute to the perception of emotional prosody in different etiologic groups of brain-damaged patients. In addition to impaired cognitive functioning, an acoustic processing deficit was noted in the PD group. The findings for systematic variations of duration and pitch cues in emotional prosodic utterances point to a subtle speech time processing deficit in PD, which may affect patients' ability to correctly classify vocal emotions. These PD subjects also performed significantly worse than the HC group on a simple test of tone duration discrimination. It could be that defective acoustic processing renders PD patients more susceptible to listening to the linguistic sentence meanings.

Future studies should continue the search for additional predictor variables of prosody perception in PD. A potential candidate to explain the remaining variance in the emotional prosody score could be a deficit in the nondeclarative emotional learning or memory system, i.e., the overlearned routine of associating a certain inflection with an emotional attitude of a speaker is impaired in PD.

APPENDIX A
Stimuli Used in the Duration and Pitch Discrimination Tasks

Trial number	Stimulus 1	Stimulus 2
	Duration Discrimination[a]	
01	300 ms	300 ms
02	400 ms	200 ms
03	100 ms	100 ms
04	300 ms	500 ms
05	400 ms	600 ms
06	500 ms	500 ms
07	100 ms	500 ms
08	400 ms	400 ms
09	200 ms	200 ms
10	400 ms	100 ms
	Pitch Discrimination[b]	
01	100 Hz	400 Hz
02	500 Hz	500 Hz
03	200 Hz	300 Hz
04	100 Hz	300 Hz
05	400 Hz	400 Hz
06	500 Hz	750 Hz
07	200 Hz	200 Hz
08	700 Hz	100 Hz
09	200 Hz	750 Hz
10	100 Hz	100 Hz

[a] Frequency of all tones: 500 Hz; interval between stimulus 1 and stimulus 2: 200 ms.

[b] Duration of all stimuli: 1 s; interval between stimulus 1 and stimulus 2: 200 ms.

APPENDIX B
Acoustic Data of the Original Sentences (Pooled across the Four Linguistic Sentence Meanings)

	Mean pitch (in Hz)	Pitch variation (F0-SD/mF0)	Duration (in s)
Happy	209	.19	1.4
Sad	158	.08	1.6
Angry	193	.17	1.6
Frightened	239	.07	0.9
Neutral	162	.15	1.3

Note. F0-SD = standard deviation of F0; mF0 = mean F0.

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