Emotion Processing in Parkinson's Disease: The Role of Motor Symptom Asymmetry

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Preface

Emotion is an essential element of our daily life. We express happiness when something that we consider positive happens, or we get angry when things do not work out in the way we want them to. As social creatures, we are not only confronted with our own emotional reactions, but rather we also continuously encounter emotional expressions in the people we interact with every day. It is important for us to recognize emotions in others quickly and accurately in order to adequately react to them, thereby ensuring successful interpersonal interactions.

What happens, however, if the recognition of other people's emotional expressions does not work properly? And - an even more basic question - how can we experimentally test the integrity of emotion processing functions?

In Parkinson's disease (PD), a very common movement disorder, it is to date widely acknowledged that the *expression* of emotion is disturbed. This deficit concerns, e.g., speech intonation or facial expressions (Bowers et al., 2006; Pell, Cheang, & Leonard, 2006). Furthermore, there is evidence of impaired emotion *processing* in PD (Breitenstein, Daum, & Ackermann, 1998; Kan, Kawamura, Hasegawa, Mochizuki, & Nakamura, 2002; Pell & Leonard, 2003). However, research on this topic has so far primarily relied on behavioral investigations using explicit tasks, e.g., assigning emotion labels to face or voice stimuli. This raises the question as to whether these methods are able to provide adequate measures of emotion processing in PD and in general. One can assume that the validity of these techniques is limited, as only late, controlled processing stages can be captured by them (Pell, 2002). Furthermore, explicit tasks go along with a certain level of task difficulty and may thus be confounded by cognitive dysfunction (Benke, Bösch, & Andree, 1998), which is a frequent symptom in PD (Williams-Gray, Foltynie, Brayne, Robbins, & Barker, 2007).

Apart from these methodological constraints encountered in many previous studies on emotion processing in PD, the disease is often considered a unitary disorder, while there is actually high heterogeneity among patients. One distinctive disease characteristic is the sidedness of motor symptoms. Symptoms in idiopathic PD generally start at one side of the body (Hoehn & Yahr, 1967), and even though both sides become involved at some point during the disease progression, a certain degree of asymmetry remains. Importantly, the basal ganglia of the hemisphere contralateral to the predominantly affected side are more involved in neuronal degeneration (Nahmias, Garnett, Firnau, & Lang, 1985; Tatsch et al., 1997). Thus, considering motor symptom asymmetry in PD could provide novel insight into a possible functional lateralization of the basal ganglia and their respective circuits.

The present thesis aimed to investigate receptive emotional functioning in PD with special emphasis on the sidedness of motor symptoms. The method applied to do so were event-related brain potentials, which provide an excellent temporal resolution. Thus, this method allows describing the precise time course of emotion processing in PD. Furthermore, no explicit task instructions are required, and thus receptive emotional functions in PD can be tested under low task demands and without an attentional focus on emotion. Importantly, in this thesis cognitive functions in the patients were carefully controlled for.

The theoretical part of the present thesis starts with a brief introduction to electroencephalography and the event-related potentials technique (**Chapter 1**). **Chapter 2** then deals with Parkinson's disease, the neural changes which go along with the disease, and the numerous symptoms which can occur in a PD patient. **Chapter 3** and **Chapter 4** are the "emotion chapters", providing a general overview of the emotion literature and of investigations on emotion processing in PD, respectively.

In the empirical part, **Chapter 5**, **Chapter 6**, and **Chapter 7** are devoted to vocal emotion processing (prosody), reporting data from a healthy pilot sample and a patient investigation in PD. **Chapter 8**, **Chapter 9**, and **Chapter 10** take this evidence a step further, presenting data from healthy participants and PD patients on implicit cross-modal emotional priming with dynamic face and voice stimuli.

Finally, the results of the present thesis and the implications of these findings are discussed in **Chapter 11**.

Part I

Theoretical and empirical background

Chapter 1

Event-related potentials

This chapter provides a brief introduction to electroencephalography and scalp-recorded event-related brain potentials, which is the main experimental method used in the present thesis.

1.1 Electroencephalography

More than 80 years ago, the German psychiatrist Hans Berger measured for the first time the electrical activity from a human's scalp surface and introduced the term "electroencephalography" for this procedure (Berger, 1929). Electroencephalography (EEG) is a psychophysiological method which captures the brain's electrical activity, resulting in the electroencephalogram. To this end, electrodes are attached to the scalp surface, which renders the scalp-recorded EEG a non-invasive procedure. Next to the advantage of non-invasivity provided by the EEG, it also stands out for its excellent temporal resolution in the milliseconds-range which cannot be offered other contemporary methods (e.g., fMRI, PET). However, the spatial resolution of EEG is very low compared to other techniques (Birbaumer & Schmidt, 2006). Several source localization algorithms have been developed which can help to get an idea of where the activity actually comes from (see Michel et al., 2004, for an overview), but as these methods are not as precise as, e.g., fMRI, the trade-off between spatial and temporal resolution in neuroscientific methods remains.

The EEG records voltage fluctuations over time from the scalp surface. The main source of oscillations observed in the EEG are excitatory and inhibitory post-synaptic potentials generated in cortical pyramidal neurons (Speckmann & Elger, 2005). In order to cause an oscillation that becomes visible in the EEG, tens of thousands of neurons need to be activated simultaneously (Pizzagalli, 2007). Summation and propagation of neuronal activity in the cortex is facilitated by the perpendicular orientation of these neurons relative to the scalp surface (Coles & Rugg, 1995).

Recording of the EEG is mostly accomplished with metal electrodes, typically silver-silverchloride (Ag/AgCl) electrodes, together with an electrolyte solution to allow for an electron exchange between the skin and the recording electrode (Picton, Lins, & Scherg, 1995). In research environments, it is common to use large arrays of electrodes distributed across the scalp surface. For electrode placement on the scalp surface, Jasper (1958) proposed the 10–20 system. It is based on four fiducial points, namely the nasion, the inion, and two preauricular spots. Along imaginary lines drawn between these points, electrodes are located at certain percentages (10, 20, 50) of these lines, and additional electrodes may be placed halfway in between for high-density EEG recordings. A common nomenclature for the electrode positions was introduced by the American Electroencephalographic Society (Sharbrough et al., 1991). The electrode locations are displayed graphically in Figure 1.1

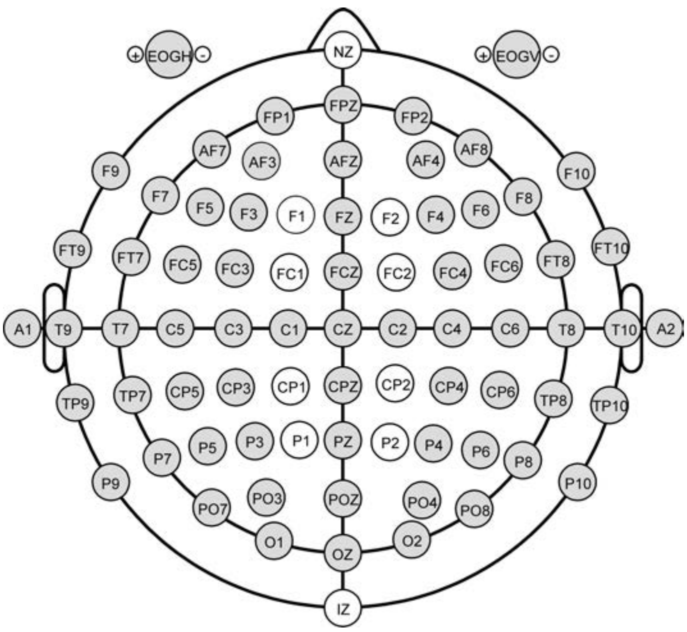

Figure 1.1: Electrode locations in accord with the extended 10–20 system (Sharbrough et al., 1991). Electrodes relevant for the present thesis are shaded in grey.

EEG recordings can be made with either a mono- or a bipolar setup (Pinel, 1997). In monopolar recordings, each scalp electrode is referred to a common site of low electrical activity (the reference), while in bipolar recording, electrodes placed over electrically active sites are linked together by twos. The monopolar setup is most widely used in current research and implies the problem of reference placement. Ideally, this should be a location devoid of any electrical activity, which is not possible (Pizzagalli, 2007). Commonly used references are the ears (mastoid bones or earlobes), the nose tip, or an average reference (see Pizzagalli, 2007, for a discussion of different references and reference-free procedures). What turns out to be an oscillation in the EEG is the difference of activity at a certain scalp channel in relation to the reference.

As the potentials of interest in the EEG are very small, they need to be amplified by a specific device. The amplified signal is then converted from analog to digital at a predefined sampling rate, which indicates how many samples are acquired during a period of time (e.g., a 500 Hz sampling rate would indicate 500 samples per second or a two-milliseconds acquisition rate).

1.2 Event-related potentials technique

The EEG signal is always a composition of signal (stimulus-related) and noise. A common way of increasing the signal-to-noise ratio of a recording is to average it over certain epochs. The idea of averaging is that the cerebral response to a certain stimulus type is comparable over its re-occurrences, while noise is rather randomly distributed over the signal.[1] Thus, by time-locking to the onset of a stimulus and averaging the epochs pertaining to that stimulus, the random noise is averaged out and what becomes visible is a characteristic pattern of waveforms, the event-related potential (ERP). The more trials that are averaged for one condition, the better is the signal-to-noise ratio in the ERPs (Luck, 2005). The ERP is a characteristic pattern of positive and negative peaks and slow waves elicited by the event to which they are time-locked. Figure 1.2 displays how to get from the ongoing EEG to ERPs.

ERPs can be classified into evoked and emitted ERPs, and evoked ERPs can be further subdivided into exogenous and endogenous components (Picton et al., 1995). Exogenous components are thought to be driven mainly by physical stimulus characteristics whereas endogenous components are triggered by the psychological effects of the stimulus, so one may speak of bottom-up and top-down modulated components, respectively. Brainstem potentials, which occur very early after stimulus onset, are considered exogenous, while components occurring at long latencies and reflecting cognitive processes are considered endogenous (e.g., language-related components). Some components may be a mix of endogenous and exogenous processes, such as the N100, and are therefore referred to as mesogenuous (Fabiani, Gratton, & Federmeier, 2007). Emitted ERPs are all endogenous and can be observed, e.g., during the initiation of a response (Picton et al., 1995).

[1]Of course, noise is not always distributed randomly. Noise may be rhythmic, which can be circumvented by variations of the inter-stimulus interval, or noise may be related to the stimulus onset. The latter case mainly occurs in terms of micro-reflexes within the first 80 milliseconds after stimulus onset, which makes the interpretation of very early ERPs difficult (Picton et al., 1995).

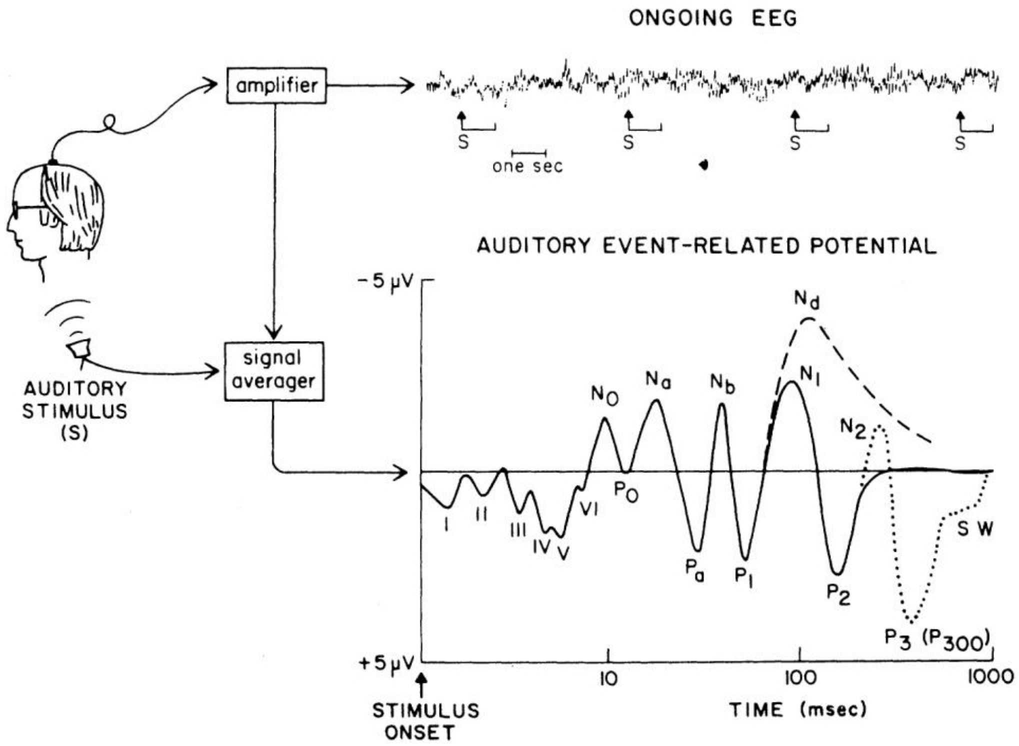

Figure 1.2: How to get from the ongoing EEG to ERPs. Taken from Coles and Rugg (1995), p. 6.

For the majority of ERP components, the nomenclature refers to their typical polarity and peak latency. For example, an N100 would be a negative deflection peaking approximately 100 milliseconds after stimulus onset. Another way of naming the components is according to their polarity and sequential order, e.g. the first positive deflection after stimulus onset would be the P1, the next positive peak would constitute the P2, and so forth. Other components bear their names due to their supposed function, e.g., the mismatch negativity as measure of change detection (Näätänen, Gaillard, & Mäntysalo, 1978) or the Bereitschaftspotential as a signal of motor preparation (Kornhuber & Deecke, 1965). Components with a very variable time course and no clear peak get less specific names, e.g., the slow wave or the late positive potential. It is a widely accepted convention that negative values are plotted upwards and positive values downwards in ERP illustrations (Picton et al., 1995).

Besides the characteristic latency and polarity[2] of many ERP components, they often show typical topographical distributions across the scalp. However, as mentioned above, the spatial resolution of EEG is not very high. Thus, these topographies are not necessarily indicative of the underlying neuronal source. ERPs are mainly generated by cortical

[2]note though that polarity may change as a function of the reference

neurons, but the neurons are not necessarily located below the electrode site from which they are recorded, as summation and propagation across large neuronal populations is necessary to yield oscillations in the EEG (Coles & Rugg, 1995). Furthermore, subcortical sources may also be involved in the generation of ERPs (Pizzagalli, 2007). In a similar way, there may be a great deal of neural activity in the brain which is not reflected in the ERP (Coles & Rugg, 1995).

1.3 Specific ERP components

This section introduces ERP components relevant for the present thesis. More information on these components is provided in chapter 3.

N100/P1. The N100 is an early negativity peaking at a latency of approximately 100 ms (80 – 120 ms) after stimulus onset, with maximal amplitudes over frontal and central electrodes (Rosburg, Boutros, & Ford, 2008). The auditory N100 is presumably generated in the auditory cortex, but there may be contributions from frontal and motor areas to this component, too (Näätänen & Picton, 1987). When there is visual stimulation, the N100 is limited to fronto-central leads, and a P1 is observed at posterior electrodes (e.g., Luo, Feng, He, Wang, & Luo, 2010). Latter component is generated in the visual cortex (V. P. Clark, Fan, & Hillyard, 1994).

N170/VPP. The N170 is a face-related component and follows the P1 at occipital electrode sites. Its amplitude is enhanced to faces compared to other visual stimuli such as houses (Ashley, Vuilleumier, & Swick, 2004; Eimer, 1998). It is thought to reflect configural processing of the face and its neuronal generators are supposed around the fusiform face area (Bentin, Allison, Puce, Perez, & McCarthy, 1996), a region in visual cortex that appears to be specialized for face processing (Kanwisher, McDermott, & Chun, 1997). The N170's fronto-central counterpart is the vertex positive potential (VPP), which occurs with the same latency. It may rely on the same neural generators as the N170 (Joyce & Rossion, 2005), although there is an ongoing debate about this in the literature (e.g., Wong, Fung, McAlonan, & Chua, 2009). Note that the VPP is sometimes termed the P2 (Eimer & Holmes, 2002), P200 (Ashley et al., 2004; Paulmann & Pell, 2009), or P150 (Campanella, Quinet, Bruyer, Crommelinck, & Guerit, 2002).

P200. The auditory P200 is strongest at fronto-central electrodes, and its main generators have been localized in the auditory cortex, some millimeters more frontally than the generators of the auditory N100 (Papanicolaou, Rogers, Baumann, Saydjari, & Eisenberg, 1990). The P200 is a central component in emotional prosody processing, as will be shown in the following chapters.

Later stage negativities. The most classical late negativity is the N400 which was first observed in response to semantic anomalies (Kutas & Hillyard, 1980). It is typically observed within a 300 – 500 ms latency after the onset of such an anomaly. By now, N400-like negativities have been related to many different contexts which go beyond semantics, e.g., enhanced N400 amplitudes have been observed with cross-modal priming in terms of emotional valence (Schirmer, Kotz, & Friederici, 2002, 2005; Zhang, Lawson, Guo, & Jiang, 2006; Zhang, Li, Gold, & Jiang, 2010) or emotional category (Paulmann & Pell, 2010a). In emotional contexts, late negativities in response to incongruencies may sometimes occur earlier than the classical N400 (Bostanov & Kotchoubey, 2004). These negativities are called N400-like, as they may differ from the classical N400 with respect to their time course and topography (Kutas & Federmeier, 2011).

1.4 Summary

We have seen in the present chapter that the EEG methodology provides a means to record brain activity with a very high temporal resolution in the milliseconds range, which allows to specify the precise time course of brain processes. With EEG, these processes can be captured long before a behavioral response occurs. When averaging many EEG epochs together that are time-locked to a certain stimulus type, a characteristic pattern of positive and negative deflections (ERPs) emerges.

Chapter 2

Parkinson's disease

Idiopathic (alternatively: sporadic) Parkinson's disease (PD) makes up 75% of all Parkinsonian syndromes (Iglseder, 2008). The first systematic description of Parkinsonism dates back almost 200 years ago. The author of this influential report called "An essay on the shaking palsy" was the physician James Parkinson (Parkinson, 1817), which is why the disease today bears his name.

Epidemiological data underline the impact of idiopathic PD on our ageing society: Its prevalence in the German population older than 60 years is about one percent, and it rises up to two to three percent in people older than 70 years (Heidbreder & Dominiak, 2010). The disease is 1.5 to 2 times more common in men than in women (Heidbreder & Dominiak, 2010).

2.1 Neuropathological changes in PD

PD primarily affects the basal ganglia (BG). The BG are a group of subcortical nuclei comprising the striatum (caudate and putamen), the substantia nigra (pars compacta and pars reticulata), the subthalamic nucleus, and the globus pallidus (internal and external segment). The striatum is considered to be the major input structure to the BG, while the internal pallidum and the substantia nigra pars reticulata are the major output nuclei of the BG (Wichmann & DeLong, 1996).

2.1.1 The neurodegenerative process

The key mechanism in PD is the degeneration of dopamine-producing neurons in the substantia nigra pars compacta (SNc), most strongly involving its ventrolateral portion. This affects the dopaminergic projection from the SNc to the dorsal putamen (nigrostriatal pathway), leading to striatal dopamine depletion (Lang & Lozano, 1998).

Neurodegeneration starts long before diagnosis. It is estimated that around 15 to 20 years before patients seek medical treatment for emerging motor symptoms, first pathological changes begin to take place at the neural level (Leplow, 2007). However, data on this preclinical phase are controversial and it may actually be shorter than five years (Lang & Lozano, 1998). When first motor symptoms become evident, patients are considered to be already at a later disease stage (Braak & Del Tredici, 2009) with 50 to 70% of the SNc dopaminergic neurons being lost (Lang & Lozano, 1998; Leplow, 2007; Schwarz & Storch, 2007).

Importantly, PD is not exclusively a BG disorder. Rather, it leads to more wide-spread structural changes in the brain (Tinaz, Courtney, & Stern, 2011). In fact, there is evidence that the first pathological processes take place outside the SNc. Braak and colleagues have put forward a six-stage model of pathological changes in PD (Braak et al., 2003, 2006; Braak & Del Tredici, 2008, 2009). According to this model, first pathological changes, i.e., inclusions of pathological Lewy bodies, are observed in the dorsal motor nucleus of the vagal nerve as well as in anterior olfactory structures. In the second stage the disease proceeds towards the lower brainstem, and recently the third stage has been described to involve the SNc as well as the central subnucleus of the amygdala. From the fourth to the sixth stage neurodegeneration gradually proceeds to more structures such as the thalamus, insula, amygdala, and prefrontal regions.

2.1.2 Changes in basal ganglia loops

The BG are heavily interconnected with several brain regions and receive input from virtually the whole cortex (Utter & Basso, 2008). In their seminal article, Alexander, DeLong, and Strick (1986) described five different cortico-striato-thalamocortical loops: the motor, the oculomotor, the dorsolateral prefrontal, the lateral orbitofrontal, and the anterior cingulate loop. These loops originate from the cortex and innervate the striatum through glutamatergic projections (Hammond, Bergman, & Brown, 2007). The signal is then projected back to the cortex via the thalamus. These circuits were originally considered as relatively closed, segregated systems (Alexander et al., 1986). Each circuit innervates a distinct region of the striatum and the existence of further sub-circuits within these five major pathways has been shown, for example in terms of a somatotopic organization of input and output activities within the sensorimotor part of the putamen (DeLong, 2000; Wichmann, DeLong, Guridi, & Obeso, 2011). Nevertheless, it is now assumed that the segregation is not that strong, as the pathways heavily interact with each other through collaterals and via projections within the striatum (DeLong & Wichmann, 2009; Haber & Calzavara, 2009; Saint-Cyr, 2003). Furthermore, the five-circuits model has been expanded by more circuits, e.g., a circuit linking the temporal cortex with the striatum (Middleton &

Strick, 1996, 2000). According to the involvement of the striatum in different circuits, this structure can be roughly divided into a motor (dorsal putamen), a limbic (ventral striatum), and an associative/cognitive (caudate) portion.

In PD, the motor circuit is of major significance to understand the pathology. It originates from different motor fields of the cortex (Wichmann et al., 2011) and projects to the putamen (Alexander et al., 1986), which is the BG region that is most affected by dopamine depletion in PD. Before reaching the thalamus and other brain regions, the striatal medium spiny neurons (MSNs), which are the striatum's projection neurons, project to different loci within the BG. MSNs expressing substance P and D1 dopamine receptors give rise to the direct pathway, while MSNs expressing enkephalin and D2 receptors bring on the indirect pathway (DeLong & Wichmann, 2009; Schwarz & Storch, 2007; Wichmann et al., 2011). The direct pathway consists of a striatal projection to the motor thalamus (ventrolateral and ventromedial portions) via the internal globus pallidus as well as a striatal projection to the substantia nigra pars reticulata. These projections are GABAergic and inhibitory. This reduces the inhibition exerted by the BG on the thalamus. The indirect pathway involves a striatal projection to the external globus pallidus, reaching the internal pallidum either directly or via the subthalamic nucleus. Subsequently, the internal pallidum projects to the thalamus. With the exception of the excitatory glutamatergic subthalamic nucleus output, all projections within the indirect pathway are mainly GABAergic and inhibitory. By activation of the internal pallidum through the subthalamic nucleus, the inhibitory output from the BG to the thalamus increases. While the direct pathway is important for the initiation of movement, the indirect pathway terminates movement (DeLong & Wichmann, 2009). Figure 2.1 graphically illustrates the direct and indirect BG pathways.

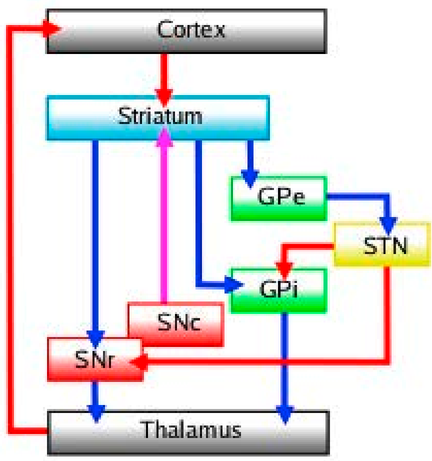

Figure 2.1: Illustration of the classical direct and indirect BG pathways model (Wikipedia, 2005). Blue: GABAergic connections, red: glutamatergic connections, magenta: dopaminergic connection. SNc/r: substantia nigra pars compacta/reticulata, GPe/i: external/internal globus pallidus.

Based on the concept of direct and indirect pathways, a “rate model” of PD has been proposed to explain the motor pathology (Albin, Young, & Penney, 1989; DeLong & Wichmann, 2009; Obeso et al., 2008). In this model, striatal MSNs, which give rise to the indirect pathway become overactive, as dopaminergic inhibition, which normally operates upon these neurons, is reduced. As a consequence of the thus overexcited indirect pathway, the subthalamic nucleus overexcites the internal globus pallidus, increasing the inhibitory activity of the internal pallidum on the thalamus. This is even boosted by a reduced function of the direct pathway. The enhanced inhibition of the thalamus, which leads to hypoactivation of the supplementary motor area, may account for hypokinesia (Braak & Del Tredici, 2008; Grafton, 2004). Today it is clear that the model cannot explain the complete clinical picture of PD. However, due to its simplicity and explicatory value it is still very prominent in the literature. Furthermore, the connections within the BG and between the BG and other brain regions appear to be much more complex than originally assumed (Saint-Cyr, 2003). For example, the somato-motor cortical areas project directly to the subthalamic nucleus (hyperdirect pathway; Hammond et al., 2007), and thalamic signals reach the striatum (Haber & Calzavara, 2009), but these connections are not acknowledged within the classical model. Newer concepts put emphasis on abnormal neural firing and synchronization in the BG in PD. More specifically, it has been suggested that PD goes along with excessive alpha and beta-band oscillations within the motor circuit and abnormally high neuronal synchronization in the BG as well as at the cortical level (DeLong & Wichmann, 2009; Hammond et al., 2007; Wichmann & DeLong, 1996). Importantly, striatal projection neurons seldom fire, which may be a filter mechanism against uncoordinated cortical input (Hammond et al., 2007). In the Parkinsonian state this selection mechanism appears to be disturbed due to reduced dopaminergic inhibition in the striatum, leading to increased BG output (Hammond et al., 2007; Saint-Cyr, 2003).

2.2 Symptomatology in PD

2.2.1 Motor symptoms

PD is a movement disorder as it most strikingly manifests itself in motor symptoms. Four cardinal symptoms have been defined (Schwarz & Storch, 2007):
1) Bradykinesia (sometimes termed hypo- or akinesia), meaning a slowing of voluntary movements, which cannot be attributed to a paralysis,
2) Resting tremor, meaning the involuntary, rhythmic oscillation of body parts, most typically affecting the limbs or jaw. The classical resting tremor has a frequency of four to six Hertz. It is reduced or disappears completely during the execution of voluntary movements,

3) Rigor (or rigidity), which refers to a heightened muscle tone. It can be detected as an increased muscle resistance during the passive movement of body parts, e.g., by the physician, and
4) Postural instability, referring to difficulties in maintaining the adequate body posture during standing and walking, which may lead to falling.
The diagnosis of idiopathic PD requires the presence of bradykinesia, in combination with at least one of the remaining three cardinal symptoms (Schwarz & Storch, 2007). Depending on the degree of severity of each motor symptom, three basic types of PD can be distinguished: tremor dominant, akineto-rigid, and equivalent (Leplow, 2007; Schwarz & Storch, 2007). Other researchers suggest the distinction between a tremor-dominant and a "postural imbalance and gait disorder" subtype, the latter presenting strong akininesia, rigidity, and balance impairments and a very rapid disease progression (Obeso et al., 2010). Thus, these subtypes may be of higher prognostic value than the classical distinction.

Disease severity is often indicated with the popular Hoehn and Yahr scale (Hoehn & Yahr, 1967). The authors defined a total of five disease progression stages ranging from mild, unilateral involvement in stage I up to severe disability in stage V. While the original scheme is limited to these five stages, the newer, modified version allows for 0.5 increments between stages I and III, thereby offering a more fine-grained classification (Goetz et al., 2004). For detailed symptom assessment, the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn & Elton, 1987) is the most commonly used tool.

As evident from the Hoehn and Yahr scale, the first motor symptoms in idiopathic PD become evident unilaterally, i.e., on one side of the body. Even though the symptoms spread to the other body side during the disease progression, they remain stronger at the initial side. Importantly, this asymmetry also involves an asymmetry at the neural level. Post-mortem studies and modern imaging techniques which can visualize striatal dopamine transporter availability converge on stronger neuronal degeneration and dopamine depletion in the BG contralateral to the most affected body side (Morrish, Sawle, & Brooks, 1995; Nahmias et al., 1985; Tatsch et al., 1997). This leads to two PD subgroups: those with stronger left-sided motor symptoms and right-lateralized dopamine depletion (named LPD throughout) and patients with stronger right-sided symptoms, associated with greater left-hemispheric dopamine depletion (in the following abbreviated as RPD). However, despite of this asymmetry at the neural level, the ipsilateral BG are also affected already during early disease stages (Schwarz et al., 2000; Tissingh et al., 1998).

2.3 Non-motor symptoms

Even though PD is a movement disorder, so-called non-motor symptoms associated with the disease have also been reported and are recently gaining increased attention. They may cause significant disability, even more than motor symptoms, which can be dominated relatively well with modern medical treatment (Obeso et al., 2010; Kehagia, Barker, & Robbins, 2010).

Non-motor symptoms can be assigned to four different categories: sensory symptoms, autonomic symptoms, sleep disorders, and cognitive-behavioral symptoms (Pandya, Kubu, & Giroux, 2008). Sensory symptoms comprise, among others, diffuse pain or impairments of the olfactory system. Orthostatic hypotension, abnormal sweating, or gastrointestinal problems represent autonomic symptoms. Sleep disorders encompass phenomena like excessive daytime sleepiness and insomnia. Lastly, cognitive-behavioral symptoms are a very broad category, comprising cognitive dysfunction on the one hand and psychopathological changes on the other. The following paragraphs provide a short overview of how PD may affect cognitive functions.

Cognition Mild cognitive impairment, which may be a precursor of dementia, affects more than 50% of PD patients in the first three to five years after diagnosis (Williams-Gray et al., 2007). Cognitive deficits observed in PD largely converge with impairments exhibited by frontal lobe patients, e.g., concerning planning or attentional set-shifting tasks (Caviness et al., 2007; Owen et al., 1992, 1993). This points to a significant role for the fronto-striatal circuitry, which has been confirmed with fMRI (Lewis, Dove, Robbins, Barker, & Owen, 2003). Especially the dopaminergic function of the caudate nucleus, which is considered the associative division of the striatum and heavily interacts with the frontal lobe, may modulate the performance of PD patients in many cognitive tasks (Jokinen et al., 2009). However, cognitive impairments in PD are not limited to tasks assessing classical frontal lobe functions: deficits in memory, learning, visuo-spatial function, or language have also been reported (M. Grossman, 1999; Kehagia et al., 2010; Zgaljardic, Borod, Foldi, & Mattis, 2003). Anti-Parkinsonergic medication can restore some cognitive functions but may boost deficits in others (Kehagia et al., 2010). The extreme case of cognitive impairment, dementia, affects about 20 – 30% of the PD patients at some point during the disease progression (Pandya et al., 2008).

Asymmetry and cognition RPD and/or increased right motor score have been associated with cognitive dysfunction in several studies (Cooper et al., 2009; Foster et al., 2010; Huber, Miller, Bohaska, Christy, & Bornstein, 1992; Spicer, Roberts, & LeWitt, 1988; Starkstein, Leiguarda, Gershanik, & Berthier, 1987; Williams et al., 2007). However, other studies have associated greater left-sided involvement with cognitive deficits (Katzen, Levin, & Weiner, 2006; Tomer, Levin, & Weiner, 1993; Tomer, Aharon-Peretz, & Tsitrinbaum, 2007) or failed to find group differences (St. Clair, Borod, Sliwinski, Cote, & Stern, 1998; Finali, Piccirilli, & Rizzuto, 1995; Piacentini, Versaci, Romito, Ferré, & Albanese, 2011). One important aspect in this context is the task: It appears that verbal tasks are more likely to reveal deficits associated with right-sided motor symptoms (Amick, Grace, & Chou, 2006; Blonder, Gur, & Gur, 1989; Huber et al., 1992; Spicer et al., 1988; Starkstein et al., 1987), while visuo-spatial deficits are more commonly observed in the case of left-sided motor symptoms (Amick et al., 2006; Cubo et al., 2010; Starkstein et al., 1987; Tomer et al., 1993). This may be due to different functional roles of the left and right striatum and their respective circuits in these tasks (Cronin-Golomb, 2010). Conversely, a recent imaging study associated right-striatal function with performance in a spatial planning task and left-striatal dopamine storage capacity with performance in a verbal memory task in PD patients (Cheesman et al., 2005). However, this dissociation is not always supported (St. Clair et al., 1998). With respect to “classical” executive tasks such as the Stroop task or the Wisconsin Card Sorting Test, there may be an LPD advantage (Cubo et al., 2010; Starkstein et al., 1987), but other studies have failed to reveal sidedness effects in these measures (Cooper et al., 2009; Finali et al., 1995; St. Clair et al., 1998; Tomer et al., 1993, 2007) or support an advantage for patients whose first motor symptom was right-sided tremor (Katzen et al., 2006). Thus, it appears that motor sidedness does not differentially modulate executive deficits in PD. Results concerning sidedness of PD and cognition may further be influenced by medication, which for example deteriorates cognitive flexibility measures in LPD (Tomer et al., 2007). The degree of asymmetry may also play a role, with stronger asymmetry yielding more consistent impairments (Cubo et al., 2010; Tomer et al., 1993). Lastly, there may be a dissociation between grouping the patients into LPD and RPD as compared to correlating left and right motor scores with cognitive variables (Cooper et al., 2009).

2.4 Summary

PD is one of the most common age-related diseases. Its primary manifestation is dopamine depletion in the BG, but the disease is by no means confined to this structure; rather, it may affect wide-spread regions of the brain. The most striking manifestation of the disease are the motor symptoms, e.g., tremor and rigidity, but PD may also affect non-motor functions. For instance, the disease has been associated with a more rapid cognitive decline than would be expected by normal aging. A central characteristic of idiopathic PD is the unilateral onset of motor symptoms, which implies that the contralateral BG are predominantly affected by neurodegeneration and the subsequent dopamine depletion. This asymmetry at the neural level persists throughout the disease even though motor symptoms become bilateral at some point. This sidedness of motor symptoms in PD is one of the central aspects in the present thesis.

Chapter 3

Emotion

3.1 What is emotion?

There have been many attempts to define the term “emotion”, which has turned out to be a difficult endeavor. In a relatively recent intent, Davidson, Scherer, and Goldsmith (2003) wrote: “Emotion refers to a relatively brief episode of coordinated brain, autonomic, and behavioral changes that facilitate a response to an external or internal event of significance for the organism.” (Davidson, 2003, p. xiii). Thus, emotion needs to be differentiated from mood, which is a more diffuse and longer-lasting affective state. Emotion is also different from feelings which may share all parts of this definition, but are the subjective representations of emotion. In the context of individual differences, the term “affective style” is of relevance; it refers to a personal and relatively stable disposition to present with certain emotional reactions or moods towards objects or people, which in early life or in a more genetically-oriented context may be called “temperament”. In addition, there are attitudes which are also quite stable over time and may trigger different affective reactions towards people and objects (Davidson et al., 2003).

Thus, from the definition it becomes apparent that emotions are relatively discrete events in time (unlike diffuse mood states), which go along with an **elicitor**, **bodily changes**, and a **behavioral reaction**. Many authors consider that the **subjective experience** of emotion is also an indispensable element of emotion, but this notion is not always agreed upon (LeDoux, 1996). Likewise, an early influential theory by William James (James, 1884)[3] proposed the revolutionary view that the elicitors trigger a bodily reaction, which then leads to the subjective feeling of emotion. This proposition completely contrasted with commonsense beliefs at that time and also received massive critique from the scientific community. For example, Walter Cannon (1927) reported that the surgical separation of

[3] A similar view was published almost at the same time by Lange in 1885; English version: Lange (1912). Conversely, this view is termed the James-Lange theory.

the viscera from the central nervous system did not lead to a complete loss of emotion. His alternative proposal stated that elicitors trigger processes in the central nervous system, which then lead simultaneously to physiological arousal and the subjective experience of emotion (Cannon, 1927).

Apart from this debate about what exactly triggers and comprises an emotion (which is to date still ongoing), there has also been some controversy in the literature about the classification of emotion. The two main approaches in this realm are the categorical and the dimensional approach. While the categorical approach aims to define a limited set of discrete emotions, the dimensional approach states that each emotion can be located on dimensional scales. A classical dimensional approach comes from Wundt (1908) who suggested that all emotions could be located along the three scales of pleasantness–unpleasantness, calmness–excitation, and tension–relaxation. The two former scales are still widely used and today mostly referred to as valence and arousal. The categorical approach was already advocated by Darwin who suggested a set of universal and innate basic emotions crucial for survival (Darwin, 1872). Many "basic emotion" accounts have followed these first observations, the most popular one published by Ekman (1970). Ekman assumes that there are six basic or primary emotions, namely anger, disgust, fear, sadness, happiness, and surprise. These emotions are considered universal, as they are well recognized from facial expressions across many different cultures, even cultures which have never been exposed to Western influence (Ekman, 1970, 1971; Ekman & Friesen, 1971). The evidence is, however, mixed with respect to surprise, which may not represent a distinctive emotion category (Ekman, 1992).

3.2 Neural basis of emotion perception

Emotion relies on a wide-spread and not yet fully understood network in the brain; however, it would be beyond the scope of the present thesis to specify this whole network. The following sections provide a short overview of regions involved in emotion perception and especially on the possible role of the BG in this process. The issue of hemispheric lateralization during emotional processing is also addressed. More detailed information is then provided in the sections on vocal and facial emotion perception.

3.2.1 Emotion network in the brain

Several parts of the brain have been implicated in emotion processing, with the amygdala constituting probably the most "classical " emotion region. This almond-shaped structure, which forms part of the brain's limbic system, has been originally associated with the emotion of fear. Amygdala damage has been shown to lead to impaired recognition of fear (Adolphs, Tranel, Damasio, & Damasio, 1994; Adolphs et al., 1999) and reduced fear experience (Sprengelmeyer et al., 1999). However, even though the role of the amygdala in processing fearful stimuli is confirmed by several recent neuroimaging studies (for meta-analyses see Costafreda, Brammer, David, & Fu, 2008; Fusar-Poli, Placentino, Carletti, Landi, et al., 2009; Vytal & Hamann, 2010), it is far from exclusive. Rather, the amygdala seems to play a role in a range of different emotions, including positive ones (Sergerie, Chochol, & Armony, 2008). Its role may be that of a "relevance detector" related to novel, motivationally salient and significant stimuli in the environment (Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2011; Pessoa & Adolphs, 2010; Straube, Mothes-Lasch, & Miltner, 2011), which is corroborated by the finding that the amygdala response, especially concerning the right amygdala, habituates rapidly to external stimulation (Wright et al., 2001). The amygdala may be involved in a fast, "low" subcortical emotion road, as well as in a slower and more controlled "high" road, receiving pre-processed information from cortical areas (LeDoux, 1996). Even though this concept has been criticized in that there may be many emotion roads in the brain and that the cortex may play a greater role for emotion than originally assumed by LeDoux's concept (Pessoa & Adolphs, 2010), the significance of the amygdala for emotional processes is indisputable.

Since the famous cases of frontal lobe patients such as Phineas Gage or EVR whose personality and social behavior changed completely as a result of frontal lobe lesions while leaving their intellectual functions intact (H. Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; A. Damasio, 1997), the role of the frontal cortices, especially the orbitofrontal cortex (OFC) in emotion is widely acknowledged. OFC lesion patients have problems in emotion identification (Hornak, Rolls, & Wade, 1996; Paulmann, Seifert, & Kotz, 2010) and show pathological gambling behavior (Bechara, Damasio, Tranel, & Damasio, 1997). It has been proposed that the OFC plays a role in stimulus-reinforcement learning (Rolls, 2000), or that it may be involved in developing "somatic markers" from prior emotional experiences to anticipate the consequences of current behavior (A. Damasio, 1996). Thus, the role of the OFC could constitute the integration of internal and external information to guide behavior and generate adequate emotional responses (Lindquist et al., 2011).

A special role for socially relevant stimuli has been attributed to the temporal lobes. Activity in the posterior superior temporal sulcus (STS) is elicited by biological motion of different types (Grafton, Arbib, Fadiga, & Rizzolatti, 1996; E. Grossman et al., 2000; Puce, Allison, Bentin, Gore, & McCarthy, 1998) and by speech (Belin, Zatorre, Lafaille, Ahad, & Pike, 2000). The temporal cortex, especially the posterior STS, may be a key player in the multimodal integration of social and emotional stimuli (Beauchamp, Lee, Argall, & Martin, 2004; Kreifelts, Ethofer, Grodd, Erb, & Wildgruber, 2007) and in Theory of Mind (Frith & Frith, 2003). The right anterior temporal lobe, as well as frontal areas may cross-modally activate to explicit emotional judgments of stimuli (Lindquist et al., 2011; Schirmer & Kotz, 2006).

Apart from these regions, many other parts of the brain have been implicated in emotion processing, such as the anterior insula (Phillips et al., 1997) or the anterior cingulate cortex (see Phan, Wager, Taylor, & Liberzon, 2004; Etkin, Egner, & Kalisch, 2011, for overviews). Thus, emotion relies on a wide-spread network in the brain. One region that has been classically attributed to motor functions and is recently gaining attention within the context of emotion processing is the BG, which are treated in the next section.

3.2.2 Emotion and the basal ganglia

The function of the BG seems to be much more complex than originally thought; they may play an important role in attention, cognition, and language (Kotz, Schwartze, & Schmidt-Kassow, 2009), and – most importantly for the present thesis – emotion. An early and influential report suggested a connection between BG lesions and impaired emotion recognition (Cancelliere & Kertesz, 1990, see also Starkstein, Federoff, Price, Leiguarda, & Robinson, 1994). Particularly, the BG have been attributed a pivotal role in disgust processing, which they may play in concert with the insula (Calder, Keane, Manes, Antoun, & Young, 2000; see also Calder, Lawrence, & Young, 2001, for a review). These data gathered from patients with BG damage converge with imaging studies implicating the BG in disgust (Phillips et al., 1998; Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998). A very interesting study result even suggests a linear relationship between an individual's disgust sensitivity and the right-striatal reaction to disgust-inducing pictures (Mataix-Cols et al., 2008). However, the BG have also been implicated in the processing of other emotions, and of emotion in general, including positive emotions (Fusar-Poli, Placentino, Carletti, Landi, et al., 2009; Phan, Wager, Taylor, & Liberzon, 2002; Vytal & Hamann, 2010). Thus, their exact significance in emotion processing is not well defined yet, but an involvement of the BG in emotion is quite well established. Due to the dense connections of the striatum with limbic areas, most notably the amygdala, and the motor functions of the BG on the other hand, this structure may serve as an emotional-motor interface regulating rapid motor responses to emotionally salient stimuli (Groenewegen & Trimble, 2007). The possible role the BG may accomplish in vocal emotion and facial emotion processing is treated in sections 3.3.3 and 3.4.3, respectively.

3.2.3 Lateralization of emotion in the brain

Since the early days of emotion research, the topic of hemispheric lateralization has been hotly debated. The most prominent accounts of hemispheric lateralization of emotion are the right hemisphere hypothesis, the valence hypothesis, and the approach-withdrawal hypothesis.

The **right hemisphere hypothesis** (Ross, Harney, deLacoste-Utamsing, & Purdy, 1981; Blonder, Bowers, & Heilman, 1991) posits a general dominance of the right hemisphere in all emotional processes, involving the perception, expression, and experience of emotion independent of valence. Regarding the perceptual aspect, support for this hypothesis is provided by patient studies reporting that right-hemispheric damage leads to deficits in facial and vocal emotion recognition (Adolphs, Damasio, Tranel, & Damasio, 1996; Borod et al., 1998). Likewise, hemifield presentations in the visual domain and dichotic listening in the auditory domain have revealed a left-eye or left-ear advantage, respectively, for the processing of emotional stimuli (corresponding to the right hemisphere; Landis, Assal, & Perret, 1979; King & Kimura, 1972). Neuroimaging studies have also reported greater right- than left-sided activations during emotional processing (Kotz, Meyer, et al., 2003; Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004).

Despite of this evidence supporting the right-hemisphere hypothesis, there are data which would rather be in favor of the **valence hypothesis** (Silberman & Weingartner, 1986). The valence hypothesis assumes hemispheric specialization in the brain as a function of valence, with the right hemisphere dominant for negative emotions, and the left one for positive. For example, emotion recognition after right-hemispheric damage is mostly impaired for negative emotional stimuli, while the recognition of positive emotion is widely preserved (Adolphs et al., 1996). Likewise, hemifield studies of emotional facial expressions reported that the advantage of a certain hemifield may be modulated by valence (Reuter-Lorenz, Givis, & Moscovitch, 1983). However, this valence division may be confined to the frontal lobes (Sutton & Davidson, 2000).

Finally, the **approach-withdrawal hypothesis** (Davidson, 1992, 2003) posits that approach emotions are related to the left hemisphere, while withdrawal draws on right-sided anterior brain structures. Thus, even though there is huge conceptual overlap with the valence hypothesis, differences emerge especially in the case of anger, which is a negative emotion, but normally involves approach behavior and would thus rely on the left rather than the right hemisphere posited by the valence hypothesis.

3.3 Vocal emotion processing

Emotionally intoned speech or prosody comprises, among others, pitch and intensity (loudness) variations and temporal aspects (speech rate) of spoken language (Pell et al., 2006). While faces can be presented in static displays, one inherent characteristic of speech stimuli used for research is that speech is always dynamic and continuously changing over time.

Another characteristic of speech stimuli is that they may be very different, ranging from nonlinguistic vocalizations to single syllables and words up to complete sentences. Semantics may be matching with the emotional intonation or not, or be completely absent as occurs in pseudo-speech or filtered speech. Thus, research on vocal emotion stands out due to its stimulus variability which means that studies may not always be comparable. However, some basic principles could apply to the processing of all kinds of emotional speech stimuli, as will become evident in the following section on models.

3.3.1 Models of vocal emotion processing

Processing the emotional tone from speech consists of three basic steps (Schirmer & Kotz, 2006, see also Kotz, Meyer, & Paulmann, 2006): sensory processing, derivation of emotional significance, and higher cognitive processes. The first step is accomplished in the auditory cortex within the first 100 milliseconds after the onset of a vocal stimulus. It results in the N100 ERP component which is generated by the bilateral secondary auditory cortices, with the right hemisphere sensitive to spectral and the left hemisphere to temporal features of the incoming speech stream. In the second step, which is taken after approximately 200 milliseconds post stimulus onset, emotional significance is derived while the signal gets integrated towards the right anterior superior temporal sulcus. This process is reflected in the P200 component. Finally, from around 400 milliseconds after speech onset, higher order cognitive processes come into play. At this point, inferior frontal and orbito-frontal structures play a major role. The model is displayed schematically in Figure 3.1.

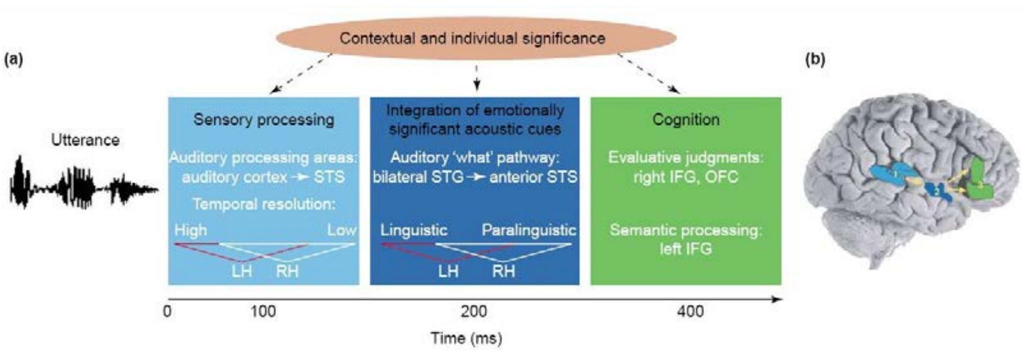

Figure 3.1: Schematic illustration of the emotional prosody processing model proposed by Schirmer and Kotz (taken from Schirmer & Kotz, 2006, p. 25). LH: left hemisphere, RH: right hemisphere, STG/STS: superior temporal gyrus/sulcus, IFG: inferior frontal gyrus, OFC: orbito-frontal cortex.

A model which pretty much converges with Schirmer and Kotz (2006) was proposed by Wildgruber, Ackermann, Kreifelts, and Ethofer (2006; see also Wildgruber, Ethofer, Grandjean, & Kreifelts, 2009): They propose a first extraction of suprasegmental auditory information involving primarily right primary and secondary auditory cortices, a subsequent representation of these suprasegmental sequences in the right posterior STS, and finally, frontal areas mediate task-related cognitive processes.

Belin, Fecteau, and Bédard (2004; see also Belin, Bestelmeyer, Latinus, & Watson, 2011), whose model is directed towards speech perception in general, assume an initial low-level analysis of the speech stream in subcortical nuclei and the auditory cortex. Then, the signal is processed further by three parallel and partly segregated pathways, a speech information pathway, an affective information pathway, and a vocal identity pathway. The affective pathway may rely on medial temporal and inferior prefrontal cortices, the amygdala and the anterior insula, with a predominance of the right hemisphere. When the experimental task is directed towards emotion, inferior frontal and orbito-frontal regions also participate in emotional prosody processing.

Thus, even though the models may differ slightly with respect to the neural correlates involved in emotional speech perception, they converge on the three steps of (1) sensory proces-sing, (2) extraction of emotionally significant cues, and (3) higher cognitive processes. An important role of superior temporal areas in the first two steps and frontal structures during cognitive processing is also assumed by all authors.

3.3.2 Neural correlates and hemispheric lateralization of vocal emotion processing

The role of the auditory cortices and the superior temporal sulci and gyri in vocal emotion perception is an established notion. What is also a quite robust finding is the involvement of frontal cortical areas, most notably the right inferior frontal gyrus, in explicit judgements of emotional prosody when compared to implicit tasks (Beaucousin et al., 2007; Buchanan et al., 2000; Ethofer, Anders, Erb, Herbert, et al., 2006; Wildgruber et al., 2005). However, the role of other structures, especially subcortical ones, has not been well elucidated. Schirmer and Kotz (2006) hypothesized that subcortical regions such as the amygdala or the striatum may operate as early bottom-up instances especially when the prosodic input is of personal relevance or requires immediate behavioral reactions to it. In fact, a fast auditory "low road" has been described for the amygdala (LeDoux, 2000), consisting of auditory nerve – brainstem – medial geniculate nucleus of the thalamus – amygdala. Conversely, a recent MEG study reports very early (around 100 milliseconds post stimulus onset) responses of the auditory cortex to emotional prosody changes (Thönnessen et al., 2010; see also Yagura et al., 2004). This effect may be mediated by the fast thalamic-amygdala pathway. Even though EEG or MEG may not be able to capture amygdala activations per se due to the subcortical location of this structure, it may send signals to the superior temporal cortex via back-projections (Straube et al., 2011), which can then be captured from the scalp surface.

Regarding lateralization of emotional prosody perception in the brain, the picture seems to be much more complex than the one posited by the lateralization hypotheses outlined in section 3.2.3. While right hemisphere damage leads to deficits in emotion recognition from prosody in several studies (e.g., Baum & Pell, 1999; Blonder et al., 1991; Heilman, Bowers, Speedie, & Coslett, 1984; Harciarek, Heilman, & Jodzio, 2006), the right-hemispheric dominance is called into question by neuroimaging studies which imply both hemispheres in emotional prosody processing (Beaucousin et al., 2007; Buchanan et al., 2000; Grandjean et al., 2005; Kotz, Meyer, et al., 2003; Schirmer, Zysset, Kotz, & von Cramon, 2004; Wiethoff et al., 2008). In fact, the right-hemispheric dominance may be rather relative than absolute (Pell, 1998, 2002).

Additionally, as evidenced in neuroimaging studies, several factors may impact on lateralization, e.g., explicit, emotion-related tasks may rely more strongly on the right hemisphere while the opposite is true for different implicit tasks (Buchanan et al., 2000; Ethofer, Anders, Erb, Herbert, et al., 2006; Mitchell, Elliott, Barry, Cruttenden, & Woodruff, 2003; Wildgruber et al., 2005). When lexical information (semantics) is available, then activations also tend to be more left-lateralized as compared to pure prosody (Kotz, Meyer, et al., 2003; Mitchell, 2006). Even the experimental design (blocked versus event-related) may make a difference in terms of lateralization patterns (Kotz et al., 2006). Thus, lateralization of receptive emotional prosody in the brain is a complex issue and may depend on many factors.

A critical point with respect to lateralization may be the time course of prosody processing. As outlined in section 3.3.1, several processing steps need to be considered in which the involvement of the cerebral hemispheres may differ. Emotional salience detection, which occurs approximately 200 milliseconds after the onset of an emotional-prosodic stimulus, is hypothesized to be predominantly mediated by right superior temporal areas (Schirmer & Kotz, 2006). Here, a positive deflection (P200) is observed in the ERP, with an amplitude elicited by neutral prosody that differs from the amplitude elicited by emotional intonations (Paulmann & Kotz, 2008). It has been proposed that the two hemispheres may differ with respect to their temporal resolution, with the left hemisphere tracking fast changes and the right hemisphere tracking slower transitions in speech. This would predestine the left hemisphere for the processing of temporally rapidly-changing linguistic information, and the right hemisphere for spectral information that relies on larger time scales, e.g., pitch transitions (Schirmer & Kotz, 2006; Sidtis & Van Lancker Sidtis, 2003; Zatorre, Belin, & Penhune, 2002). Using emotionally intoned pseudo-words and thus pure prosodic transitions, Thönnessen et al. (2010) could show that the right temporal cortex is more involved than the left even during the first step of emotional prosody processing, which is in line with the proposal by Schirmer and Kotz (2006). This assigns the right hemisphere a dominance over the left during the early stages of vocal emotion processing.

3.3.3 The role of the basal ganglia in vocal emotion processing

Lesions of the basal ganglia have been related to impaired emotion identification from prosody (Cancelliere & Kertesz, 1990; Paulmann, Pell, & Kotz, 2005, 2009; Paulmann, Ott, & Kotz, 2011). Activation of the striatum has also frequently been reported in response to emotional prosody in neuroimaging studies (Bach et al., 2008; Beaucousin et al., 2007; Grandjean et al., 2005; Kotz, Meyer, et al., 2003; Leitman et al., 2010; Morris, Scott, & Dolan, 1999; Phillips et al., 1998; Quadflieg, Mohr, Mentzel, Miltner, & Straube, 2008; Wittfoth et al., 2010). In terms of specific emotions, there is evidence of a striatal involvement for anger (Bach et al., 2008; Grandjean et al., 2005; Kotz, Meyer, et al., 2003; Quadflieg et al., 2008; Wittfoth et al., 2010), fear (Phillips et al., 1998), and happiness (Kotz, Meyer, et al., 2003). As outlined in section 3.2.2, the BG have been repeatedly associated with disgust, but this relation may not be true for prosodically conveyed disgust (Phillips et al., 1998, see also Sprengelmeyer, Schroeder, Young, & Epplen, 2006, for convergent findings in Huntington's disease).

The functional role the BG may accomplish during emotional prosody processing is to date not quite clear. Paulmann et al. (2011) could show that left-striatal lesions do not alter early neural processes of emotional prosody perception; they rather affect later stages of processing (Paulmann, Pell, & Kotz, 2009; Paulmann et al., 2011). Moreover, the striatum may play a special role when prosodic cues are accompanied by semantic information (Kotz, Meyer, et al., 2003; Paulmann, Pell, & Kotz, 2009). Thus, the BG may be involved during cognitive or task-related processing of prosodic stimuli. This is underlined by strong connections between the striatum and the frontal cortices (Alexander et al., 1986), which in turn have been implicated in explicit prosody judgements (Schirmer & Kotz, 2006; Kotz & Paulmann, 2011). Conversely, two recent fMRI studies reported stronger striatal activations during explicit emotional prosody judgements when compared to an implicit task (Bach et al., 2008; Beaucousin et al., 2007). It has been suggested that the BG may accomplish a sequencing function during speech processing, tracking acoustic speech input in terms of pitch, intensity, and the like over time to integrate them into a coherent percept (Kotz & Schwartze, 2010; Kotz, Hasting, & Paulmann, in press; Paulmann & Pell, 2010b). Thus, the BG may be related to late, cognitive processing stages, which rely on the fronto-striatal circuitry.

On the other hand, recent connectivity studies suggest a heavy interaction between the striatum and superior temporal areas (Di Martino et al., 2008; Habas, Guillevin, & Abanou, 2011). More strikingly, increased connectivity between emotion-sensitive superior temporal areas and the right putamen has been observed during listening to emotional prosody (Ethofer et al., 2012). Thus, the possibility that the right striatum modulates the early superior temporal response to emotional prosody cannot be ruled out; however, no available study has tested this issue. In fMRI, temporal resolution is not high enough to determine at which processing stages this cortical-subcortical interaction may take place; a model to study this open question would be the use of time-sensitive ERPs together with patients who suffer from right-striatal damage.

3.4 Emotion perception from faces

Face stimuli are widely used in the emotion literature. As opposed to most prosodic stimuli, they are independent of language. Thus, the same face stimuli may be used across different countries, which has led to several standardized face databases. The oldest (and still widely used) database is the Ekman faces (Ekman & Friesen, 1976). Other popular sets of emotional face stimuli are the NimStim (Tottenham et al., 2009) or the Karolinska databases (Lundqvist, Flykt, & Öhman, 1998). Even though photographs of facial expressions are easy to use and the available databases render high comparability across different studies, these stimuli are not very natural, as we normally encounter moving and dynamic facial stimuli in daily life. Dynamic facial stimuli are advantageous over static ones in that they are easier to recognize, especially in the case of non-prototypical expressions (Ambadar, Schooler, & Cohn, 2005; Bould & Morris, 2008), and they yield more wide-spread neural activation patterns, most notably in temporal cortical regions, which points to their higher social relevance (Kilts, Egan, Gideon, Ely, & Hoffman, 2003; LaBar, Crupain, Voyvodic, & McCarthy, 2003; Sato et al., 2004; Trautmann, Fehr, & Herrmann, 2009).

3.4.1 Models of facial emotion processing

A seminal model of face perception was proposed by Bruce and Young (1986). It was aimed to describe face perception in general and included an element called "expression analysis", which targeted the emotionality of a face. This process was proposed to be largely separated from other mechanisms of face processing, especially facial identity analysis. By the time the model was developed, cognitive neuroscience was still in its infancy, and the dissociation of identity and expression analysis was mainly based on findings in prosopagnosia patients who could not recognize the identity of a face, but still performed well in expression recognition tasks. Today, it is widely acknowledged that this strong separation concept cannot be maintained (Schweinberger & Soukup, 1998; Young & Bruce, 2011).

In a more recent model which is based on Bruce and Young (1986), Haxby, Hoffman, and Gobbini (2000) distinguish between unchangeable aspects of a face which are related to identity, and changeable aspects such as eye gaze or facial expression, related to social communication. The model involves a core system and an extended system. The core system is the basis of face perception and is related to the visual analysis of stimuli. It is hierarchically organized and consists of a route from the inferior occipital cortex to the lateral fusiform gyrus (computing the unchangeable aspects of a face), and from the inferior occipital cortex to the STS (computing the changeable aspects). The extended system contains regions which may additionally be recruited during face processing. These comprise additional temporal regions, the intraparietal sulcus, and, most importantly in the context of emotion, the amygdala, insula, and the limbic system in general. The authors propose a coordinated interaction between these regions during face processing (Haxby et al., 2000; Haxby, Hoffman, & Gobbini, 2002).

A model which specifically targets the processing of emotion from faces and furthermore provides a detailed time course of processing was proposed by Adolphs (2002b). In this framework, the first 120 milliseconds comprise the early, structural encoding of the stimulus which corresponds to the core system proposed by Haxby et al. (2000). Here, highly salient stimulus features are processed which is accomplished by subcortical and brainstem structures (superior colliculus, thalamus, amygdala) feeding into the striate visual cortex. In the second step occurring around 170 milliseconds after stimulus onset, the recognition modules (Haxby et al.'s extended system) come into play to lead to more detailed emotion perception and prepare an emotional reaction. This step involves projections from the striate cortex to numerous loci, e.g., the superior temporal gyrus (STG), amygdala, OFC, or BG. Finally, beyond 300 milliseconds, more cognitive processing steps are accomplished, retrieving conceptual knowledge about facial emotion. Here, the fusiform face area, the STG, the OFC, and somatosensory regions, especially the insula, are thought to be involved. Figure 3.2 shows a graphical display of Adolph's model.

Another specific model with respect to the time course of processing emotional faces was proposed by Luo et al. (2010). It involves three different steps: The first step, which is accomplished in the first 100 milliseconds, consists of an automatic processing of negative valence and the detection of potential threat, particularly from faces expressing fear or anger. The most relevant neural correlate at this point in time is the OFC which modulates the response of the extrastriate visual cortex, probably mediated by the amygdala. The second step, which occurs after 200 milliseconds, involves a differentiation between neutral and emotional stimuli and primarily involves the fusiform gyrus. In the third step, which occurs after 300 milliseconds and beyond, a further affective evaluation takes place and different emotion categories are distinguished at the neural level. As the model was derived from implicit tasks, it does not contain a cognitive component.

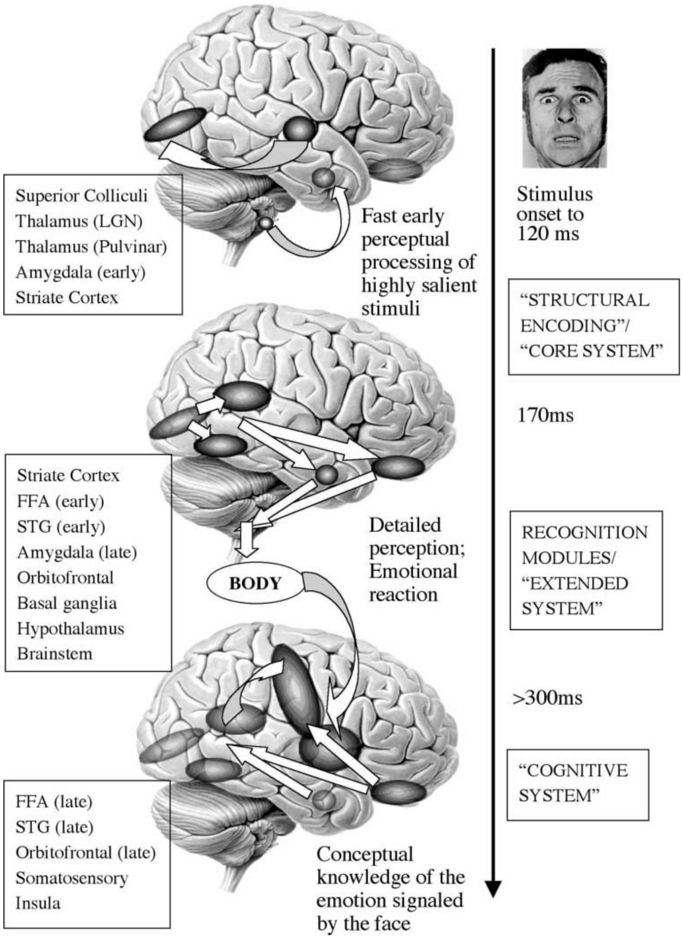

Figure 3.2: Schematic illustration of the emotional face processing model proposed by Adolphs (taken from Adolphs, 2002, p. 52). LGN: lateral geniculate nucleus, FFA: fusiform face area, STG: superior temporal gyrus.

3.4.2 Neural correlates and hemispheric lateralization of facial emotion processing

As indicated by the models of emotional face processing, there may be very early emotion effects, even before configural processing of the face and before the emotion is recognized. In fact, ERP studies have reported a modulation of the very early components N100 and P1, which both occur with a latency of approximately 100 milliseconds after stimulus onset at fronto-central and posterior electrode sites, respectively (Batty & Taylor, 2003; Eimer & Holmes, 2002; Luo et al., 2010; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005). Especially coarse visual information relying on magnocellular visual pathways may be engaged at this stage (Pourtois et al., 2005). Conversely, these early effects have been ascribed to the influence of a fast, subcortical pathway or "low road" from the superior colliculus via the pulvinar nucleus of the thalamus to the amygdala, feeding into visual cortical areas (Vuilleumier & Pourtois, 2007).

The most characteristic ERP component during face processing is the N170, a negative component over posterior electrode sites which peaks approximately 170 milliseconds after face onset, accompanied by the VPP at fronto-central electrodes. Several studies report an N170/VPP modulation by facial emotion (Ashley et al., 2004; Batty & Taylor, 2003; Luo et al., 2010). Converging neuroimaging evidence indicates stronger reactions of the fusiform face area, where the N170 is supposedly generated (Joyce & Rossion, 2005), to emotional as compared to neutral stimuli (Fusar-Poli, Placentino, Carletti, Landi, et al., 2009). This may explain the observed emotion effects in the N170.

Following the N170/VPP, different components can be observed, such as the N2 (or N300), early posterior negativity (EPN; Schupp, Junghöfer, Weike, & Hamm, 2003), or the late positive potential (LPP), which all have been observed to be modulated by the emotionality of a face (Van Strien, De Sonneville, & Franken, 2010). Especially the EPN may be the visual counterpart to the prosodic P200 and reflect emotional salience detection (Schupp et al., 2003), although this role could be accomplished by an earlier component, the VPP (Paulmann & Pell, 2009).

With respect to lateralization of facial emotion processing, no clear picture has emerged. On the one hand, a left visual field (and thus right hemisphere) advantage is widely supported by studies using hemifield presentations of visual emotional stimuli (see section 3.2.3). On the other hand, right-lateralization is not convincingly suggested by activation patterns in imaging studies (Fusar-Poli, Placentino, Carletti, Allen, et al., 2009). However, as already discussed in the context of emotional prosody, lateralization patterns may rely on many factors and on the structure one is looking at. For example, the right temporal cortex appears to be consistently more involved in emotional face processing than its left counterpart

(Sabatinelli et al., 2011). On the other hand, the right amygdala may be more involved than the left one in subconsciously perceiving facial expressions than during conscious processing, whereas the opposite is true for the left amygdala (Costafreda et al., 2008). Thus, even though there may be a certain dominance of the right hemisphere, the picture seems to be much more complex.

3.4.3 The role of the basal ganglia in facial emotion processing

The BG have been repeatedly associated with processing disgust from faces, a role which they may accomplish in concert with the insula. Compelling evidence associates BG damage with impaired disgust recognition from faces (Calder et al., 2000; Hennenlotter et al., 2004; Sprengelmeyer et al., 1996, 2006), and neuroimaging studies have reported BG activations to facially conveyed disgust (Phan et al., 2002; Phillips et al., 1998; Sprengelmeyer et al., 1998; Vytal & Hamann, 2010). However, even though a great deal of evidence of a BG involvement in facial disgust processing has accumulated, it is unlikely that the BG are disgust-selective. For example, in a study by Calder, Keane, Lawrence, and Manes (2004), lesions of the ventral striatum most consistently impaired anger recognition from faces, and to a lesser extent prosody. One BG patient from that study was selectively impaired for disgust and not for anger; however, his lesion was differently located than in the other patients and additionally involved the insula. Thus, there is a considerable association between disgust perception from faces and the BG, but the significance of the BG in facial emotion perception most certainly goes beyond disgust, as already discussed in section 3.2.2.

3.5 (Cross-modal) emotional priming

This last part of the emotion chapter deals with emotional priming by social stimuli (face and voice). The emphasis lies on cross-modal effects, but as experimental evidence on this issue is still sparse, the topic of within-modality effects is also touched upon.

3.5.1 Priming: the basics

In a nutshell, priming refers to how one stimulus (the prime) affects the processing of another one (the target). To test this, the congruency between prime and target is manipulated, for example in terms of matching or mismatching emotional categories or valence. The basic assumption is that prime-target congruency should facilitate the processing of the target. At the behavioral level, this is manifested in reduced reaction times and error rates for congruent trials in comparison to incongruent trials.

One prominent account of priming is the **spreading activation** account (Bower, 1991; Fazio, Sanbonmatsu, Powell, & Kardes, 1986). It assumes that by processing the prime, the underlying concept of that prime is activated in the brain, and this spreads to related concepts or "nodes". Thus, the processing of a congruent target becomes easier, as it was already pre-activated by the prime.

Another well-known approach to priming is the **affective matching** account which postulates that both prime and target automatically trigger evaluative processes, and these evaluations are compared in terms of their affective consistency. In terms of behavioral reactions, the feeling of evaluative compatibility should facilitate affirmative responses and thus lead to shorter reaction times (Klauer & Musch, 2003).

3.5.2 Emotional priming

Emotional congruency between different facial expressions can modulate ERP responses already around 100 milliseconds after target onset, and thus very early (Dai, Feng, & Koster, 2011; Werheid, Alpay, Jentzsch, & Sommer, 2005). Likewise, Pourtois, de Gelder, Vroomen, Rossion, and Crommelinck (2000) reported that the emotional congruency of a face prime with a vocal target affected the N100, which was greater in amplitude when the vocal stimulus was congruent than when it was incongruent to the facial prime. Thus, emotional congruency between social stimuli may be detected very early, even before the target emotion is recognized. Other emotional priming studies using facial and vocal stimuli report congruency effects in the P200 (Pourtois et al., 2000; Pourtois, Debatisse, Despland, & de Gelder, 2002) and in an N400-like component (Paulmann & Pell, 2010a). Especially the N400 seems to be consistently modulated by prime-target congruency in the ERP literature on cross-modal priming testing different modalities (Goerlich, Witteman, Aleman, & Martens, 2011; Schirmer et al., 2002, 2005; Steinbeis & Koelsch, 2011; Zhang et al., 2006, 2010).

In the behavioral literature, emotional congruency manipulations between vocal primes and facial targets have also yielded consistent priming effects (Pell, 2005; Pell, Jaywant, Monetta, & Kotz, 2011). Generally, it is assumed that short prime durations below 300 milliseconds give rise to automatic processes, whereas longer prime durations reveal more controlled processes (Hermans, De Houwer, & Eelen, 2001; Klauer & Musch, 2003). However, when emotional prosody constitutes the prime it probably needs a certain duration to appropriately establish context. At the behavioral level, 300 milliseconds are not enough to lead to cross-modal priming effects (Pell, 2005). In the ERP a 200 milliseconds duration of the prosodic prime led to reversed priming effects while a 400 milliseconds duration revealed the classical N400-like pattern, with greater amplitudes to incongruent as compared to congruent voice-face pairs (Paulmann & Pell, 2010a). Thus, prime modality seems to play an additional role in cross-modal priming. In any case, it is striking that a prosodic prime duration of 200 ms already induced congruency effects, even though these were reversed. This converges with emotion effects in the P200 when processing emotional prosody (e.g., Paulmann & Kotz, 2008). Cross-modal priming may also add to the debate of dimensional versus categorical emotion accounts, as recently shown by Jaywant and Pell (2012), whose data support emotional priming in terms of categories rather than valence.

3.6 Summary

To sum up, emotion is not only a complex term when trying to define it, but its processing at the neural level is also quite complex. For example, the classical lateralization hypotheses (right hemisphere, valence, and approach-withdrawal hypothesis) may be too simple to describe lateralization patterns in emotion perception. A relative right-hemispheric dominance in emotion processing is, however, often supported by actual research findings. Several experimental manipulations such as task or speech intelligibility in the case of vocal stimuli may play a role for lateralization patterns. Important to acknowledge is also the accumulating evidence of a BG involvement in emotional processing, which will be furnished further in the upcoming chapter on emotion processing in PD.

Chapter 4

Emotion perception in PD

Ever since the BG have not only been linked with motor but also cognitive functions, research on nonmotor aspects of the BG has increased. One model of impaired BG function is offered by Parkinson's disease. The following chapter deals with what is to be considered the heart of the present thesis, i.e., emotion processing in PD.[4] While it is well established that PD impairs the expression of emotion, both through face and voice (Bowers et al., 2006; Pell et al., 2006), data on receptive emotion are somewhat inconclusive. In the following, the pertaining literature on this topic is reviewed and integrated.

4.1 Perception of vocal emotion in PD

A considerable amount of research on receptive emotional prosody in PD has accumulated during the last three decades. However, even though this research output is very informative, what is still lacking are studies considering the (early) neural mechanisms of vocal emotion processing in PD. While categorization, discrimination, or rating of emotional prosody is widely used in PD research, there is only one ERP study and no fMRI or PET experiments on this topic.

The ERP study was published by Schröder et al. (2006). The authors used an oddball procedure in which the neutrally intoned name "Anna" served as standard, and happy and sad intonations of the same name were presented as rare deviants. The oddball was ran once with a passive instruction to elicit the mismatch negativity (MMN), a measure of pre-attentive change detection, which is calculated as the amplitude difference between deviants and standards. Another block was run with an active instruction, having participants catego-

[4]Studies assessing this topic with patients receiving deep-brain stimulation (DBS), a common treatment for advanced PD, are considered only if data on the pre-operative state or of a non-DBS PD control group are available. Even when the DBS is turned off, operated patients may not be comparable to non-operated patients, probably due to lesions induced by the surgery (Biseul et al., 2005; Okun et al., 2009).

rize the emotional prosody of each stimulus to assess the P3b, a measure of voluntary attention allocation. In the passive task, patients showed an overall reduced MMN amplitude, and there were no emotion-specific effects, even though numerically the MMN was especially reduced for the sad stimuli. Visual inspection of the data plots suggests that this MMN reduction is due to higher P200 amplitudes to sad and happy stimuli in the PD compared to the healthy control (HC) group, leading to a reduced difference between the ERP amplitudes elicited by emotional and neutral stimuli in PD. In the active block, the P3b to happy prosody was reduced in amplitude in PD patients, and they additionally showed reduced behavioral hit rates for happy and sad intonations. The MMN data indicate that PD may lead to alterations during emotional prosody processing in the time window of emotional salience detection. However, these group differences should be treated with caution as no emotion-specific effects were evident. Along these lines, the neutral stimuli were only used as standards but not as deviants, leaving open the possibility that more general deficits in pre-attentive change detection in PD account for the results (see Brønnick, Nordby, Larsen, & Aarsland, 2010; Vieregge, Verleger, Wascher, Stüven, & Kömpf, 1994, for reduced MMNs to tones in PD). The P3b finding is more indicative, suggesting a deficit in PD to voluntarily allocate attention towards happy prosody at later, more cognitive processing stages.

Numerous behavioral studies report impairments for receptive emotional prosody in PD (Ariatti, Benuzzi, & Nichelli, 2008; Benke et al., 1998; Breitenstein et al., 1998; Breitenstein, Van Lancker, Daum, & Waters, 2001; Dara, Monetta, & Pell, 2008; Pell, 1996; Pell & Leonard, 2003; Péron, Grandjean, et al., 2010; Schröder et al., 2006; Scott, Caird, & Williams, 1984; Yip, Lee, Ho, Tsang, & Li, 2003). However, there are also some studies which do not report any group differences (Blonder et al., 1989; U. S. Clark, Neargarder, & Cronin-Golomb, 2008; Kan et al., 2002; Mitchell & Bouças, 2009). This may partly be due to the degree of the disease progression and cognitive impairment (Benke et al., 1998; Blonder et al., 1989; Breitenstein et al., 1998, 2001; Mitchell & Bouças, 2009; Pell & Leonard, 2003). An influence of cognitive impairment, however, emphasizes that explicit categorization and the like do not measure "pure" emotional prosody processing; rather, they may be subject to confounds with cognitive impairments and dysfunction of the fronto-striatal circuitry, as often observed in PD (see section 2.3). Along these lines, semantic information matching the emotional tone of a stimulus may facilitate emotion recognition in PD (Dara et al., 2008; Paulmann & Pell, 2010b; Pell & Leonard, 2003), probably by means of a reduced cognitive load. Moreover, it appears that impairments are generally higher for recognition or discrimination tasks than for studies using rating, which may induce less cognitive load than other tasks; however, this is limited by the low number of available studies which use rating procedures (Gray & Tickle-Degnen, 2010). One factor which may also play a role for the observed deficits is sequencing. As discussed in section 3.3.3, the BG may accomplish a sequencing function during the processing of emotional prosody. In line with this, one study (Breitenstein et al., 2001) reports that PD patients have problems in using speech rate information to correctly identify emotional prosody. Another study on emotion processing in PD from different emotional communication channels (face, semantics, and prosody) which were presented both in isolation and in combination, revealed that PD patients – as opposed to controls – virtually did not benefit from the presence of prosodic information in addition to the other channels, while they considerably benefitted from available facial as well as semantic information (Paulmann & Pell, 2010b). Thus, PD may lead to problems in the interpretation of dynamically changing prosodic patterns (Pell & Leonard, 2003; Pell & Monetta, 2008).

With respect to discrete emotion categories, the picture is not yet clear. Several studies report specific behavioral deficits for negative emotions in PD (Breitenstein et al., 1998; Dara et al., 2008; Pell & Leonard, 2003; Péron, Grandjean, et al., 2010; Schröder et al., 2006; Yip et al., 2003), and a recent meta-analysis confirmed this observation reporting the highest effect sizes for anger and disgust deficits and a significantly higher effect size for negative than positive emotion impairments in PD, a result derived from facial and vocal emotion categorization studies as a whole (Gray & Tickle-Degnen, 2010). On the other hand, there are studies reporting specific deficits for happy prosody in PD (Ariatti et al., 2008; Breitenstein et al., 1998, 2001; Schröder et al., 2006), and it must also be kept in mind that there is only one positive emotional category (although sometimes surprise is also considered a positive emotion, e.g., Gray & Tickle-Degnen, 2010) while there are several negative emotional categories, thus the likelihood to observe deficits for negative as compared to positive emotions is generally higher.

To date, the possible impact of motor sidedness in PD on receptive emotional-prosodic processes has not been well elucidated, as this factor has been widely neglected in the literature. Ariatti et al. (2008) reported happiness-specific impairments in LPD and a deficit for disgust in RPD. The data from Yip et al. (2003) concur with this disgust deficit in unilateral RPD and suggest an additional sadness deficit in this group. LPD patients were not part of that study. On the other hand, two studies which also looked at motor symptom asymmetry reported no LPD-RPD differences; however, both studies also generally failed to report any vocal emotion recognition impairments in PD (Blonder et al., 1989; U. S. Clark et al., 2008). In line with a possible association of linguistic deficits and RPD (see also section 2.3), Blonder et al. observed that RPD patients had problems to use stress pattern information from linguistic prosody. In Ariatti et al.'s (2008) study, however, both PD groups presented with impairments of receptive linguistic prosody, i.e., the discrimination of intonation patterns. The impairment was slightly more pronounced in RPD than LPD, though. Thus, the influence of sidedness in receptive emotional prosody processing in PD is to date unclear and has been widely neglected in research.

To sum up, the data on emotional prosody processing in PD are still equivocal with respect to the presence of deficits per se, the emotion specificity of these deficits, and the influence of motor symptom asymmetry. What is especially problematic is that all but one study use techniques which can only capture later stage processes while early neural mechanisms remain largely unexplored. Besides the possible confound with cognitive variables in the classical tasks, there may be a dissociation between the early neural response to emotional prosody and late, explicit emotional decision-making. In fact, such an early-late dissociation has previously been reported in combined ERP and behavioral studies testing lesion patients (Paulmann et al., 2010, 2011), and in PD it has been observed using emotional pictures (Wieser et al., 2006). Thus, a lot remains to be done to shed more light on emotional prosody processing in PD.

4.2 Perception of facial emotion in PD

A great deal of behavioral studies is available on facial emotion processing in PD. Research in this domain is a little more advanced than for emotional prosody, as some ERP and imaging studies have been published to complement and broaden the findings from behavioral research.

A very recent ERP study comes from Wieser et al. (in press): The authors presented PD patients and HC with photographs of emotional facial expressions (anger, disgust, fear, happiness, sadness, and neutrality) in a passive viewing paradigm. While the early components P1 and N170 were comparable among the groups, PD patients failed to show an amplitude differentiation between neutral and emotional faces in the EPN. This result indicates that emotional salience detection from faces may be compromised in PD while early perceptual and structural face processing appears to be intact.

An fMRI study with fearful and angry faces suggests that the amygdala may account for facial emotion processing deficits in PD (Tessitore et al., 2002): PD patients in the off-state did not show significant amygdala activations during emotional face processing whereas the HC group did. However, in that study the amygdala activation was reinstated after dopaminergic treatment. This is in contrast to another study which – with the same paradigm – observed comparable amygdala activation between patients and controls in the off state, but in both experimental groups the administration of levodopa led to reduced right amygdala activation (Delaveau et al., 2009). This is a puzzling result, as medication appears to have beneficial effects in one study and detrimental consequences in another. Delaveau et al. discuss that this may be due to patient characteristics and different disease progression between the two samples. They further consider that in their study only levodopa was administered in order to compare the effects of levodopa in PD with levodopa effects in HC. In Tessitore et al.'s study, patients took their normal medication including also dopamine agonists, which may lead to different results. One factor not discussed by Delaveau et al. is the possible association between stimulus novelty and amygdala activation (e.g., Lindquist et al., 2011): Tessitore et al. used only a small set of stimuli, which were repeated several times during the study. By contrast, no stimulus was repeated in the study by Delaveau et al. Thus, amygdala activation was generally more likely in latter experiment and ceiling effects may account for the findings. What may also have played a role in Delaveau's study is the placebo effect, as participants did not explicitly know whether they were on medication or not. Additional evidence on the neural basis of facial emotion perception in PD comes from an ERP study using source localization, in which medicated PD patients failed to show an amygdala response to fearful faces (Yoshimura, Kawamura, Masaoka, & Homma, 2005).

Taken together, it is to date unclear whether possible receptive emotional deficits in PD may be related to the amygdala and how this may be influenced by medication. Looking beyond the amygdala, there is one fMRI study on the processing of emotional gestures in PD, accompanied by facial expressions (Lotze et al., 2009). The authors report reduced activations of the right STS and left prefrontal regions in response to emotional gestures in PD patients withdrawn from their dopaminergic medication. As the left prefrontal activation correlated with dopamine transporter availability in the left striatum, the authors hypothesized that dopaminergic medication may reduce these differences between patients and controls, a hypothesis that still needs to be tested.

Behavioral studies on receptive facial emotion in PD have yielded contradictory results: Deficits are supported by several studies (Ariatti et al., 2008; Blonder et al., 1989; Breitenstein et al., 1998; U. S. Clark et al., 2008; U. S. Clark, Neargarder, & Cronin-Golomb, 2010; Dujardin, Blairy, Defebvre, Duhem, et al., 2004; Herrera, Cuetos, & Rodríguez-Ferreiro, 2011; Ibarretxe-Bilbao et al., 2009; Jacobs, Shuren, Bowers, & Heilman, 1995; Kan et al., 2002; Lawrence, Goerendt, & Brooks, 2007; Martins, Muresan, Justo, & Simão, 2008; Sprengelmeyer et al., 2003; Subramanian, Hindle, Jackson, & Linden, 2010; Suzuki, Hoshino, Shigemasu, & Kawamura, 2006), whereas other researchers report an intact performance in PD patients (Adolphs, Schul, & Tranel, 1998; Biseul et al., 2005; Caekebeke, Jennekens-Schinkel, van der Linden, Buruma, & Roos, 1991; Dara et al., 2008; Dujardin, Blairy, Defebvre, Krystkowiak, et al., 2004; Le Jeune et al., 2008; Pell & Leonard, 2005; Péron, Biseul, et al., 2010; St. Clair et al., 1998; Wieser et al., in press). Thus, the picture is quite heterogeneous. Gray and Tickle-Degnen (2010) reported in their meta-analysis that emotional face discrimination and categorization tasks are more likely to reveal deficits in PD than ratings; however, this finding may be skewed as not many rating studies are available. In any case, this points again to the possible role of task demands in these studies. This is underlined by an fMRI study using voxel-based morphometry in PD (Ibarretxe-Bilbao et al., 2009): Performance on the widely used Ekman 60 faces task was significantly correlated with OFC volume in PD patients. This points to the impact of the fronto-striatal circuitry in explicit emotion tasks.

Furthermore, the face processing studies in PD suggest an important influence of medication. For example, Sprengelmeyer et al. (2003) compared a group of early, untreated PD patients with a group of more advanced, medicated patients. Latter group outperformed the former in recognizing disgust from facial expressions and also showed less performance differences with the HC group. A similar picture emerges from two studies by Dujardin et al. (Dujardin, Blairy, Defebvre, Duhem, et al., 2004; Dujardin, Blairy, Defebvre, Krystkowiak, et al., 2004), with the advanced but medicated group showing no difference compared to controls, but a generalized emotion recognition impairment in the early, unmedicated sample. Furthermore, only one of the studies reporting intact facial emotion recognition performance in PD tested patients withdrawn from medication (Caekebeke et al., 1991), and deficits are reported in two further studies assessing performance in facial emotion tasks in the off-state (Lawrence et al., 2007; Martins et al., 2008). These data indicate that anti-Parkinsonergic medication may have a beneficial effect in explicit tasks on receptive facial emotion in PD. However, even though in the meta-analysis by Gray and Tickle-Degnen (2010) the effect sizes for behavioral deficits were higher in the hypodopaminergic as compared to a dopamine-replete state, this difference was not significant.

With respect to a more generalized versus an emotion-specific deficit, the picture to date is mixed. Several studies report deficits for specific facial emotion expressions in PD (Ariatti et al., 2008; U. S. Clark et al., 2008, 2010; Ibarretxe-Bilbao et al., 2009; Kan et al., 2002; Lawrence et al., 2007; Martins et al., 2008; Sprengelmeyer et al., 2003; Suzuki et al., 2006). The deficits most frequently affect disgust, anger, or fear, and thus negative emotions. In contrast, no study reveals deficits for facial expressions conveying happiness. This may be attributed to a ceiling effect, as happiness is normally very easily recognized from facial expressions (Kan et al., 2002; Paulmann & Pell, 2011).

Concerning sidedness of the disease, only five studies have considered this factor. No effect of sidedness was evident in two studies (Blonder et al., 1989; St. Clair et al., 1998). However, both studies had very small trial numbers and thus may not provide sufficient sensitivity to detect group differences. Ariatti et al. (2008) reported a specific deficit in recognizing sad faces in LPD and fearful faces in RPD. In contrast, another study reported that LPD led to anger recognition impairments while RPD was associated with deficits in recognizing surprise from faces (U. S. Clark et al., 2008). This result was replicated in a subset of the original sample by U. S. Clark et al. (2010). Thus, it is to date completely unclear if and how motor symptom asymmetry may affect facial emotion recognition in PD.

Notably, in one study (Kan et al., 2002), dynamic face stimuli were used in addition to static ones. Even though patients exhibited a deficit in recognizing fearful and disgusted facial expressions from the video stimuli, they significantly benefitted from dynamics. While the recognition of happy expressions was always at ceiling, the dynamic displays improved anger, disgust, and sadness recognition in PD. Unfortunately, no statement on a possible motion benefit in the HC group was made in that study. This would be interesting as some authors have suggested that static face displays trigger motor simulation processes in the perceiver in order to recognize the emotion (Jabbi & Keysers, 2008), which may be reduced due to motor impairments in PD. Thus, if PD patients showed a higher motion benefit than controls, this could indicate that the simulation process induced by static facial displays may play a role in facial emotion recognition deficits in PD.

In summary, the research on facial emotion perception in PD is to date largely limited to behavioral studies while the neural correlates and time course of this process have not been well elucidated. Nevertheless, the ERP study by Wieser et al. (in press) provides important evidence of a possible deficit in decoding the emotional significance from faces in PD, as revealed by EPN alterations, and motivates further research.

4.3 Emotional priming in PD

This title may be misleading, as there is virtually no work on emotional priming in PD. One study used complete unintelligible sentences in emotional intonation as primes and facial expressions of emotions as targets (Pell & Dara, 2007). Participants decided whether the target face displayed an emotion or not (Facial Affect Decision Task). Intact priming was observed in PD with this task, while explicit emotion recognition from prosody was impaired in the same group of patients (Pell & Dara, 2007). This, again, points to the importance of task demands in PD. Another study addressed classical affective priming (i.e., with visually presented words and valence manipulations) in patients with electrodes implanted in the subthalamic nucleus (Castner et al., 2007). When the stimulator was turned off, which is most comparable with pre-surgical patients, an affective priming effect was observed in PD patients. However, HC exhibited slower reaction times to negative than neutral targets, independent of congruency, which was not the case in patients. Note though that operated patients may behave differently than non-operated patients, even off stimulation (Biseul et al., 2005; Okun et al., 2009).

4.4 Summary

Regarding the behavioral data on emotion processing from face and voice in PD, it appears that the presence of deficits in the patients is more straightforward regarding prosody than face. The meta-analytic data by Gray and Tickle-Degnen (2010) support this notion, with higher effect sizes reported for vocal than facial emotion tasks. Pell and Leonard (2005) discussed that this may be due to the proposed sequencing function of the BG which is necessary for emotional prosody processing. It must also be considered that emotion recognition from faces is generally easier than from speech intonation (Paulmann & Pell, 2011). As explicit emotion tasks may also tap general cognitive functions and rely on the integrity of the fronto-striatal circuitry (Breitenstein et al., 1998), the cognitive confound for prosody recognition may be higher than for face recognition due to the higher difficulty level. In any case, the findings from explicit emotion tasks may not converge with early neural mechanisms of emotional processing (Paulmann et al., 2010, 2011; Wieser et al., 2006). The available ERP studies suggest that processing emotion from faces (Wieser et al., in press) and vocal cues (Schröder et al., 2006) may be affected during the early emotional salience detection stage in PD, but more research on this topic is clearly needed.

Part II

Experiments

Chapter 5

Experiment 1: Vocal emotion

Experiment 1 aimed to shed more light on the early neural mechanisms of vocal emotion processing from an ERP perspective. It has previously been shown that emotional prosody elicits reduced amplitudes compared to neutral intonation in the P200 ERP component (Paulmann & Kotz, 2008; Paulmann, Schmidt, Pell, & Kotz, 2008). This early emotion discrimination at the neural level has been termed "emotional salience detection" (Paulmann & Kotz, 2008). It has also been reported that this early emotional salience detection can be observed in the absence of semantics, i.e., in unintelligible speech providing only a prosodic contour (Paulmann, 2006). Even though the P200 is reduced in amplitude to unintelligible speech (Paulmann, 2006), which indicates that its processing may differ from natural, semantic speech, this observation indicates that pure prosody is able to elicit emotional salience detection.

What has to date hardly been tested are the possible effects of task instructions on early emotional salience detection. While task-related processing is thought to take place at later processing stages (Schirmer & Kotz, 2006), it would be conceivable that the experimental task may have an impact on early processes in terms of attention allocation to the prosodic stimuli. According to one study, emotional salience detection from prosody was observed earlier during implicit than during explicit processing (Wambacq, Shea-Miller, & Abubakr, 2004). In latter study, single words whose intonation could be either of neutral or negative valence were used. Thus, apart from testing whether the task effects in that study can be replicated in the present study, Experiment 1 aimed to transfer them to sentence context and more emotional categories, including positive emotion.

Another aim of the present investigation was to test for emotion effects even before the P200, as the literature on facial emotion processing suggests that a coarse emotion evaluation - in most cases related to rapid detection of stimuli associated with potential threat - may take place earlier in time (Eimer & Holmes, 2002; Luo et al., 2010; Pourtois et al., 2004, 2005). In the prosody domain, sparse evidence points to such early effects (Thönnessen et al., 2010; Yagura et al., 2004), but more evidence on this issue is surely warranted. Thus, the N100 will be of interest in the present study.

Chapter 6

Experiment 1A – Pilot study

The pilot study aimed to replicate and extend the findings from previous studies on the early neural modulations during emotional prosody processing (Paulmann, 2006; Paulmann & Kotz, 2008; Paulmann, Schmidt, et al., 2008). Specifically, the possible influence of an explicit versus an implicit task needed to be explored.

To this end, the present study utilized previously employed intelligible and unintelligible prosodic stimuli (Paulmann, 2006; Paulmann & Kotz, 2008) in five different intonations (angry, disgusted, fearful, happy, and neutral). In line with prior evidence, it was hypothesized that emotionally intoned stimuli should be differentiated from the neutral intonation in the P200 component. Furthermore, emotional salience detection was also predicted for the unintelligible stimuli, which, however, should lead to generally lower P200 amplitudes than intelligible material.

Additionally, the present study aimed to explore two things: (1) whether explicit versus implicit task instructions affect emotional salience detection in the P200 and (2) whether the early threat detection effects reported in some facial emotion processing studies (e.g., Luo et al., 2010) can be observed for prosody. An analysis of the N100 component should shed some light on this issue.

6.1 Methods

6.1.1 Participants

Thirty-five volunteers took part in the pilot experiment. Seven participants had to be excluded from the sample due to excessive artifacts or poor behavioral performance (criterion: less than 50% of trials left for at least one of the two tasks). The remaining sample of 28 participants included 13 women. Participants had a mean age of 24.29 years (SD = 2.30, range = 20 – 30), reported normal hearing abilities and normal or corrected-to-normal vision. All were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971), with a mean laterality quotient of 93.14 ($SD = 8.91$, range = 70 – 100). None reported any history of neurological or psychiatric illness and none was taking medication known to affect the central nervous system. Participants were paid seven Euros per hour for their effort.

6.1.2 Stimulus material

The stimulus material consisted of sentences produced by one male and one female speaker, both semi-professional actors. Sentences were recorded in German speech and in an unintelligible speech version (pseudo-speech), which matched the phonotactic rules of German. The syntactic structure was identical for all sentences. Speakers were instructed to produce the sentences in one of four emotional intonations (anger, disgust, fear, or happiness) or in a neutral tone. Semantic content, if available, matched the emotional intonation of all sentences. The material was normalized and digitized at a 16-bit/44.1 kHz sampling rate. Sentence duration was around three seconds. Prior studies have successfully used these stimuli (e.g., Paulmann et al., 2010, 2011). For each emotional category and intelligibility condition, 30 sentences were selected according to their recognition rates assessed in prior categorization studies. Lexical sentences used in the present experiment were recognized at the following rates: anger 99% ($SD = 2.69$), disgust 98% ($SD = 3.30$), fear 80% ($SD = 11.26$), happy 80% ($SD = 8.45$), and neutral 88% ($SD = 10.84$). Recognition rates for unintelligible sentences were: anger 94% ($SD = 7.07$), disgust 78% ($SD = 20.27$), fear 74% ($SD = 18.90$), happy 70% ($SD = 8.31$), and neutral 90% ($SD = 15.42$). The 30 sentences per category (15 per speaker) added up to 240 emotional sentences in total. Furthermore, 240 neutral sentences were presented (120 per speaker, 50% unintelligible), resulting in 480 sentences. As only 50 neutral sentences per speaker and intelligibility condition were available, 10 of these 50 sentences were repeated. This high amount of neutral sentences (50% of the stimuli) was necessary to balance the unequal proportion of negative (3 categories) and positive emotional sentences (1 category) in the present study. Examples of the stimuli are available in Table 6.1.

6.1.3 Procedure

The EEG was acquired during two sessions separated by one week. In each EEG session, all 480 trials were presented in a pseudo-randomized order determined by one of four possible randomization lists, which were equally distributed across participants. Two different task instructions were used: The implicit task (IT) was a language-related task in which participants were asked to decide whether a sentence was in German or not. The explicit

Category		Sentences
anger	lexical	Er hat das Paar gereizt und aufgebracht.
		He has teased and upset the couple.
	pseudo	Hung set das Raap geleift ind nagebrucht.
disgust	lexical	Er hat die Hygiene vernachlässigt und gestunken.
		He has ignored the hygiene and smelled.
	pseudo	Hung set die Quadrul verinlussigt ind gepfunken.
fear	lexical	Sie hat das Messer geschliffen und gezogen.
		She has sharpened and whipped out the knife.
	pseudo	Mon set das Bakobi gedellen ind gezagen.
happiness	lexical	Er hat die Prüfung bestanden und gejubelt.
		He has passed the exam and cheered.
	pseudo	Hung set die Pillant gestöngen ind gekobelt.
neutral	lexical	Sie hat die Speisen erhitzt und angeboten.
		She has heated and offered the meals.
	pseudo	Mon set die Galuppe itzmitzt ind ingebaten.

Table 6.1: Example sentences used in Experiment 1.

task (ET) was related to emotion; participants were instructed to decide whether a sentence conveyed an emotional intonation or not. Thus, both of the tasks required that half of the trials were answered with "yes" and half with "no" responses. One session always involved both tasks; the change occurred in the middle of a session. Half of the participants started with the IT and half with the ET task, respectively. The sequence of the two tasks was reversed in session 2. For 50% of the participants, the left button was the "yes" button and "no" responses were submitted with the right button; the other 50% proceeded vice versa. The measurement took place in an electrically-shielded, sound-attenuated EEG chamber. Participants sat in a comfortable chair at a distance of approximately one meter from the screen.

Trials were as follows: A white fixation cross appeared at the center of a black background for 1000 ms. Then, the sentence was presented via two loudspeakers, one at the left and one at the right side next to the monitor. The cross remained on the screen until the end of the stimulus. Then, the question ("German or not German?" for the IT or "Emotional or not emotional?" for the ET) was flashed on the screen for 300 ms. Response time, indicated by a white question mark on a black background, was limited to 1500 ms. The inter-trial-interval (black screen) lasted for 1500 ms, and then the next trial started. Participants were asked to refrain from blinking during sentence presentation to avoid artifacts. The 480 trials were divided into eight blocks (60 trials per block). Total run-time per session was about one hour.

6.1.4 Data acquisition and analysis

Sixty-one Ag/AgCl electrodes mounted in an elastic cap were used to record the EEG from the scalp. The electrode locations following the nomenclature of the American Electroencephalographic Society (Sharbrough et al., 1991) were: FPZ, FP1, FP2, AFZ, AF3, AF4, AF7, AF8, FZ, F3, F4, F5, F6, F7, F8, F9, F10, FCZ, FC3, FC4, FC5, FC6, FT7, FT8, FT9, FT10, CZ, C1, C2, C3, C4, C5, C6, T7, T8, CPZ, CP3, CP4, CP5, CP6, TP7, TP8, TP9, TP10, PZ, P3, P4, P5, P6, P7, P8, P9, P10, POZ, PO3, PO4, PO7, PO8, OZ, O1, O2 (cf. Figure 1.1, for a graphical display of these locations). The acquisition was realized with a bandpass between DC and 70 Hz and a sampling rate of 250 Hz. An average reference was used during the recording. Offline, the data were re-referenced to the linked mastoids. Vertical and horizontal electrooculograms (EOG) were recorded bipolarly from above and below the right eye and bilateral outer canthi, respectively. The ground electrode was placed on the sternum. Electrode resistance was kept below five kΩ. To improve data quality and remove slow drifts, the continuous EEG data were filtered with a bandpass from 0.5 – 30 Hz offline (1785 coefficients, Blackman window). A 10 Hz highpass filter was applied for graphical display only.

Only correctly-answered and artifact-free trials entered the analysis. Artifact rejection was accomplished in two steps: First, an automatic rejection algorithm identified trials, in which the EOG electrodes or CZ exceeded an amplitude of 30 or 40 V, respectively. The data were then scanned manually to detect additional artifacts.

For statistical purposes, seven topographical regions of interest (rois) were set up as follows: left-frontal (LF; F7, F5, F3, FT7, FC5, FC3), left-central (LC; T7, C5, C3, TP7, CP5, CP3), left-posterior (LP; P7, P5, P3, PO7, PO3, O1), right-frontal (RF; F8, F6, F4, FT8, FC6, FC4), right-central (RC; T8, C6, C4, TP8, CP6, CP4), right-posterior (RP; P8, P6, P4, PO8, PO4, O2), and midline (ML; AFZ, FZ, FCZ, CZ, CPZ, PZ, POZ, OZ). The data were averaged over 1800 ms time-locked to sentence-onset. A 200 ms pre-stimulus baseline was applied. The N100 was analyzed from 90 – 150 ms after stimulus onset. For the P200, a time window between 190 – 300 ms post stimulus-onset was identified. A 5 (emotion) x 2 (intelligibility) x 2 (task) x 7 (roi) repeated-measures ANOVA was conducted using the general linear model procedure (proc GLM) in SAS 8.02. All these factors were treated as within-subjects factors, and the ERP amplitude was the dependent variable. As there were more neutral trials than trials per emotional condition, Type II Sums of Squares were requested in the ANOVA (Langsrud, 2003) to better handle the unbalanced design. The ten neutral sentences per speaker which were repeated in the experimental halves (see

Section 6.1.2) were not included in the statistics. Greenhouse-Geisser corrected *p*-values were used where necessary to correct for nonsphericity in the data. Main effects of roi are not reported here, as this factor in isolation is not of interest to the present study. In case of a significant main effect of emotion, contrasts of the neutral condition against each emotion were computed. As this calculation involved four comparisons, the Bonferroni-adjusted significance level was $p < .0125$. Effect sizes were calculated using ω^2 (Olejnik & Algina, 2003).

The behavioral data were also analyzed statistically. This was limited to percent-correct rates, as the fixed and delayed response window did not permit an analysis of reaction times. A repeated-measures ANOVA with three within-subjects factors was calculated in a 5 (emotion) x 2 (intelligibility) x 2 (task) model. Percent-correct rate was the dependent variable.

6.2 Results

6.2.1 Behavioral data

On average, participants answered 94% of the trials correctly ($SD = 9.70$), indicating a very high performance. All effects in the omnibus ANOVA were significant, which can be seen in detail in Table 6.2. To characterize the emotion main effect, all emotional categories

Effect	df	F	p	ω^2
Emotion	4,108	**18.83**	$<$ **.0001**	**.181**
Intelligibility	1,27	**4.47**	$<$ **.044**	**.058**
Task	1,27	**47.71**	$<$ **.0001**	**.455**
Emotion x Intelligibility	4,108	**6.43**	$<$ **.001**	**.052**
Emo x Task	4,108	**24.81**	$<$ **.0001**	**.142**
Intelligibility x Task	1,27	**6.43**	$<$ **.018**	**.046**
Emotion x Intelligibility x Task	4,108	**16.10**	$<$ **.0001**	**.073**

Table 6.2: Results of the omnibus ANOVA on percent-correct rates, Experiment 1A.

were contrasted against the neutral baseline. Percent-correct rates for neutral (95%) were significantly higher than for disgust (92%), $F(1,27) = 12.01$, $p < .002$ and happy (89%), $F(1,27) = 14.96$, $p < .001$. Anger was the category with the highest percent-correct rate (97%), and the difference with neutral was significant, $F(1,27) = 7.77$, $p < .01$. Fear (96%) was comparable to neutral, and there was no significant performance difference between these two conditions ($p > .282$).

The intelligibility main effect was caused by higher percent-correct rates for unintelligible (94%) than intelligible (93%) speech. Moreover, performance in the IT (97%) was significantly higher than in the ET (90%) (main effect of task).

The emotion x intelligibility interaction was tested by means of an emotion-wise intelligibility main effect. It was significant for happiness, $F(1,27) = 11.10$, $p < .003$ and neutral, $F(1,27) = 6.10$, $p < .021$. While for the happy intonation, performance was better in the unintelligible condition than in the intelligible condition (91% versus 87%), the opposite pattern applied for neutral (95% versus 96%). Intelligibility exerted no significant influence on task performance in the angry ($p > .970$), disgusted ($p > .107$), or fearful ($p = .453$) speech conditions.

Task affected the participant's performance in four emotion conditions (emotion x task interaction), pronounced in a main effect of task for disgust, $F(1,27) = 31.19$, $p < .0001$, fear, $F(1,27) = 13.33$, $p < .002$, happy, $F(1,27) = 46.81$, $p < .0001$, and neutral, $F(1,27) = 7.22$, $p < .013$. In all cases, percent-correct rates were higher for the IT compared to the ET. Anger performance was generally at ceiling, with no significant impact of task ($p > .247$).

To analyze the intelligibility x task interaction, the main effect of intelligibility was tested task-wise. There was a significant main effect of intelligibility in the ET, $F(1,27) = 6.52$, $p < .017$, with higher performance for unintelligible (92%) than intelligible (89%) speech. In the IT, performance was at ceiling and the influence of intelligibility was not significant ($p > .368$).

Finally, the three-way interaction was tested through an emotion-wise intelligibility x task interaction. This interaction turned out significant only in the case of happy intonations, $F(1,27) = 29.17$, $p < .0001$. Further step-down analyses returned a significant main effect of intelligibility for both the ET, $F(1,27) = 19.97, p = .0001$ and IT, $F(1,27) = 9.47$, $p < .005$. Unintelligible happy sentences were recognized better than intelligible ones in the ET (87% versus 75%). The opposite was true during implicit processing, with better performance for intelligible than unintelligible speech (98% versus 96%), even though performance in both conditions was at ceiling. The step-down analysis yielded no significant intelligibility x task interaction for anger ($p > .269$), disgust ($p > .146$), fear ($p > .366$), or neutral ($p > .064$).

6.2.2 ERP data

Results of the omnibus ANOVAs are presented in Table 6.3.

N100. For the emotion main effect, post-hoc contrasts revealed a significantly lower N100 amplitude for the fearful than for the neutral intonation, $F(1,27) = 9.27$, $p < .006$. No

		N100 (90 – 150 ms)			P200 (190 – 300 ms)		
Effect	df	F	p	ω^2	F	p	ω^2
E	4,108	**3.54**	$<$ **.009**	**.051**	**38.71**	$<$ **.0001**	**.486**
I	1,27	**5.49**	$<$ **.027**	**.074**	**53.96**	$<$ **.0001**	**.486**
T	1,27	0.09	$>$ .374	-.002	1.10	$>$ .303	.002
E x I	4,108	1.84	$>$ .126	.011	**5.61**	$=$ **.001**	**.052**
E x T	4,108	0.71	$>$ .584	-.003	1.03	$>$ .385	.000
I x T	1,27	0.33	$>$ .570	-.006	2.16	$>$ .153	.010
E x R	24,648	**1.99**	$<$ **.004**	**.006**	**4.34**	$=$ **.001**	**.022**
I x R	6,162	**2.19**	$<$ **.047**	**.007**	**10.56**	$=$ **.0001**	**.049**
T x R	6,162	1.42	$>$ .210	.002	**4.46**	$<$ **.018**	**.017**
E x I x T	4,108	0.16	$>$ .960	-.005	0.69	$=$ .552	-.002
E x I x R	24,648	**1.90**	$<$ **.007**	**.003**	1.75	$>$ .103	.003
E x T x R	24,648	1.39	$>$ .104	.001	1.00	$>$ .429	.000
I x T x R	6,162	0.84	$>$ .544	-.001	1.09	$>$ .350	.000
E x I x T x R	24,648	1.27	$>$ .175	.001	0.86	$>$ .531	-.000

Table 6.3: Results from the omnibus ANOVAs, Experiment 1A. E = Emotion, I = Intelligibility, T = Task, R = Roi.

significant difference emerged between angry and neutral ($p > .474$), disgust and neutral ($p > .865$), or happy and neutral intonations ($p > .184$). The emotion main effect is depicted in Figure 6.1.

To scrutinize the emotion x roi interaction, a main effect of emotion was observed at roi LC, $F(4,108) = 4.58$, $p < .005$, ML, $F(4,108) = 3.80$, $p < .015$, RF, $F(4,108) = 3.48$, $p < .017$, and RC, $F(4,108) = 3.73$, $p < .019$. At roi LC, fear elicited significantly smaller amplitudes than neutral, $F(1,27) = 14.95$, $p < .001$, while anger ($p > .812$), disgust ($p > .189$), and happy ($p > .723$) did not significantly differ from neutral. The same observation accounted for roi RC. Fear differed significantly from neutral, $F(1,27) = 7.62$, $p < .011$, but there was no significant difference between neutral and anger ($p > .457$), neutral and disgust ($p > .627$), or neutral and happy ($p > .043$) when adopting the Bonferroni-adjusted p-value ($p < .0125$). At roi ML, the picture was also comparable: While the amplitude difference between fear and neutral was significant, $F(1,27) = 9.77$, $p < .005$, this was not true for anger ($p > .365$), disgust ($p > .954$), or happy ($p > .326$). The emotion main effect was, however, characterized differently at roi RF. Happy intonations elicited significantly lower N100 amplitudes than neutral ones, $F(1,27) = 11.84$, $p < .002$, while the neutral-fear difference did not survive Bonferroni correction ($p > .029$). Comparable to the other rois, neither the anger-neutral difference ($p > .986$) nor the disgust-neutral difference ($p > .163$)

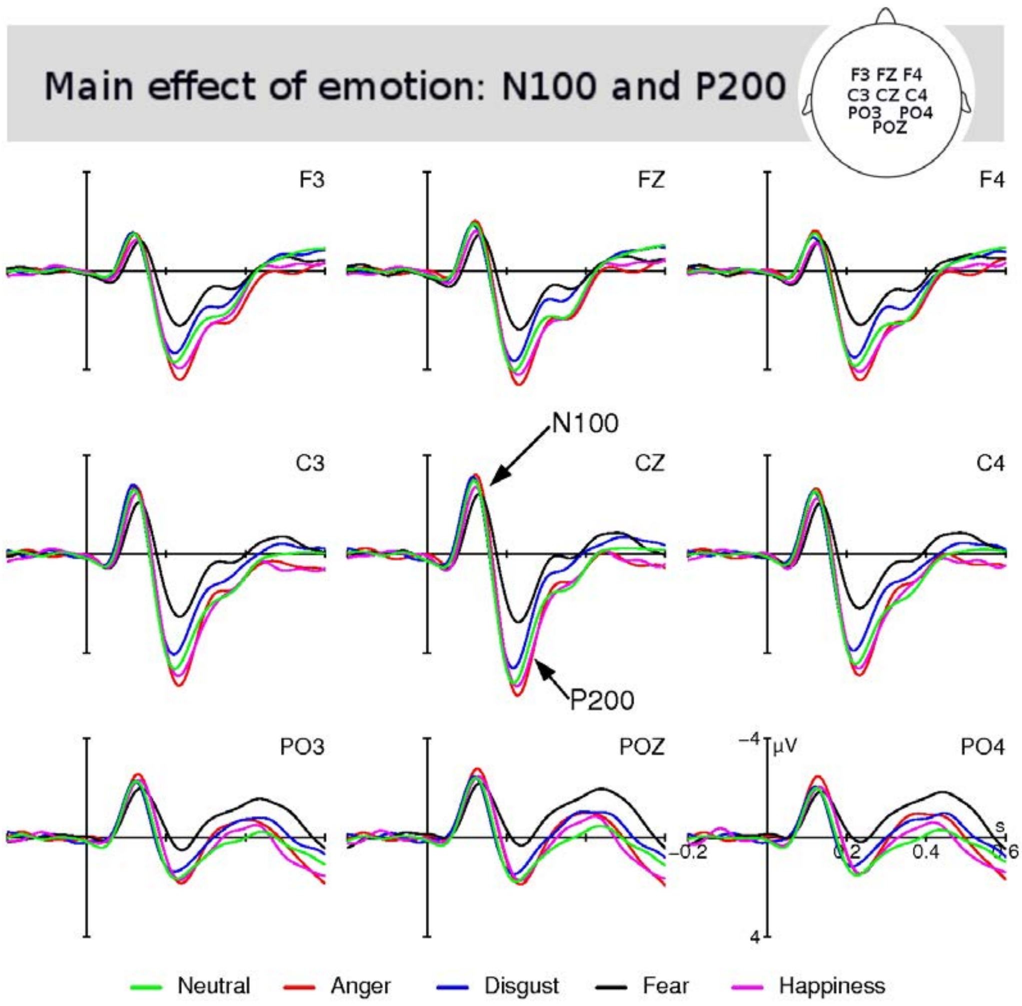

Figure 6.1: Main effect of emotion, Experiment 1A.

were significant. The main effect of emotion did not prove significant at roi LF, $F(4,108) = 1.77$, $p > .160$, LP, $F(4,108) = 2.13$, $p > .105$, or RP, $F(4,108) = 2.48$, $p > .076$.

The intelligibility main effect was pronounced in higher N100 amplitudes to intelligible than unintelligible speech. This effect is depicted in Figure 6.2.

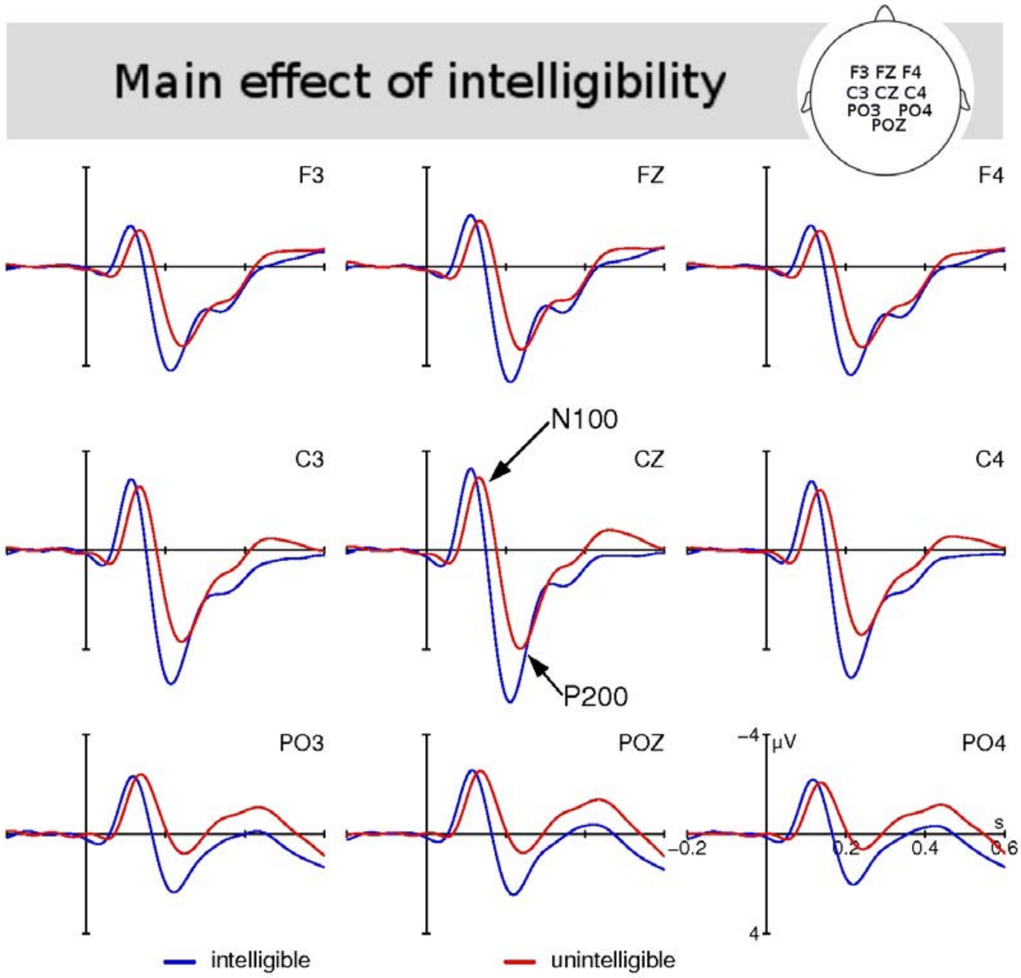

Figure 6.2: Main effect of intelligibility in the N100 and P200, Experiment 1A.

The analysis of the intelligibility x roi interaction revealed a main effect of intelligibility at roi LC, $F(1,27) = 5.28$, $p < .030$, RF, $F(1,27) = 4.45$, $p < .045$, RC, $F(1,27) = 11.18$, $p < .003$, and RP, $F(1,27) = 5.19$, $p < .031$. At each of these rois, the N100 amplitude to intelligible speech was higher than to unintelligible. No significant intelligibility effect emerged at roi LF ($p > .081$), LP ($p = 0.369$), or ML ($p > .080$).

Finally, the emotion x intelligibility x roi interaction was analyzed. In a first step, the significance of the emotion x intelligibility interaction was tested at each roi. This interaction was significant at two right-sided rois, namely RC, $F(4,108) = 3.54$, $p < .013$, and RP, $F(4,108) = 2.96$, $p < .031$. To test which emotional intonations were affected by intelligibility, a second step-down analysis was performed at these two rois. At roi RC, an main effect of intelligibility was observed for the disgusted $F(1,27) = 11.40$, $p < .003$, and the neutral intonation $F(1,27) = 21.73$, $p < .0001$. In turn, no significant intelligibility effect emerged for anger ($p > .618$), fear ($p = .564$), or happy ($p > .490$). A comparable pattern applied to roi RP, with intelligibility being significant in the case of disgust $F(1,27) = 8.14$, $p < .009$, and neutral $F(1,27) = 11.64, p = .002$, but not for anger ($p > .919$), fear ($p > .876$), or happy ($p = .790$). The N100 amplitude was higher for intelligible compared to unintelligible disgust and neutral stimuli at these rois. The emotion x intelligibility interaction was not significant at roi LF ($p = .724$), LC ($p > .163$), LP ($p > .090$), ML ($p > .267$), or RF ($p = .315$).

P200. Results of the omnibus ANOVA are presented in Table 6.3. The main effect of emotion was pronounced in a significant amplitude difference between neutral and fearful sentences, $F(1,27) = 80.59$, $p < .0001$, and between neutral and disgust, $F(1,27) = 7.75$, $p < .01$. In both cases, the P200 amplitude was reduced for emotional compared to neutral. The amplitude elicited by neutral sentences did not significantly differ from anger ($p = .303$) or happy ($p > .407$).

Next, the main effect of emotion was scrutinized at the roi level (emotion x roi interaction). Emotion was significant at all rois: LF, $F(4,108) = 26.00$, $p < .0001$, LC, $F(4,108) = 42.85$, $p < .0001$, LP, $F(4,108) = 15.68$, $p < .0001$, ML, $F(4,108) = 29.60$, $p < .0001$, RF, $F(4,108) = 37.37$, $p < .0001$, RC, $F(4,108) = 45.26$, $p < .0001$, and RP, $F(4,108) = 13.62$, $p < .0001$. Left-frontally, there was a significant amplitude reduction for fearful compared to neutral sentences, $F(1,27) = 42.71$, $p < .0001$. The other emotions were not significantly different from neutral at the Bonferroni-corrected significance level (anger: $p > .020$; disgust: $p > .027$; happy: $p > .019$). The same pattern applied at roi LP: only the fear-neutral difference proved to be significant, $F(1,27) = 42.23$, $p < .0001$, while this was not the case for the angry-neutral ($p > .770$), disgusted-neutral ($p > .063$), or happy-neutral ($p > .524$) comparison. Similarly, at midline electrodes, fear differed significantly from neutral, $F(1,27) = 60.41$, $p < .0001$, while the other conditions did not (anger: $p > .182$; disgust: $p > .030$; happy: $p > .530$). Finally, the fear-neutral difference became significant at roi RP, $F(1,27) = 43.58$, $p < .0001$, and there was no difference between neutral and the remaining emotion conditions (anger: $p > .474$; disgust: $p > .025$; happy: $p > .123$). Left-centrally, the step-down analysis yielded a significant amplitude reduction for fearful, $F(1,27) = 99.20$, $p < .0001$, and disgust sentences $F(1,27) = 11.40$, $p < .01$, compared to neutral. Anger ($p = .335$) and happy ($p = .138$) were not significantly different from neutral. This was comparable to the right-central roi. The analysis yielded a significant difference between fear and neutral, $F(1,27) = 107.31$, $p < .0001$ and between disgust and neutral, $F(1,27) = 8.20, p = .008$, but not between anger and neutral ($p > .576$) or happiness and neutral ($p > .5$). At right-frontal sites, the fearful-neutral difference was again significant, $F(1,27) = 57.41$, $p < .0001$, and a significant anger-neutral difference was additionally observed, $F(1,27) = 7.62$, $p < .011$, with anger eliciting higher amplitudes than neutral. The contrast between disgust and neutral ($p > .02$) and happy and neutral ($p > .029$) did not survive Bonferroni correction. Thus, fear differed significantly from neutral at all rois, while the disgust-neutral difference became significant at the central rois. The P200 amplitude for anger compared to neutral was enhanced at the right-frontal roi.

Regarding the main effect of intelligibility, amplitudes elicited by intelligible speech were higher than those to unintelligible speech.

Intelligibility was assessed roi-wise to test the intelligibility x roi interaction. A significant main effect of intelligibility emerged at all rois: LF, $F(1,27) = 13.12$, $p < .002$, LC, $F(1,27) = 64.56$, $p < .0001$, LP, $F(1,27) = 64.30$, $p < .0001$, ML, $F(1,27) = 40.54$, $p < .0001$, RF, $F(1,27) = 23.16$, $p < .0001$, RC, $F(1,27) = 53.54$, $p < .0001$, and RP, $F(1,27) = 37.92$, $p < .0001$. Thus, intelligible stimuli elicited higher amplitudes than unintelligible sentences at all rois.

The emotion x intelligibility interaction was explored emotion-wise. A main effect of intelligibility was confirmed for disgust, $F(1,27) = 24.51$, $p < .0001$, fear, $F(1,27) = 8.31$, $p < .008$, happiness, $F(1,27) = 4.94$, $p < .035$, and neutral, $F(1,27) = 63.51$, $p < .0001$. Convergent with the intelligibility main effect of the omnibus ANOVA, intelligible speech elicited higher P200 amplitudes than unintelligible speech in these emotion conditions. The only emotion not affected by intelligibility was anger ($p > .670$).

Finally, the task x roi interaction was characterized by a significant main effect of task at roi LF, $F(1,27) = 4.27$, $p < .049$ and RF, $F(1,27) = 4.44$, $p < .045$. The P200 amplitude at these rois was higher in the explicit task than during implicit processing. Task was not significant at roi LC ($p = .108$), LP ($p > .671$), ML ($p > .474$), RC ($p > .261$), or RP ($p > .078$). This frontally-distributed task effect is shown in Figure 6.3.

6.3 Discussion

The present study explored the early neural mechanisms of emotional prosody processing by means of ERPs. While the effect of different emotional intonation categories has been explored previously (Paulmann, 2006; Paulmann & Kotz, 2008; Paulmann, Schmidt, et al., 2008), this study elucidates how the early mechanisms of emotional prosody perception may be influenced by the attentional focus, which was achieved by means of an implicit

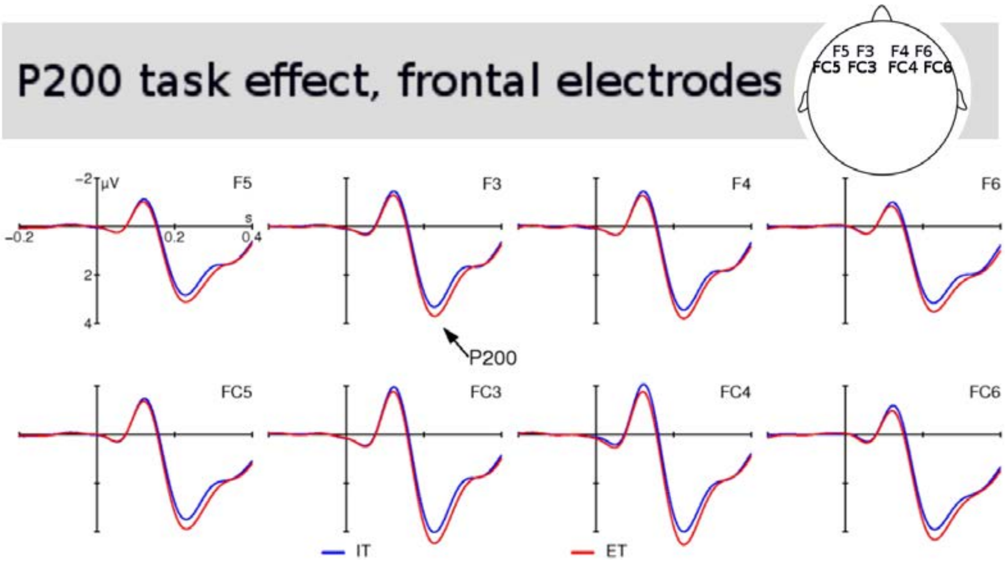

Figure 6.3: P200 task effect at left and right-frontal electrode sites, Experiment 1A. IT = implicit task, ET = explicit task.

versus an explicit task. Furthermore, the very early nature of some emotion effects (N100) is a relatively novel finding.

N100. Strikingly, there was a significant main effect of emotion in the N100, driven by reduced ERP amplitudes in the fearful compared to the neutral condition. This would parallel some findings from the visual domain in which fearful faces led to effects in this early time range (Eimer & Holmes, 2002; Luo et al., 2010; Pourtois et al., 2004, 2005). Regarding emotional prosody, evidence of early emotion effects is very sparse. Yagura et al. (2004) could show very early differences between happy and sad prosody in an MEG study, starting around 100 ms after stimulus onset. Furthermore, Thönnessen et al. (2010) reported very early MMN effects to emotional-prosodic deviants embedded in a sequence of neutral standards. These effects also started around a 100 ms latency, while this was not the case for the comparison condition in which deviants were characterized by speaker changes. Regarding the evolutionary significance of fearful stimuli and the findings from the visual domain, this early emotion effect seems plausible. For faces, these early emotion effects have been attributed to the fast subcortical "low road" of processing (Vuilleumier & Pourtois, 2007). As there is evidence of such a "low road" in the auditory domain, too (LeDoux, 2000), one could attribute this early ERP modulation by fear to this account.

Interestingly, as revealed by the interaction between the factors emotion and roi, there was a right-frontal amplitude reduction for the happy compared to the neutral speech intonation. This seems to contradict work by Davidson and colleagues (e.g., Davidson, Schwartz, Saron, Bennett, & Goleman, 1979), who report frontal EEG asymmetries, with right-frontal electrodes associated with negative and left-frontal electrodes with positive valence. However, these studies are not really comparable to the present experiment, as they were aimed at the emotional states of participants and did not deal with the perception of emotional stimuli per se. It must also be considered that the right-frontal difference between fearful and neutral stimuli was close to significance. Thus, it cannot be stated that only the happy intonation modulated the N100 response at right-frontal leads. Future studies will have to investigate whether this very early right-frontal response to happy prosody can be replicated and whether it is happiness-specific or not.

Another important finding in this study was the intelligibility effect at a very early point in time. It is unlikely that this observation reflects semantic processing, which is a rather late phenomenon (Kutas & Hillyard, 1980). On the one hand, it can of course not be discarded that physical stimulus characteristics may have driven this effect, as the N100 is a partly exogenous component (Fabiani et al., 2007). This is supported by the finding that some emotional categories were more affected by intelligibility than others, which could be due to greater physical differences between unintelligible and intelligible stimuli in these categories. However, this explanation is weakened by the presence of a main effect of intelligibility, which supports a more wide-spread phenomenon. Furthermore, we are experts in processing speech and tuned to rapidly process and understand it, which is the basis of our everyday interactions. Manipulated speech such as unintelligible speech used in the present study may thus trigger less strong neural reactions due to its lower relevance, leading to reduced N100 amplitudes. This early distinction of intelligible and unintelligible stimuli indicates that a rapid selection of socially relevant stimuli can be observed with emotional prosody.

P200. As reported in previous studies (Paulmann, 2006; Paulmann & Kotz, 2008; Paulmann, Schmidt, et al., 2008), a main effect of emotion was observed in the P200, reflecting emotional salience detection. Interestingly, in the present study there was evidence of an enhanced P200 amplitude for neutral compared to fearful and disgust stimuli only. In contrast, the above-cited studies found P200 amplitude reductions for all emotional intonations tested, which comprised all of the intonations used in the current study. On the one hand, the fear effect is far the most robust in previous studies as well as in the present investigation, with p-values $< .0001$. Other categories, even though also significant, did not achieve such high significance levels (only the sad intonation did, but it was not part of the present study; Paulmann, 2006; Paulmann & Kotz, 2008; Paulmann, Schmidt, et al., 2008). Thus, due to its robustness, the fear effect is more likely to be replicated. An important notion to be considered is that in the present study, as opposed to previous ones, 50% of the complete stimulus material were neutral sentences, while in previous experiments the number of sentences conveying a neutral intonation was the same as for each emotional category. As a consequence, the amount of neutral sentences was higher than for the different emotions, resulting in a higher degree of habituation for the neutral stimuli and an improved signal-to-noise ratio, leading to reduced ERP amplitudes (Luck, 2005). Thus, experimental factors may have reduced the P200 amplitude to neutral speech in the present study. Despite of this enhanced threshold, an amplitude reduction for disgust stimuli could be confirmed at the global level (main effect of emotion), and is thus in perfect accord with previous findings. It must also be mentioned that at frontal electrodes, none of the emotional-neutral differences was far from significance, so the results do not contradict previous reports.

The only effect which is somewhat contradictory to the literature is the P200 enhancement to angry prosody at the right-frontal roi, as normally emotional-prosodic stimuli elicit reduced amplitudes in comparison to neutral. Here, it must be kept in mind that no impact of intelligibility was observed for the P200 amplitude to angry prosody, whereas for other emotions amplitudes were reduced in the case of unintelligible speech, resulting in overall lower mean amplitudes. In fact, when resolving the emotion x intelligibility interaction by intelligibility, it turns out that a significant main effect of emotion is observed for both intelligibility conditions, but an amplitude enhancement of angry compared to neutral stimuli applies only to the unintelligible condition. In general, the P200 reduction to unintelligible as compared to intelligible stimuli is in accord with previous work (Paulmann, 2006).

Even though explicit and implicit vocal emotion processing are supposed to differ, the current results only revealed a frontally distributed task effect and no interactions with emotion. Probably, this is due to the early point in time at which ERPs were quantified, as task-related processing is thought to come into play at later processing stages (Schirmer & Kotz, 2006). The mechanism with which task effects may influence early processing stages lie more within the domain of the attentional focus. As clear-cut task effects were absent in the present study, it appears that early steps of emotional prosody perception are relatively independent of attention allocation, which is, however, contradicted by one study (Wambacq et al., 2004). Possibly, task demands will have more impact in the patient study, as an explicit instruction appears to involve the basal ganglia more than implicit processing demands (Bach et al., 2008). However, this depends on the point in time at which this enhanced BG recruitment takes place.

Summary and conclusion. To sum up, the present experiment provides novel evidence of a very early processing advantage for salient (fearful) emotional stimuli and expands previous knowledge of the role of the P200 in emotional prosody processing.

Even though the early fear effect in the N100 is striking, it has to be treated with some caution. As mentioned above, the N100 is considerably affected by bottom-up influences, i.e., physical stimulus characteristics (Fabiani et al., 2007); thus, the difference could be simply due to low-level acoustic variations between the stimuli (Banse & Scherer, 1996). Along similar lines, a recent study (Sauter & Eimer, 2010) reported no difference in the N100 amplitude to fearful vocalizations and their spectrally inverted and physically highly comparable counterparts which were, however, emotionally not meaningful. Thus, this alternative explanation of a bottom-up effect cannot be ruled out.

In general, the design proved to be a valid approach to study emotional salience detection in the P200, even though not all emotional stimuli elicited P200 amplitudes that were significantly different from neutral; possible reasons for this are discussed above. However, as only one positive and three negative categories were included in the study, it is important to present more neutral stimuli to avoid a dominance of negative materials in the experiment and to maintain a balanced response button assignment across implicit and explicit task instructions.

Chapter 7

Experiment 1B – Patient study

As discussed in the introduction, there is evidence that the basal ganglia are involved in vocal emotion processing. While the left BG, or more specifically the left striatum (caudate and putamen), appears to play a role in late, integrative processing stages (Paulmann et al., 2011), the role of the right striatum for vocal emotion perception remains unclear.

Parkinson's disease offers a model to study striatal dysfunction which is predominant in either the left or the right hemisphere, depending on the sidedness of motor symptoms. The P200, as the ERP correlate of early emotional salience detection from prosody, is thought to rely primarily on right-hemispheric processes in superior temporal areas (Schirmer & Kotz, 2006). In latter paper, the possibility of bottom-up influences from subcortical structures during these early processing steps is considered, and a recent diffusion tensor imaging study (Ethofer et al., 2012), in fact, reported an increased connectivity between the right putamen and superior temporal areas while participants were listening to affective prosody. To date, it is, however, unclear at which point in time this interaction may take place, and thus Experiment 1 aims to shed light on whether the striatum is involved in early emotional salience detection from prosody (P200). If the interaction between the right striatum and superior temporal areas involved in vocal emotion processing is early, then LPD patients should exhibit P200 alterations.

To this end, sentences conveying different emotional intonations were presented in an ERP study. As explicit and implicit processing of emotional prosody may differ – not only concerning task demands per se but also in terms of their underlying neural correlates (Beaucousin et al., 2007; Schirmer & Kotz, 2006; Wildgruber et al., 2005) – an explicit and an implicit task was applied. It was hypothesized that PD, especially LPD, would be particularly associated with alterations in explicit processing, as the right striatum appears to be more involved in this kind of task (Bach et al., 2008; Beaucousin et al., 2007). Furthermore, the right hemisphere is more strongly engaged in explicit than implicit processing (e.g., Wildgruber et al., 2005), which supports this hypothesis. However, the point in time at which this may happen remains unclear. The task manipulation in the ERP study was further complemented by a behavioral prosody categorization experiment, in which deficits were expected for both patient groups (Ariatti et al., 2008; Blonder et al., 1989).

An additional factor manipulated in the present study was speech intelligibility. This may also play a role, as the processing of intelligible speech has been reported to involve the putamen more strongly than unintelligible speech (Kotz, Meyer, et al., 2003). This is supported by another study which, however, does only report a stronger BG involvement for semantic speech compared to pure-prosodic stimuli in the case of mismatching prosody and semantics (Mitchell, 2006). Thus, as long as no semantics are present, emotional prosody processing may not significantly engage the BG, which would mean that processing of unintelligible speech may be largely intact in PD. In contrast, if the BG are involved in early prosodic-semantic alignment during speech processing, then intelligible speech may reveal alterations in PD.

To sum up, three different aspects of emotional prosody processing were central to the present study:
(1) the possible impact of sidedness of motor symptoms in PD,
(2) early (N100/P200) and late processing stages (behavioral emotion categorization study), and
(3) explicit versus implicit task settings.
Furthermore, it was considered important to carefully control for cognitive decline.

7.1 Methods

7.1.1 Participants

Thirty-two patients diagnosed with idiopathic PD completed the experiment. Ten of them were excluded from the sample. One exclusion criterion was a high depression score, obtained with the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). The cutoff was set at 17 points, which was exceeded by seven participants. Two participants were excluded due to poor behavioral performance in the experiment, which indicated that they had not understood the task instructions. As the present study explores motor symptom asymmetry in PD, one patient without a clear asymmetry was also excluded. Thus, the final sample consisted of $N = 22$ PD patients (11 female). The group was subdivided into an LPD ($n = 10$) and an RPD group ($n = 12$) according to the body side most affected by motor symptoms. Motor score assessment (with the UPDRS part III; Fahn & Elton, 1987) and Hoehn and Yahr staging (Hoehn & Yahr, 1967) were realized by an experienced neurologist specialized for movement disorders while patients were on medication. The difference between left and right motor scores was at least two points for all patients. Negative asymmetry indices (AI)[1] indicating RPD ranged from -1 to -0.2 and positive AI indicating LPD were in the range between 0.2 and 1. Thus, motor symptom asymmetry was at least 20% for all participants. Patients were recruited at the University Clinic Leipzig, in a local patient organization and in a neurologist's practice in Leipzig. The PD participants did not show signs of dementia, indicated by a score of at least 25 points in the Mini-Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975). All were native speakers of German, right handed according to self-report, and reported no history of neurological or psychiatric illness except PD. Detailed information about the patient sample is provided in Table 7.1. Patients were paid eight Euros per hour for their effort, and travel expenses were reimbursed.

The healthy control (HC) group consisted of $N = 22$ volunteers (11 women), matched with the patient sample for age, sex, education, and handedness. One HC was on antidepressant treatment (with a selective serotonin reuptake inhibitor) by the time of testing, but scored below 18 points in the BDI. Thus, he was not excluded from the experimental sample. The rest of the HC group did not report any history of neurological or psychiatric conditions. The HC group members were paid seven Euros per hour and additionally received a financial compensation for their travelling expenses.

Table 7.2 provides a comparative overview of different group characteristics.

7.1.2 Stimulus material

The stimuli were the same as in the pilot study (Experiment 1A), with only one difference: the number of trials was reduced in order to reduce the duration of the experiment. Twenty sentences were selected for each emotion and intelligibility condition, resulting in a total of 160 emotional stimuli. 160 neutral sentences (40 per actor, 50% unintelligible) were included adding up to 320 experimental stimuli. The intelligible stimuli used in the patient experiment yielded the following recognition rates in prior rating studies: anger 100% ($SD = 1.40$), disgust 100% ($SD = 0$), fear 86% ($SD = 9.34$), happiness 87% ($SD = 7.51$), and neutral 91% ($SD = 7.57$). For unintelligible stimuli, recognition rates were: anger 95% ($SD = 5.05$), disgust 83% ($SD = 17.01$), fear 78% ($SD = 17.47$), happiness 74% ($SD = 6.91$), and neutral 90% ($SD = 15.42$).

To test voluntary attention allocation, an auditory oddball study was employed. The frequent standards were 600 Hz tones and 660 Hz tones were presented as rare deviants (probability: 0.25). The tones had a duration of 200 ms each and were separated by an inter-stimulus interval of 1000 ms. The oddball sequence comprised 300 tones in total.

[1] calculation: AI = (left - right motor score) / (left + right motor score)

No.	Age	Sex	Dur	Type	Med	HY	MS	L/R	MM	BDI
Left-dominant motor symptoms group (LPD)										
01	44	f	13	eq	$L^{1,3}$ D G	3	10	3/1	28	11
02	64	m	6	ar	L^{1} D	2	19	9/1	28	1
03	77	m	3	td	D	2	21	9/6	27	8
04	67	f	15	eq	L^{3} D	3	13	7/0	27	17
05	64	f	7	eq	L^{1} D	2	10	5/0	30	3
06	69	m	1	eq	D	1.5	17	6/0	27	17
07	58	f	3	eq	D	1.5	9	5/0	29	11
08	72	m	3	eq	D	2	19	8/4	30	10
09	51	f	1	eq	D M	2	18	13/1	30	17
10	73	f	8	eq	L^{1} D	2	21	11/6	26	7
Right-dominant motor symptoms group (RPD)										
11	72	m	5	td	L^{2} D	2	12	0/4	29	9
12	72	m	3	td	D	2	11	2/5	30	5
13	69	f	1	ar	–	1	9	1/7	30	11
14	80	m	6	eq	L^{1} G	2.5	17	2/7	27	9
15	70	f	12	ar	L^{1} D M C	4	17	4/6	30	17
16	66	m	3	td	D	1.5	10	0/7	28	9
17	55	m	1.5	td	D M	2	6	1/3	29	3
18	67	m	11	ar	L^{1} D M	3	14	1/5	29	7
19	74	f	11	eq	$L^{1,3}$	3	20	3/7	25	5
20	71	f	5	eq	$L^{1,3}$ D	2	8	0/6	29	6
21	62	f	3	eq	L^{3} D	2.5	19	1/14	28	1
22	65	m	5	eq	L^{2} D	2.5	21	0/10	29	17

Table 7.1: Detailed patient history. Dur: disease duration (years); Med: medication; HY: modified Hoehn & Yahr stage (Goetz et al., 2004); MS: motor score (UPDRS); L/R: left/right motor score; MM: Mini-Mental Status Examination; eq: equivalent, ar: akineto-rigid, td: tremor dominant; L: levodopa (^{1} + benserazide, ^{2} + carbidopa, ^{3} + carbidopa and COMT inhibitor), D: dopamine agonist, G: glutamate antagonist, M: MAO inhibitor, C: COMT inhibitor.

Variable	HC	LPD	RPD	*p*
Age	65.91 (8.49)	63.90 (10.29)	68.58 (6.33)	$> .415$
Education (median)[1]	5.5	4.5	7	$> .325$
MMSE	29.00 (0.87)	28.20 (1.48)	28.58 (1.44)	$> .332$
BDI	6.82 (4.44)	10.20 (5.69)	8.25 (4.96)	$> .199$
Hoehn & Yahr (median)	–	2	2.25	$> .347$
UPDRS motor score	–	15.70 (4.50)	13.67 (4.84)	$> .356$
Disease duration in years	–	6.00 (4.60)	5.54 (3.64)	$> .906$

Table 7.2: Summary of group characteristics with means, standard deviations and statistics. [1]Educational attainment was scored on a scale from 1 to 9, with higher numbers indicating higher education.

Comprehensive background testing was performed. Tests applied were: MMSE, the Benton Facial Recognition Test (Benton, Sivan, Hamsher, Varney, & Spreen, 1983), forward and backward digit spans (Wechsler, 1997), the Trail-Making Test, part A and B (Reitan, 1992), an in-house listening span test (auditory version of the reading span by Daneman & Carpenter, 1980, translated into German), the Token Test (De Renzi & Vignolo, 1962), and an in-house phoneme discrimination and word fluency measure (phonemic and semantic fluency). Furthermore, participants completed several questionnaires: Spielberger State-Trait Anxiety Inventory (STAI; Spielberger & Gorsuch, 1983), the Depression Anxiety Stress Scales (DASS; Lovibond & Lovibond, 2004), the BDI, and the Freiburg Personality Inventory (FPI; Fahrenberg, Hampel, & Selg, 1994).

7.1.3 Procedure

Participants came in for a total of three test sessions. The background testing was completed in the first session, followed by the two EEG sessions. The two EEG sessions were separated by one week (six to eight days), except for one patient who was ill in between, leading to a gap of four weeks. Session one and the neurological assessment took place at a maximum of two months before the first EEG session.

The procedure for the EEG experiment resembled that of the pilot study, but with fewer trials. One session included 320 trials divided into eight blocks of 40 stimuli each. Thus, the run-time was shortened to approximately 40 minutes.

Each EEG session started with the oddball experiment which had a run-time of circa six minutes. The task was to silently count the deviant ("high") tones in order to report the number to the experimenter afterwards. After the second EEG session, participants completed a brief behavioral emotion categorization experiment. A subset of 100 sentences which had been part of the EEG study was played again to test explicit emotion recognition from prosody. Half of the sentences were in unintelligible speech, and they were equally distributed across the five categories of anger, disgust, fear, happiness, and neutral. Thus, per emotion/intelligibility condition, 10 sentences were tested. The selection was based on the top ten stimuli of each category, based on prior categorization studies. Participants were given eight seconds after sentence offset to assign one of the five emotion labels to a sentence in a forced-choice task.

7.1.4 Data acquisition and analysis

To reduce EEG preparation time, a reduced set of 25 Ag/AgCl electrodes mounted in an elastic cap was measured in the patient study. The following locations were selected: FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FC4, FT8, T7, C3, CZ, C4, T8, CP5, CP6, P7, P3, PZ, P4, P8, O1, and O2 (cf. Figure 1.1, for a graphical display of these locations). The electrodes were referred to the left mastoid bone during the measurement and re-referenced to linked mastoids offline. Vertical and horizontal electrooculograms (EOG) were recorded unipolarly and re-calculated to bipolar setups offline. Acquisition was carried out with a bandpass between DC and 250 Hz and the sampling rate was 500 Hz. The ground electrode was placed on the sternum. Electrode resistance was kept below five kΩ. An EOG correction (Pfeifer, Novagk, & Maess, 1995) was applied to the EEG data to increase the number of trials. Data quality was improved offline with a bandpass filter applied to the continuous data (0.5 – 30 Hz, 3571 points, Blackman window). This filter behaves identically to the one used in the pilot experiment. An additional 10 Hz lowpass filter was used only for graphical illustrations.

Topographical regions of interest (rois) were formed as follows: left-frontal (LF; FT7, F3, FC3), left-central (LC; T7, C3, CP5), left-posterior (LP; P7, P3, O1), right-frontal (RF; FT8, F4, FC4), left-central (LC; T7, C3, CP5), right-central (RC; T8, C4, CP6), right-posterior (RP; P8, P4, O2), and midline (ML; FZ, CZ, PZ). Statistical tests for normality were applied to the data and indicated that the assumptions of a normal distribution were violated. Therefore, the ERP data and the behavioral data were transformed before conducting the ANOVA. The following procedure was adopted to do so: Transform regression was run in SAS 8.02 to estimate the most suitable lambda value for the Box-Cox transformation procedure (Box & Cox, 1964). A lambda of $= 0$ corresponds to a log-transformation and $= 0.5$ to square root transformation, which were the procedures applied in those cases, respectively. For all other -values, the Box-Cox formula was used to transform the data. Before transformation, a constant was added to all data to make sure that no data point had a value below one, as the named transformation methods can only handle positive data which should be greater than one (LaLonde, 2005). Adding a constant is a linear transformation and does therefore not alter the data distribution. The rest of data handling was similar to the pilot study.

No significant group difference emerged for the number of trials per condition which entered the ANOVA (all p-values $> .21$). Two time windows were defined: The N100 was analyzed from 96 – 160 ms after stimulus onset, and the P200 from 200 – 380 ms. The threefold between-subjects factor group (LPD, RPD, HC) was included into the analysis. The P300 from the oddball experiment was analyzed from 250 – 600 ms after tone onset using a 2 (condition) x 7 (region) x 3 (group) analysis with group as a between-subjects factor and the remaining variables as within-subjects factors. Here, the first 100 ms after tone onset served as baseline. In the case of main effects of group or interactions involving group, the Scheffé test was applied to scrutinize the group differences.

Behavioral emotion categorization study. The data were analyzed in a 5 (emotion) x 2 (intelligibility) ANOVA. Apart from these two within-subjects factors, group served as a threefold between-subjects variable. Number of correct answers was the outcome measure.

Background test scores and correlation analyses. Each background test was surveyed separately for main effects of group. To do so, nonparametric Kruskal-Wallis tests in conjunction with Monte-Carlo exact estimates were run to reduce the impact of ties on the results. Significant results were followed up with Mann-Whitney tests comparing the groups against each other. As this post-hoc analysis involved three comparisons of interest, a Bonferroni-corrected significance level of $p < .017$ was defined.

Many test results significantly correlated with each other which is why it is not recommended to correlate each test score with the ERP data. Therefore, three different composite scores were constructed. This was guided by theoretical knowledge of what the tests are supposed to measure, and by intercorrelations between the test results. The composite measures were frontal functions, working memory, and emotional stability and consisted of the following measures: frontal functions – word fluency, Trail-Making test A and B; working memory – forward and backward digit spans, listening span; emotional stability – STAI (trait scale), BDI, DASS (depression scale), FPI (neuroticism and satisfaction with life scales). To calculate the composite scores, the single test scores were z-transformed ($M = 0$, $SD = 1$) on the basis of the whole sample ($N = 44$). Z-scores of test results negatively related to a composite score (e.g., the BDI which is negatively related to emotional stability) were multiplied by -1 before the composite score calculation. The MMSE (lowest score: 25/30 points), the Facial Recognition Test (lowest score: 17/27 points), the Token Test (maximal errors: 2), and the Phoneme Discrimination (lowest score: 19/25 points) were not included into the composite scores. They only served to make sure that basic perceptual and cognitive functions were intact in all participants. Group differences in the composite scores were assessed using MANOVA, as the data were normally distributed. Pearson correlations were computed between ERP amplitudes and the composite scores as well as age, education, and the oddball P300 amplitude. The whole sample ($N = 44$) was used for these analyses, and the critical alpha level was set to $p < .0083$ due to multiple comparisons. ERP amplitudes that were altered in the patients were correlated with motor scores and asymmetry indices (AI; see Section 7.1.1) of the whole patient group ($N = 22$).

7.2 Results

7.2.1 Test scores

A significant group effect was confirmed for four different test scores: the backward digit span, $H(2) = 6.86$, $p < .030$, the STAI trait scale, $H(2) = 7.06$, $p = .026$, the DASS anxiety scale, $H(2) = 6.92$, $p < .029$, and the DASS depression scale $H(2) = 8.47$, $p = .012$. Group was not significant for the forward digit span ($p > .23$), the Trail-Making Test part A ($p > .374$) and B ($p = .289$), listening span ($p > .296$), the DASS stress scale ($p > .672$), phonemic word fluency ($p > .150$), categorical word fluency ($p > .267$) and the Satisfaction with Life scale of the FPI ($p > .879$). The MANOVA yielded no significant group effects for the composite scores frontal measures ($p > .062$), working memory ($p > .178$), or emotional stability ($p > .145$).

Adopting a significance level of $p < .017$, only LPD and RPD differed significantly in the backward digit span $U(1) = 149.0$, $z = 2.24$, $p < .012$. The difference between LPD and HC only approached significance ($p < .033$), with the LPD group achieving the highest scores. RPD and HC did not significantly differ ($p > .062$).

The STAI state score was enhanced for LPD and RPD compared to HC, but only the RPD-HC difference turned out to be significant, $U = 273.5$,$z = 2.28$, $p < .011$, while the LPD-HC difference did not survive Bonferroni correction ($p > .02$). The patient groups did not score significantly different on this test ($p > .43$).

Concerning the DASS anxiety scale, the analysis yielded a significant difference between RPD and HC, $U(1) = 282.5$, $z = 2.60$, $p < .004$, but not between LPD and HC ($p = .107$) or LPD and RPD ($> .195$). Likewise, for the depression scale, the RPD-HC difference was significant, $U = 291.5$, $z = 2.93$, $p < .001$, while LPD and HC ($p > .965$), or LPD and RPD ($p > .085$) did not significantly differ.

7.2.2 P300 data

First and most importantly, group did not significantly affect the P300. The main effect of group was not significant, $F(2,40) = 0.36$, $p > .696$, $\omega^2 = -.030$. In a similar vein, interactions involving the factor group did not prove significant. These concerned group x condition, $F(2,40) = 1.04$, $p > .361$, $\omega^2 = .001$, roi x group, $F(12,240) = 0.90$, $p > .545$, $\omega^2 = -.002$, and condition x roi x group, $F(12,240) = 0.57$, $p > .861$, $\omega^2 = -.004$.

The main effect of condition was significant, $F(1,41) = 71.01$, $p < .0001$, $\omega^2 = .432$, due to a more positive-going wave for deviants than for standards. The condition x roi interaction also proved significant, $F(6,246) = 6.54$, $p < .001$, $\omega^2 = .022$. The main effect of condition was significant at all regions: LF, $F(1,41) = 31.05$, $p < .0001$; LC, $F(1,41) = 54.17$, $p < .0001$; LP, $F(1,41) = 92.85$, $p < .0001$; RF, $F(1,41) = 50.70$, $p < .0001$; RC, $F(1,41) = 91.98$, $p < .0001$; RP, $F(1,41) = 68.13$, $p < .0001$; ML, $F(1,41) = 37.34$, $p < .0001$. Thus, the positivity in response to deviants was observed across the entire scalp.

7.2.3 Behavioral data

Overall percent-correct rates were high in all groups: LPD 82% ($SD = 20.07$), RPD 86% ($SD = 19.78$), and HC 92% ($SD = 14.29$). Table 7.3 shows the complete results from the omnibus ANOVA. The Scheffé test of the group main effect yielded a significant difference between LPD and HC while the other comparisons were not significant.

The analysis of the emotion main effect indicated that percent-correct rates for neutral were significantly lower than for anger, the category with the highest percent-correct rates, $F(1,41) = 19.64$, $p < .0001$. Percent-correct rates were lowest for happy sentences, and the difference with neutral was significant, $F(1,41) = 8.17$, $p < .007$. The difference between neutral and disgust ($p > .023$) and neutral and fear ($p > .617$) was not significant at the $p < .0125$ level.

Percent-correct rates were higher in the IT than in the ET, explaining the main effect of task. Unintelligible sentences led to better performance than intelligible stimuli (main effect of intelligibility).

There was a significant interaction of emotion x task. No significant main effect of emotion was evident in the IT ($p > .887$), while there was one in the ET $F(4,164) = 20.21$, $p < .0001$. Percent-correct rates for anger were significantly higher than for neutral $F(1,41) = 21.81$, $p < .0001$, and lower for happy compared to neutral $F(1,41) = 8.57$, $p < .006$. No differences emerged with disgust ($p > .015$) or fear ($p = .432$).

Effect	df	F	p	ω^2
Group	2,41	**5.39**	$<$ **.009**	**.166**
Emotion	4,164	**17.32**	$<$ **.0001**	**.195**
Emotion x Group	8,164	0.22	$>$ .976	-.024
Intelligibility	1,41	**4.66**	$<$ **.037**	**.040**
Intelligibility x Group	2,41	1.31	$>$ 280	.007
Task	1,41	**161.70**	$<$ **.0001**	**.646**
Task x Group	2,41	1.57	$>$ .221	.006
Emotion x Intelligibility	4,164	**13.25**	$<$ **.0001**	**.091**
Emotion x Intelligibility x Group	8,164	1.50	$>$ .160	.008
Emo x Task	4,164	**17.10**	$<$ **.0001**	**.111**
Emo x Task x Group	8,164	0.65	$>$ .738	-.005
Intelligibility x Task	1,41	**14.06**	$<$ **.001**	**.069**
Intelligibility x Task x Group	2,41	1.69	$>$ .197	.008
Emotion x Intelligibility x Task	4,164	**15.40**	$<$ **.0001**	**.057**
Emotion x Intelligibility x Task x Group	8,164	0.86	$>$ .554	-.001

Table 7.3: Results of the omnibus ANOVA on percent-correct rates, Experiment 1B.

Regarding the emotion x intelligibility interaction, the emotion main effect was significant for both intelligible $F(4,164) = 21.73$, $p < .0001$ and unintelligible sentences $F(4,164) = 11.21$, $p < .0001$. In the intelligible condition, percent-correct rates were significantly reduced for disgust vs. neutral $F(1,41) = 29.28$, $p < .0001$, and for happy versus neutral $F(1,41) = 23.79$, $p < .0001$. Anger ($p > .105$) and fear ($p > .114$) were not significantly different from neutral. In the unintelligible condition, percent-correct rates were higher for anger than neutral $F(1,41) = 32.80$, $p < .0001$. No significant differences were observed when comparing neutral against disgust ($p = .186$), fear ($p > .565$), or happy ($p > .982$).

The intelligibility x task interaction was characterized by no significant main effect of intelligibility in the IT ($p > .656$) but in the ET $F(1,41) = 12.74$, $p < .001$. Performance was better for unintelligible than intelligible sentences in this task.

Lastly, the three-way interaction was characterized. A step-down analysis by task yielded a significant emotion x intelligibility interaction for the ET, $F(4,164) = 19.95$, $p < .0001$, as well as for the IT, $F(4,164) = 3.26$, $p < .021$. In the ET, a significant main effect of emotion was confirmed for both intelligible, $F(4,164) = 31.56$, $p < .0001$, and unintelligible sentences, $F(4,164) = 9.52$, $p < .0001$. In intelligible sentences, disgust, $F(1,41) = 38.85$, $p < .0001$, and happy intonations, $F(1,41) = 28.51$, $p < .0001$, yielded reduced percent-correct rates compared to neutral, while this did not apply to anger ($p >$ .024) or fear ($p > .045$). In the unintelligible condition only neutral and anger sentences,

$F(1,41) = 28.56$, $p < .0001$, were significantly different, with a higher performance for anger. No significant difference was observed between neutral and disgust ($p > .16$), fear ($p > .665$), or happy ($p > .783$). The step-down analysis for the IT did not return any significant results: The main effect of emotion was neither significant for the intelligible ($p > .289$) nor the unintelligible ($p > .077$) material.

7.2.4 ERP data

Results from the two omnibus ANOVAs testing the N100 and the P200 can be retrieved from Table 7.4.

N100. According to the analysis of the emotion x roi x group interaction, LPD patients exhibited right-posterior amplitude enhancements in response to happy prosody. This was further informed by results from the five-way interaction. Differences were found for both intelligibility conditions in the ET context while in the IT context only the N100 to pseudo-sentences was enhanced. RPD patients showed N100 enhancements in reaction to disgust at rois LF, RF, LC, and ML. Specifically, the analysis of the emotion x task x intelligibility x group interaction indicated that lexical sentences of disgust during the ET elicited an enhanced N100 in RPD patients. This was confirmed by the five-way interaction pointing to a topographically widespread effect at all but the posterior rois. Lexical disgust sentences also yielded N100 enhancements in the LPD group during the ET. This was limited to left-central and midline electrodes. RPD patients also showed generally altered processing of fearful sentences at right-frontal leads (emotion x roi x group interaction). Further specific N100 enhancements in RPD patients as revealed by the five-way interaction were found for pseudo-sentences of fear (roi RP) and lexical neutral sentences (rois LF and RF), both during the ET.

The Scheffé test of the intelligibility x group interaction did not reveal any significant group differences.

The emotion main effect was due to a significantly lower N100 amplitude for fearful, $F(1,41) = 7.48$, $p < .01$, and for angry compared to neutral sentences, $F(1,41) = 18.14$, $p = .0001$. The difference with disgust ($p > .135$) and happy ($p > .053$) was not significant.

The intelligibility main effect could be explained by higher N100 amplitudes to intelligible than unintelligible speech stimuli.

The analysis of the emotion x intelligibility interaction revealed a significant intelligibility effect for anger, $F(1,41) = 6.65$, $p < .014$, disgust, $F(1,41) = 11.57$, $p < .002$, fear, $F(1,41) = 11.80$, $p < .002$, and neutral, $F(1,41) = 19.65$, $p < 0.0001$. In the case of disgust, fear, and neutral intelligible speech elicited enhanced amplitudes compared to unintelligible speech, while the pattern was vice versa for anger. Intelligibility had no significant impact on happiness processing ($p > .762$).

To analyze the emotion x roi interaction, the main effect of emotion at each roi was tested. It was significant at LF, $F(4,164) = 3.88$, $p < .009$, LC, $F(4,164) = 3.71$, $p < .011$, RF, $F(4,164) = 3.61$, $p = .014$, and RC, $F(4,164) = 2.88$, $p < .037$. Left-frontally, anger ($F[1,41] = 11.01$, $p < .002$), fear ($F[1,41] = 9.26$, $p < .005$), and happy ($F[1,41] = 14.14$, $p < .001$), but not disgust ($p > .042$), elicited significantly reduced amplitudes compared to neutral. At the left-central roi, there was a significant amplitude reduction for anger, $F(1,41) = 9.95$, $p = .003$, and fear, $F(1,41) = 11.68$, $p < .002$ compared to neutral, but no reduction was observed for happy ($p > .033$) or disgust ($p > .3$). At roi RF, the N100 amplitude was significantly smaller for angry, $F(1,41) = 28.18$, $p < .0001$ and happy sentences, $F(1,41) = 9.01$, $p < .005$ compared to neutral, but not for the disgusted ($p > .025$) or fearful ($p > .028$) intonation. Finally, at roi RC only the angry-neutral contrast became significant, $F(1,41) = 17.50$, $p = .0001$). No significant difference emerged with disgust ($p > .228$), fear ($p > .019$), or happy ($p > .152$). No main effect of emotion emerged at rois LP ($p > .13$), RP ($p > .059$), or ML ($p > .083$).

With respect to the intelligibility x roi interaction, a significant intelligibility effect was observed at rois LF, $F(1,41) = 7.28$, $p < .011$, LC, $F(1,41) = 8.06$, $p = .007$, RF, $F(1,41) = 10.99$, $p < .002$, and RC, $F(1,41) = 14.24$, $p < .001$, with higher amplitudes to intelligible than unintelligible speech. Intelligibility was not significant at rois LP ($p > .394$), RP ($p > .473$), or ML ($p > .055$).

P200. The main effect of group was reflected in a globally enhanced P200 amplitude for the LPD group compared to HC and RPD. A graphical display of this effect can be found in Figure 7.1.

The interactions with group further informed this main effect. The Scheffé test of the emotion x task x intelligibility interaction yielded an enhanced P200 amplitude to intelligible anger sentences in the LPD group compared to HC and RPD during the ET. This enhancement was especially pronounced at rois ML and RC, as informed by the five-way interaction. Furthermore, the P200 to intelligible disgust sentences was enhanced in LPD during the IT. This effect was confirmed at all but the two posterior rois by the five-way interaction. The LPD-RPD difference in this condition was only observed at ML. Moreover, the five-way interaction indicated an enhanced P200 amplitude to intelligible happy and unintelligible disgust expressions in LPD during the IT. The difference emerged both with HC and RPD. While the P200 enhancement to happy stimuli concerned roi RP, both posterior rois were affected for disgust. The P200 enhancements in LPD concerning specific conditions are depicted in Figure 7.2.

		N100 (96 – 160 ms)			P200 (200 – 380 ms)		
Effect	*df*	*F*	*p*	ω^2	*F*	*p*	ω^2
G	2,41	1.55	$>$ .225	.024	**3.95**	$<$ **.028**	**.118**
E	4,164	**2.92**	$<$ **.036**	**.026**	**55.35**	$<$ **.0001**	**.471**
E x G	8,164	2.05	$>$ .061	.029	1.78	$>$ .092	.025
I	1,41	**8.30**	$<$ **.007**	**.077**	**41.95**	$<$ **.0001**	**.318**
I x G	2,41	**4.26**	$<$ **.021**	**.069**	0.58	$>$ .565	-.01
T	1,41	2.15	$=$ .15	.013	**4.42**	$<$ **.046**	**.036**
T x G	2,41	0.15	$>$ .864	-.02	0.31	$>$ .732	-.016
E x I	4,164	**8.89**	$<$ **.0001**	**.056**	**4.93**	$<$ **.004**	**.026**
E x I x G	8,164	0.89	$>$ .508	-.002	1.30	$>$ .262	.004
E x T	4,164	0.28	$>$ .863	-.006	0.90	$>$ .456	-.001
E x T x G	8,164	1.65	$>$ .125	.01	1.04	$>$ .406	.001
I x T	1,41	0.14	$>$ .714	-.005	1.80	$>$ .187	.004
I x T x G	2,41	0.25	$>$ .777	-.009	2.35	$>$ .108	.015
E x R	24,984	**3.12**	$<$ **.003**	**.010**	**9.77**	$<$ **.0001**	**.038**
E x R x G	48,984	**1.77**	$<$ **.038**	**.007**	1.08	$>$ .375	.001
I x R	6,246	**3.79**	$<$ **.026**	**.009**	**3.73**	$<$ **.023**	**.01**
I x R x G	12,246	1.46	$>$ .221	.003	1.42	$>$ .227	.003
T x R	6,246	2.74	$=$ .058	.007	**5.80**	$<$ **.002**	**.019**
T x R x G	12,246	1.31	$>$ .268	.002	0.38	$>$ .864	-.005
E x I x T	4,164	1.26	$>$ .289	.001	0.73	$>$ .536	-.001
E x I x T x G	8,164	**2.11**	$<$ **.047**	**.002**	**2.17**	$<$ **.05**	**.008**
E x I x R	24,984	1.72	$>$ .114	.001	1.75	$>$ .105	.002
E x I x R x G	48,984	1.61	$=$ .087	.002	1.09	$>$ .365	.000
E x T x R	24,984	1.19	$>$ .307	.000	0.35	$>$ .941	-.002
E x T x R x G	48,984	1.24	$>$ .234	.001	1.04	$>$ .412	.000
I x T x R	6,246	0.11	$>$ .954	-.002	0.98	$>$ .406	-.000
I x T x R x G	12,246	0.88	$>$ .514	-.001	0.64	$>$ .699	-.002
E x I x T x R	24,984	0.61	$>$ .745	-.000	1.36	$>$ .222	.000
E x I x T x R x G	48,984	**1.93**	$<$ **.024**	**.002**	**1.74**	$<$ **.049**	**.002**

Table 7.4: Results from the omnibus ANOVAs, Experiment 1B. E = Emotion, I = Intelligibility, T = Task, R = Roi, G = Group.

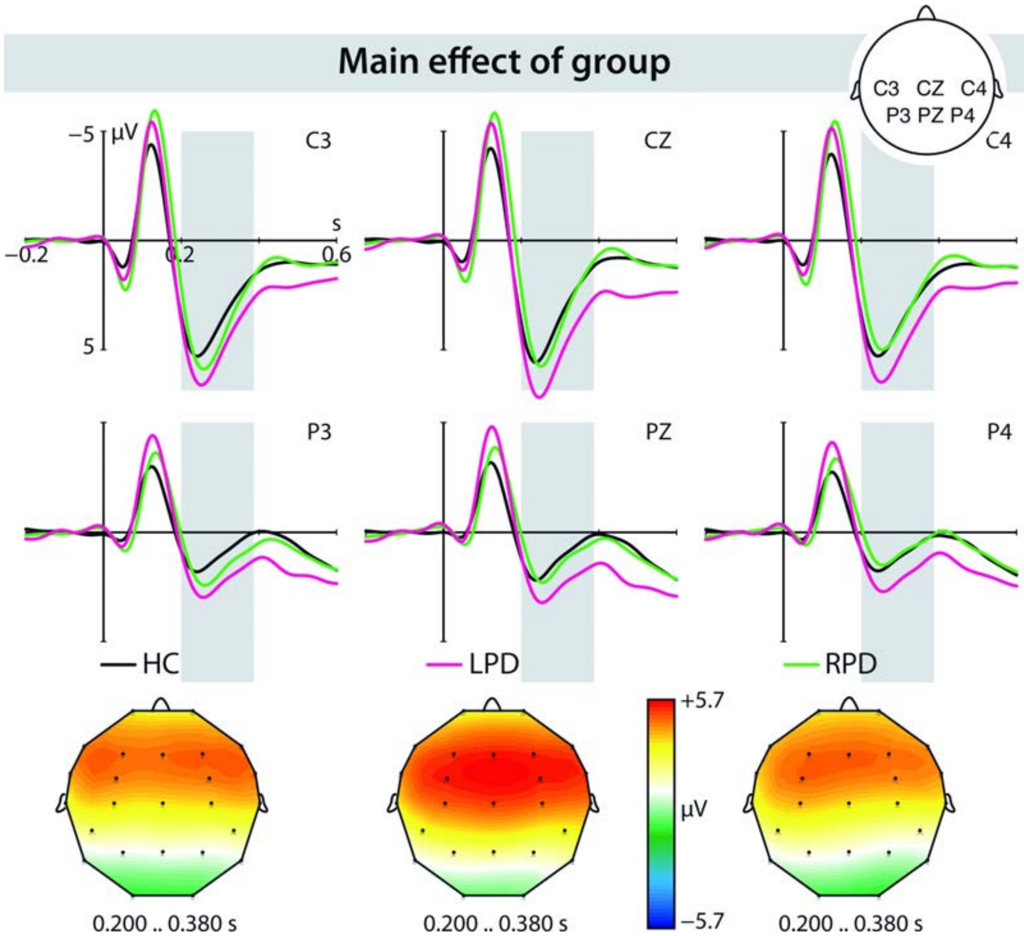

Figure 7.1: Main effect of group in the P200, Experiment 1B.

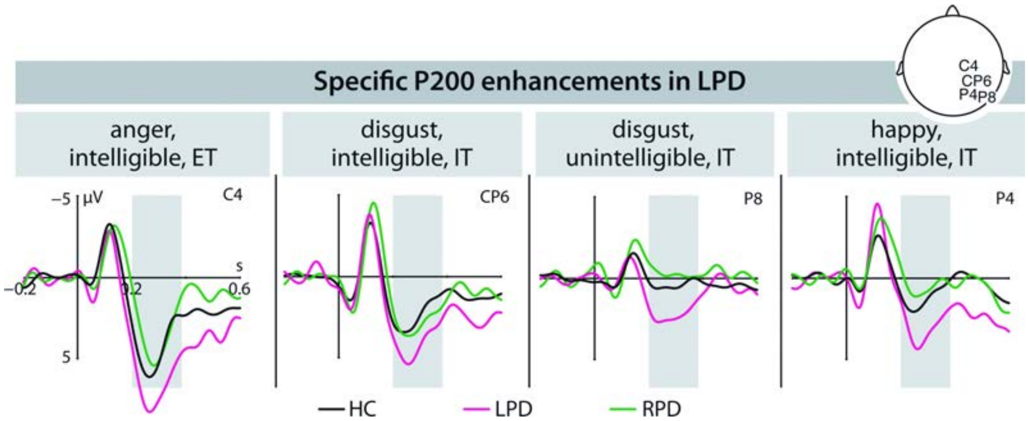

Figure 7.2: Specific P200 enhancements in the LPD group, Experiment 1B. IT = implicit task, ET = explicit task

Emotional salience detection was of outstanding interest for the present study, which is why the main effect of emotion was analyzed group-wise by means of contrasts between the neutral and the emotional conditions. A significant main effect of emotion could be confirmed in all three groups, LPD: $F(4,36) = 24.18$, $p < .0001$, RPD: $F(4,44) = 17.31$, $p < .0001$, and HC: $F(4,84) = 20.46$, $p < .0001$. All groups showed lower amplitudes to fearful versus neutral prosody, LPD: $F(1,9) = 34.06$, $p < .001$, RPD: $F(1,11) = 92.28$, $p < .0001$, and HC: $F(1,21) = 34.47$, $p < .0001$. The HC group also exhibited a reduced P200 amplitude for disgust, $F(1,21) = 7.78$, $p = .011$. This applied to the RPD group, too, although the difference was not significant after Bonferroni correction, $F(1,11) = 6.38$, $p < .029$. In the LPD group, there was no indication of a significant amplitude difference between disgust and neutral ($p > .675$). No group showed significant differences between anger and neutral (LPD: $p > .108$, RPD: $p > .255$, and HC: $p > .596$) or between happy and neutral (LPD: $p > .244$, RPD: $p = .281$, and HC: $p > .999$). Figure 7.3 shows the emotional salience detection for each group.

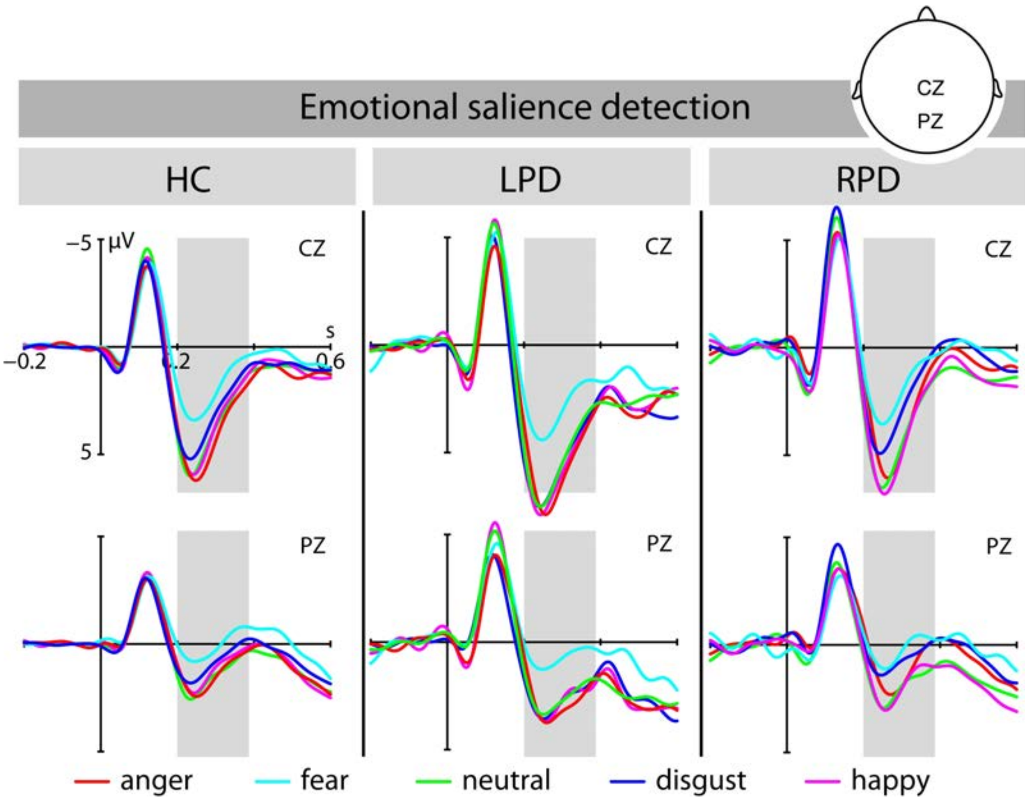

Figure 7.3: Emotional salience detection in each group, Experiment 1B.

The main effect of emotion became evident in reduced amplitudes to fearful, $F(1,41) = 116.52$, $p < .0001$, and disgust sentences, $F(1,41) = 11.12$, $p < .002$, compared to neutral. Anger ($p = .673$) and happiness ($p = .259$) did not significantly differ from neutral.

The emotion x roi interaction was analyzed by means of a roi-wise main effect of emotion. It became significant at LF, $F(4,164) = 52.97$, $p < .0001$, LC, $F(4,164) = 41.21$, $p < .0001$, LP, $F(4,164) = 9.77$, $p < .0001$, RF, $F(4,164) = 61.44$, $p < .0001$, RC, $F(4,164) = 61.06$, $p < .0001$, RP, $F(4,164) = 14.60$, $p < .0001$, and ML, $F(4,164) = 42.68$, $p < .0001$. Fearful sentences elicited significantly reduced amplitudes compared to neutral at all rois: LF, $F(1,41) = 91.57$, $p < .0001$, LC, $F(1,41) = 89.28$, $p < .0001$, LP, $F(1,41) = 30.42$, $p < .0001$, RF, $F(1,41) = 126.16$, $p < .0001$, RC, $F(1,41) = 124.71$, $p < .0001$, RP, $F(1,41) = 47.37$, $p < .0001$, and ML, $F(1,41) = 108.72$, $p < .0001$. Disgust differed significantly from neutral at rois LC, $F(1,41) = 11.01$, $p < .002$, LP, $F(1,41) = 9.16$, $p < .005$, RC, $F(1,41) = 11.18$, $p < .002$, and ML, $F(1,41) = 9.86$, $p < .004$, but not at LF ($p > .017$), RF ($p > .025$), or RP ($p > .013$). No significant anger-neutral (LF: $p > .43$, LC: $p > .815$, LP: $p > .187$, RF: $p > .057$, RC: $p > .395$, RP: $p > .704$, ML: $p > .601$) or happy-neutral difference (LF: $p > .037$, LC: $p > .222$, LP: $p > .734$, RF: $p > .077$, RC: $p > .315$, RP: $p > .263$, ML: $p > .372$) was observed.

The main effect of intelligibility was induced by higher P200 amplitudes to intelligible than unintelligible sentences. Furthermore, amplitudes were higher in the ET compared to the IT (main effect of task).

The intelligibility x roi interaction was also analyzed by roi. A significant main effect of intelligibility emerged at LF, $F(1,41) = 30.85$, $p < .0001$, LC, $F(1,41) = 72.81$, $p < .0001$, LP, $F(1,41) = 31.27$, $p < .0001$, RF, $F(1,41) = 13.43$, $p < .001$, RC, $F(1,41) = 22.77$, $p < .0001$, RP, $F(1,41) = 10.19$, $p < .003$, and ML, $F(1,41) = 33.05$, $p < .0001$, with higher amplitudes to intelligible than unintelligible sentences.

A step-down analysis of the emotion x intelligibility interaction yielded a significant main effect of intelligibility for disgust $F(1,41) = 35.77$, $p < .0001$, fear $F(1,41) = 7.44$, $p < .01$, happiness $F(1,41) = 6.03$, $p < .019$, and neutral $F(1,41) = 36.60$, $p < .0001$. Amplitudes were smaller to unintelligible than to intelligible sentences. No significant intelligibility effect was found for anger ($p > .766$).

Finally, the task x roi interaction was manifested in a significant main effect of task at rois LF, $F(1,41) = 12.22$, $p < .002$, LC, $F(1,41) = 4.56$, $p < .039$, RF, $F(1,41) = 12.65$, $p = .001$, and RC, $F(1,41) = 5.11$, $p < .03$, with higher amplitudes for the ET than the IT. Task was not significant at rois LP ($p > .979$), RP ($p > .754$), or ML ($p > .075$).

7.2.5 Correlations

The N100 amplitude in conditions with significant enhancements for patients did not significantly correlate with the composite scores, age, education, or the P300 amplitude. The right-posterior P200 amplitude to intelligible happy sentences during the IT (altered in LPD) correlated significantly with the composite score for working memory, $r = .43$,

$p < .004$. Correlations of altered ERP amplitudes with motor variables in PD are shown in Table 7.5.

Emotion	Intelligibility	Task	Roi	AI	LMS	RMS
N100 effects, LPD						
Happy	—overall—		RP	**-.55****	**-.49***	–
Happy	intelligible	ET	RP	-.45°	-.35	–
Happy	unintelligible	ET	RP	-.46°	-.28	–
Happy	unintelligible	IT	RP	-.46°	-.42	–
Disgust	intelligible	ET	LC ML	.10	.20	–
N100 effects, RPD						
Disgust	—overall—		LF LC RC ML	.38	–	-.41
Disgust	intelligible	ET	LF LC RF RC ML	.19	–	-.12
Fear	—overall—		RF	.26	–	-.33
Fear	unintelligible	ET	RP	-.42	–	.27
Neutral	intelligible	ET	LF RF	.36	–	-.41
P200 effects, LPD						
	—overall—			**.52***	.39	–
Anger	intelligible	ET	RC ML	**.65****	**.50***	–
Disgust		—overall—		**.63****	**.50***	–
Disgust	intelligible	IT	LF LC RF RC ML	.43°	.33	–
Disgust	unintelligible	IT	LP RP	**.50***	.26	–
Happy	intelligible	IT	RP	.41	.27	–

Table 7.5: Correlations of ERP amplitudes in Experiment 1B with left and right motor scores and the asymmetry index. ° $p < .05$, *$p < .025$, **$p < .01$.

7.2.6 Prosody categorization study

High recognition rates were achieved by all groups: LPD 78% (*SD* = 21.35), RPD 80% (*SD* = 22.36), and HC 85% (*SD* = 18.95). The main effect of group was not significant ($p > .065$), nor was the emotion x group ($p > .474$), intelligibility x group ($p > .211$), or emotion x intelligibility x group ($p = .952$) interaction.

A significant main effect of emotion was observed, $F(4,164) = 22.49$, $p < .0001$, $\omega^2 = .261$. Performance for neutral (92%) was significantly better than for disgust (72%), $F(1,41) = 58.07$, $p < .0001$, happiness (74%), $F(1,41) = 35.18$, $p < .0001$, and fear (86%), $F(1,41) = 10.73$, $p < .003$. For anger, percent-correct rates (88%) were not significantly different from neutral ($p > .055$).

Furthermore, the main effect of intelligibility became significant, $F(1,41) = 39.28$, $p < .0001$, $\omega^2 = 0.303$, with higher percent-correct rates for intelligible than unintelligible sentences (87% versus 72%).

The omnibus analysis yielded a significant emotion x intelligibility interaction, $F(4,164) = 3.00$, $p < 0.029$, $\omega^2 = .015$. Intelligibility influenced categorization performance for angry, $F(1,41) = 27.01$, $p < .0001$, disgusted, $F(1,41) = 16.98$, $p < .001$, fearful, $F(1,41) = 10.51$, $p < .003$, and neutral prosody, $F(1,41) = 5.86$, $p = .02$, with lower accuracy rates for unintelligible than intelligible speech. No intelligibility effect emerged for happy prosody ($p = .175$).

7.3 Discussion

The present study aimed to shed light on the early neural mechanisms of emotional prosody perception in PD as a function of motor symptom asymmetry. The P200, as the principal component of interest to this study, was altered in LPD but not in RPD patients. Thus, complementing previous neuroimaging evidence of a striatal involvement in receptive emotional prosody (Bach et al., 2008; Beaucousin et al., 2007; Grandjean et al., 2005; Kotz, Meyer, et al., 2003; Leitman et al., 2010; Morris et al., 1999; Phillips et al., 1998; Quadflieg et al., 2008; Wittfoth et al., 2010), the data indicate that the right striatum is involved in this process at an early point in time. This involvement could be reflected in an early bottom-up influence from the right striatum to superior temporal areas implicated in emotional prosody (Schirmer & Kotz, 2006) and would complement data indicating an interaction of the right striatum and superior temporal areas receptive to emotionally intoned speech (Ethofer et al., 2012). Furthermore, the point in time (P200) fits with previous MMN evidence by Schröder et al. (2006). The intact P200 response in RPD patients is in line with data from patients with left-striatal lesions (Paulmann et al., 2011). Thus, the left striatum may not be crucial for early emotional salience detection from prosody, and the data are consistent across etiologies (neurodegeneration versus lesion).

N100. In the first place, it must be considered that both patient groups exhibited N100 alterations. Thus, it cannot be discarded that early sensory deficits account for P200 alterations in the LPD group or that the RPD group also shows early deficits in emotional prosody perception, but they do not extend to the P200. However, this explanation is not that likely, as there was almost no overlap of conditions affected in the N100 and in the P200 in the LPD group and there were no P200 alterations in RPD. This points to a low correspondence between the processes reflected by these two components, respectively. Furthermore, correlations of motor scores and asymmetry indices with N100 amplitudes were almost all nonsignificant, apart from the right-posterior anomaly in LPD for processing happy prosody which furthermore extended to the P200. Thus, the right-posterior alterations for happy prosody in LPD may already start in the N100.

P200 alterations in specific conditions. Apart from the main effect of group, more detailed information on early emotional salience detection in LPD is provided by the interaction effects. The most wide-spread impairments became apparent for disgust. Implicit processing of this emotion was altered in the present study, and no amplitude reduction for disgust compared to neutral sentences was observed in the P200. The HC and RPD groups, in turn, showed this effect. The alterations in LPD are corroborated by correlations with motor variables, indicating a direct relation with the degree of right-striatal dysfunction.

To date, not much is known about a possible role of the striatum for emotional prosody perception. Pell and Leonard (2003) have previously considered the possibility of a BG involvement in receptive disgust prosody on the basis of behavioral data. Furthermore, activity in the right striatum has been observed when processing disgust from faces (Phillips et al., 1998). A recent meta-analysis reported that in visual presentation and mood induction studies, the disgust involvement of the right striatum is significantly greater than for anger, fear, or happiness (Vytal & Hamann, 2010). Generally, the striatum seems to play an important role for withdrawal emotions (Wager, Phan, Liberzon, & Taylor, 2003). Very interestingly, Mataix-Cols et al. (2008) reported a correlation between individual disgust sensitivity scores and the right-striatal response to disgust stimuli.

Thus, the right striatum may respond cross-modally to disgust cues which normally require a rapid withdrawal reaction. This would underline the presumed role of the striatum as an emotional-motor interface (Groenewegen & Trimble, 2007). However, Phillips et al. (1998) reported a dissociation between facial and vocal expressions of disgust, with the striatum reacting only to the former, which would not be in accord with the striatum as a cross-modal "disgust module". It must however be noted that in that study, the sample size ($N = 6$) was very small which limits the generalizability and statistical power of the results, and moreover the low temporal resolution of fMRI may not necessarily capture early processes of emotional salience detection from speech. Also, these researchers used emotional vocalizations, which may trigger different reactions than sentences, and the comparison condition were mildly happy stimuli instead of neutral ones. Happiness may itself trigger striatal reactions, as will be discussed below. Lastly, the sample consisted only of men who may be less sensitive to disgust stimuli than women (Haidt, McCauley, & Rozin, 1994). To sum up, more research on the role of the striatum for processing disgust cues is required. The present data indicate that the right striatum influences early emotional salience detection from prosody, which is in line with the pivotal role for disgust ascribed to the BG (Calder et al., 2001).

Another condition affected in the present study was explicit processing of intelligible anger stimuli. A significant correlation of the P200 enhancements in this condition with asymmetry indices and left motor scores foster this observation. An involvement of the striatum during the processing of angry speech intonation has been previously reported in the literature (Bach et al., 2008; Grandjean et al., 2005; Kotz, Meyer, et al., 2003; Quadflieg et al., 2008; Wittfoth et al., 2010) and is thus in line with the current results which furthermore indicate that the right striatum is involved already at an early point in time when attention is drawn to the emotionality of a vocal stimulus, i.e., during an explicit task. This fits with observations previously made by Bach et al. (2008).

Lastly, implicit processing of intelligible happiness stimuli was affected in LPD. This supports the previously assumed role of the striatum in processing happy speech intonation (Kotz, Meyer, et al., 2003; Kotz et al., 2006). While the evidence on emotional speech intonation is, however, still sparse concerning happiness, the right striatum appears to be one of the structures most consistently activated by happy facial expressions (Vytal & Hamann, 2010). Thus, aggregating these lines of evidence, a cross-modal striatal involvement in happiness processing may be assumed. Ariatti et al. (2008) have previously reported that LPD patients have difficulty recognizing happy prosody, which may be a consequence of impaired early emotional salience detection from this stimulus category.

To sum up on specific emotion deficits, disgust, anger, and happiness were affected in LPD. This result is not in line with accounts that have primarily associated PD with impaired processing of negative emotions (Dara et al., 2008; Gray & Tickle-Degnen, 2010; Pell & Leonard, 2003). According to the present results, deficits in PD may be more wide-spread. Furthermore, it becomes apparent that the convergence between the early neural response as assessed in this study and the behavioral categorization or rating performance from other studies is limited. Importantly, in the present study no deficits for fear were observed, while such impairments were evident in behavioral experiments (Breitenstein et al., 1998; Dara et al., 2008; Yip et al., 2003), and vocal fear processing seems to involve the striatum (Phillips et al., 1998). As fear is of outstanding evolutionary significance, its early perception may be intact in PD, while deficits could become apparent at later stages. This has previously been shown in the case of left-striatal lesions (Paulmann, Pell, & Kotz, 2009).

Regarding task, there was no clear pattern of impairments in the current study. While disgust was generally impaired, although more pronounced during implicit processing, anger was affected during explicit and happiness during implicit processing. Thus, the emotional category may be crucial. The behavioral categorization study yielded very high recognition rates for angry stimuli, while they were much lower for disgust and happiness.

Conversely, a gating study (Pell & Kotz, submitted) reported a much earlier recognition point for anger relative to disgust or happiness. Thus, these specific emotion categories appear to be associated with different levels of difficulty. These may interact with specific task demands that modulate the amount of attention drawn on these stimuli. Thus, it remains to be elucidated how the processing challenges imposed by different emotional categories interact with attention allocation modulated by task instructions.

As predicted, the processing of unintelligible speech proved to be largely intact in PD, apart from disgust which was associated with more wide-spread impairments in LPD. Thus, the data confirm previous reports of a greater striatal involvement in processing intelligible than unintelligible speech (Kotz, Meyer, et al., 2003; Kotz et al., 2006). An explanation for this involvement may be the proposed sequencing function previously ascribed to the BG (Kotz & Schwartze, 2010). More precisely, the BG may track the temporal patterns, pitch, and intensity variations conveyed by emotional speech in order to create a coherent percept (Kotz et al., in press; Paulmann & Pell, 2010b). A study by Breitenstein et al. (2001) provided evidence that PD patients have difficulty using speech rate information in order to successfully identify emotional prosody. Thus, there may be a potential impairment in LPD concerning the interaction of different emotional information channels, i.e., semantic and prosodic information. Therefore, in future PD investigations it would be interesting to shed more light on interactions between different communication channels providing emotional information.

Behavioral emotion categorization study. Unlike many other categorization studies, no impairments in explicit emotional prosody recognition were observed in the present experiment. This result is in line with findings from some previous studies of this kind (Blonder et al., 1989; U. S. Clark et al., 2008; Kan et al., 2002; Mitchell & Bouças, 2009). What must be considered, though, is the fact that the behavioral study took place after two complete EEG sessions and participants were thus very familiar with the stimuli presented in the behavioral experiment. Moreover, the patients showed a good performance in tests on cognitive functions, and cognitive variables may be related to performance in emotion categorization (Benke et al., 1998; Breitenstein et al., 2001; Pell & Leonard, 2003). The lack of cognitive impairments in the present patient sample, however, strengthens the experimental findings which are unlikely due to more generalized cognitive deficits.

Summary and conclusion. To sum up, the current data indicate that emotional salience detection from speech (P200) depends on the sidedness of motor symptoms in PD. While this function was preserved in RPD, LPD patients exhibited wide-spread impairments. This points to an important role for the right striatum in early vocal emotion perception and underlines that PD is not a uniform disorder. However, it must be considered that the BG involvement in PD is not completely unilateral. Already at early disease stages, both sides are involved in neurodegeneration and the laterality is thus only relative, but not absolute (Schwarz et al., 2000). Moreover, neural damage in PD is not confined to the BG (Braak et al., 2003; Tinaz et al., 2011), and it is not clear which role damage in additional brain regions may play. In any case, the group-specific results and the correlative findings of the present study are very telling and form a valid basis for future studies. In particular, as the impairments in LPD almost exclusively concerned intelligible speech, it would be interesting to further investigate the interactions of different emotional channels in PD.

Chapter 8

Experiment 2: Emotional priming

Emotion is a complex and multi-faceted construct, and emotional communication is of multisensory nature. It entails voice expressions (i.e., prosody), semantics, facial expressions, and gestures, among others. Information from all these channels is present in daily life when we perceive emotional information in others. While this seems a lot of input at a time, we normally benefit from this combination of different sources, as long as they provide congruent emotional information. This has been confirmed experimentally: Matching affective information provided concurrently by vocal and facial expressions leads to better emotion recognition performance than in unimodal input, while there is a performance decline with mismatching information (de Gelder & Vroomen, 2000; Föcker, Gondan, & Röder, 2011). In the following experiments, it was investigated how emotional information conveyed by facial expressions affects the processing of an emotionally matching or mismatching prosodic stimulus and vice versa.

To assess how the processing of affective information from one sensory channel affects the processing of another, two major streams of research have been proposed in the literature: One is to present both channels simultaneously, often accompanied by an instruction requiring participants to attend only one of them while ignoring the other, which can either convey matching or mismatching emotional information (de Gelder & Vroomen, 2000; Koizumi et al., 2011). Another means to assess the impact of one modality on another is cross-modal emotional priming, with one modality providing prime information and the other target information (Pell, 2005). In classical affective priming paradigms, two tasks are commonly used: evaluative decision and lexical decision. The evaluative decision aims at the affective valence of a target and can thus be considered an explicit task, while lexical decision involves a categorization of the target as representing a word or a non-word, and is thus implicit with respect to the emotional content. This lexical decision task illustrates how affective priming is classically tested, namely with written word stimuli (see Klauer & Musch, 2003, for a comprehensive overview of the affective priming literature).

As outlined in the introduction of this thesis, implicit tasks offer several benefits in emotion research. First, they allow examining whether emotional information is used by the perceiver even if task instructions do not require him to do so. Furthermore, an easy implicit task can reduce a potential processing load and thus lower the possibility that experimental results may be confounded with variables which are not task-related (e.g., executive functions). Lastly, in the context of basal ganglia diseases, it must be acknowledged that explicit tasks may engage the BG more than implicit ones (Bach et al., 2008; Beaucousin et al., 2007). However, with facial targets, the classical implicit task (lexical decision) cannot be used due to the nonverbal nature of these stimuli. In an attempt to develop a parallel of the lexical decision task for (cross-modal) emotional priming with facial targets, Pell (2005) invented the "Facial Affect Decision Task" (FADT), in which participants are asked whether a target face displays an emotion or not. Even though this task is not oriented towards emotional prime-target congruency, it has been shown to reliably induce priming effects at the behavioral level (Pell, 2005; Pell et al., 2011) as well as in the ERPs (Paulmann & Pell, 2010a) when prosodic cues serve as primes. Although the FADT does not require an evaluation of prime-target congruency, it is still oriented towards emotion, and the question remains whether cross-modal emotional priming works with a task that is completely implicit, i.e., not directed towards either emotion or congruency.

Some indication that this may work comes from Pourtois and colleagues (Pourtois et al., 2000, 2002). Congruency between emotional face primes and voice targets modulated the ERP response in the absence of a task. Participants were solely instructed to attend one modality and to ignore the other. However, the reverse prime-target assignment (i.e., prosodic primes and facial targets) still remains to be tested implicitly. Furthermore, in Pourtois et al.'s studies, the facial expression remained the same throughout the experiment and was combined with one of two possible emotional intonations as targets to manipulate congruency. Thus, it cannot be disclosed that the congruency effects in these studies were triggered by low-level features of the targets rather than by congruency per se.

In the part on emotional facial expressions (see section 3.4), the critical issue has been raised that most studies using face stimuli draw on static face stimuli, i.e., photographs or drawings. In daily life, however, we are exposed to dynamically changing facial information. Therefore, it would be more ecologically valid to use dynamic facial expressions in research as opposed to static ones. Some imaging studies have made direct comparisons of static and dynamic facial stimuli and revealed more wide-spread neural activation patterns, among others in temporal regions linked to the social relevance of stimuli (Sato et al., 2004; Trautmann et al., 2009). Thus, for the sake of higher ecological validity, the use of dynamic facial stimuli is recommended. Furthermore, the use of moving facial stimuli is expected to lead to a higher degree of convergence between primes and targets, as prosodic stimuli cannot be presented in a static manner.

To sum up, the basic approach of the current study was cross-modal and implicit emotional priming with facial and vocal expressions of emotion. This was investigated bidirectionally, i.e., with prosody and face once as prime and once as target stimuli, respectively. The use of dynamic facial expressions guaranteed a higher ecological validity of the face stimuli, as opposed to the more widely used static ones.

Chapter 9

Experiment 2A – Pilot study

The aim of this study was to test cross-modal emotional priming by means of ERPs in a sample of young, healthy participants. In emotional priming studies, an N400 modulation by prime-target congruency is a common observation (Paulmann & Pell, 2010a; Steinbeis & Koelsch, 2011; Zhang et al., 2006, 2010). Some studies have also reported effects at earlier processing stages, i.e., in the N100 (Pourtois et al., 2000) and P200 (Pourtois et al., 2000, 2002). Especially with regard to these earlier components, there is no clear picture as of yet, in which cases - or in which ones not - priming effects may be expected. Thus, an N400 congruency effect was expected in the present study, but with respect to early components the present study was rather explorative. In this context, it must also be considered that this is the first ERP priming study using dynamic emotional facial expressions, which entails the possibility that ERPs may be modulated differently than in research with static faces (Mayes, Pipingas, Silberstein, & Johnston, 2009).

Previous priming evidence, utilizing sentences with emotional intonation as a prime context, have reliably led to N400 modulations of visual target words (Schirmer et al., 2002, 2005). In order to ensure stimulus consistency we therefore used emotionally intoned sentences from Experiment 1. However, two major changes were implemented: First, as stimulus repetitions may have adverse effects on most types of priming (Schacter, Wig, & Stevens, 2007) except, of course, repetition priming, it may be useful to increase stimulus variability. This was accomplished by including four rather than two speakers, which prevented stimulus repetition. Second, only unintelligible speech stimuli were used. This was considered as necessary, as the use of semantic material may introduce a confound between the effects elicited by prosody and those elicited by semantics, and it would not be possible to disentangle priming by speech intonation from semantic priming. Even though at the behavioral level, priming effects elicited by pure-prosodic versus prosodic-semantic stimuli were comparable (Pell et al., 2011), it may still affect ERP results (Kotz

& Paulmann, 2007). Furthermore, it has been shown at the behavioral and at the ERP level that "pure prosody" leads to reliable cross-modal emotional priming effects (Paulmann & Pell, 2010a; Pell, 2005), indicating that the use of unintelligible speech is appropriate for the purposes of the present study.

In addition to the sentences, natural video recordings of the same four semi-professional actors who produced the prosodic stimuli were used, but excluding sound. To determine their length it was considered that the time course of emotional face processing seems to be largely comparable to emotional prosody (Paulmann & Pell, 2009). Furthermore, to ensure classical N400 priming effects, a prime stimulus (prosodic prime) needs to be at least 400 ms long (Paulmann & Pell, 2010a). It was thus determined that the presentation of dynamic facial expressions should be approximately 500 ms in order to match minimal prosodic context. This temporal reduction of face stimuli ensured that participants did not perceive cues from the speaker's lip movement and reduced the experiment duration compared to face stimuli of longer duration.

Another important aspect of the present study was speaker coherence, i.e., prime and target in one trial were always produced by the same speaker, which is not the case in many other studies of cross-modal emotion perception. This leads to a greater likelihood to consider face and voice as related stimuli (Föcker et al., 2011), and avoids possible influences of a speaker mismatch in the ERPs (Schweinberger, Kloth, & Robertson, 2011).

The perception of emotional information from different modalities is thought to be an automatic and mandatory process (de Gelder, Vroomen, & Pourtois, 2004). It also occurs under high perceptual load (Vroomen, Driver, & Gelder, 2001), and is even observed when facial expressions are not consciously perceived (de Gelder, Morris, & Dolan, 2005). These observations indicate that congruency effects in the current set-up may be observed in an implicit task, avoiding explicit emotional judgments.

In a first step, existing video material needed to be processed and rated for the use in the ERP study.

9.1 Rating study

Participants. Twenty-eight volunteers took part in an initial rating study. Three participants had to be excluded due to low performance (more than two standard deviations below the group mean for at least one emotional category). Thus, 25 participants (12 female) were included in the final sample. Their mean age was 25.48 years (*SD* = 2.63, range: 20 – 30). All participants had normal hearing and normal or corrected-to-normal vision and were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971), with a mean laterality quotient of 91.20 (*SD* = 11.29, range = 60 – 100). None reported any history of neurological or psychiatric illness. Participants were paid a total of seven Euros per hour for their participation.

Stimulus material. Black-and-white video stimuli of facial expressions produced by four semi-professional actors (two women) were used. These had been recorded while the actors produced emotionally intoned sentences and showed the corresponding facial expressions. For the present experiment, angry, happy, and neutral expressions were selected and edited with the video manipulation program Avidemux, version 2.4.3. The voice track was first removed from the videos; then the videos were cut into fragments of 520 ms duration. In order to avoid different emotion recognition points among the videos, it was assured that the respective facial expression could be recognized already at the beginning of the video. When necessary, videos were cropped to ensure that head size was comparable across all stimuli and that all faces appeared in a centered position. The image resolution was 720 x 576 pixels. Face width on the screen was approximately 10 centimeters. Videos were AVI files and used the MPEG-4 codec optimized for timing. The presentation rate was 25 frames per second.

For each actor and emotion, 40 videos were presented adding up to 160 stimuli per emotional category (angry, happy, neutral). Thus, the complete material consisted of 480 stimuli.

Procedure. The ratings were acquired in a single session which lasted about one hour. Participants sat in a quiet laboratory with a computer monitor and a computer keyboard directly in front of them. The stimuli were presented at the center of a computer screen in pseudo-randomized order that differed for each participant. 480 trials were presented, divided into eight blocks of equal length. To assess emotion recognition from the videos, a categorization task was applied in which participants chose between the labels “anger”, “happiness”, or “neutral”. Additionally, there was one button with a question mark on it. Participants were told to use it only when they could not decide on either one of the predefined labels. Arousal ratings were acquired using a nine-point SAM scale (self-assessment manikin; Bradley & Lang, 1994) on a different set of key presses of the computer keyboard. Participants were asked to rate the presented items on a scale ranging from “very calm”, represented at the left-most position of the scale, to “very aroused” at the right-most position.

A trial started with a black fixation cross on a gray background matched to the mean luminance of the videos. Then, a video was presented, followed by the question “How aroused?” printed on the screen, requiring an arousal rating, which had to be provided within four seconds. After the button press or after the response window had timed out, the question “Which emotion?” appeared on the screen. Response time was also set to a maximum of four seconds. After a short break of 1500 ms, the next trial started.

Data analysis. The purpose of this rating study was to select videos for an EEG study according to recognition rates. Therefore, a recognition rate was calculated for each video separately by dividing the count of participants who correctly identified the intended emotion from a video by the total number of subjects ($N = 25$). The obtained number was multiplied by 100 to obtain a percentage score. A ranking of videos was created for each actor and emotion separately, resulting in 12 rankings of 40 items each. These rankings provided the basis for stimulus selection in Experiment 2, which is described in more detail in section 9.2.1 for the pilot study and in section 10.1.2 for the patient study.

9.2 ERP study

9.2.1 Methods

Participants. Thirty-six volunteers took part in the second pilot experiment. Two of them were excluded from the sample due to excessive eye movements during the measurement. The remaining 34 participants (17 female) had a mean age of 24.74 years ($SD = 2.53$, range = 19 – 31) and were right-handed with a mean laterality quotient (Oldfield, 1971) of 90.29 ($SD = 11.15$, range = 66 – 100). All reported normal hearing abilities and normal or corrected-to-normal vision. None reported any history of neurological or psychiatric illness. Due to strong artifacts, data from one participant (male, 25 years, laterality quotient = 100) had to be excluded for the prosody-as-prime condition only. Likewise, another participant (female, 24 years, laterality quotient = 80) was excluded only for the video-as-prime condition. Thus, 33 subjects were included in each analysis. Participants were paid a financial compensation of seven Euros per hour for participating.

Stimulus material The video stimuli are described in section 9.1. Additionally, as indicated above, the same unintelligible sentence stimuli as utilized in Experiment 1 were used in the present study, but now including four (two female) instead of two actors. Stimulus rankings for each actor and the emotion categories happy and angry were used to select the sentence and video materials. For the prime and target positions, the 20 highest-ranking stimuli from each of the eight rankings (2 emotions x 4 actors) were selected, resulting in a set of 180 stimuli equally distributed across actors and emotional categories. Primes and targets were combined with each other. It was assured that prime and target were always produced by the same actor. Half of the happy prime stimuli were combined with a happy target, the other half with angry targets, and the same was done with the angry primes. This resulted in 80 congruent and 80 incongruent trials. Furthermore, 80 neutral primes were included as fillers in order to provide a non-emotional context; these neutral primes were combined with lower-ranking (positions 21 – 30 in each list) happy and angry stimuli as targets. Mean recognition rates of stimuli used in this experiment are listed in Table 9.1.

	Videos		Sentences	
Speaker	happy	angry	happy	angry
1	94	100	71	87
2	98	100	65	100
3	92	96	33	97
4	92	98	59	96

Table 9.1: Recognition rates in percent for the stimuli used in Experiment 2A. Note that for video stimuli, chance level was at 33% while for sentence stimuli it was at 14%.

Procedure The EEG was acquired in a single session with a total of 480 trials presented in a pseudo-randomized order that differed for each participant. The EEG measurements took place in an electrically shielded, sound-attenuated room. Participants sat in a comfortable chair at a distance of approximately one meter from the screen. In one half of the session, the videos served as primes and the sentences as targets; in the other half the procedure reversed. Half of the participants started with the video-as-prime condition, the other half with the prosody-as-prime condition. An implicit task (gender decision) was used to assess emotional priming in the absence of attention the emotion expressed in the respective stimuli. 50% of the participants pressed the "male" button with their left and the "female" button with their right hand, and the other half proceeded vice versa. The EEG recording took place in an electrically shielded, sound-attenuated EEG chamber. Participants sat in a comfortable chair at a distance of approximately one meter from the screen.

Sentences were presented via loudspeakers at a comfortable sound level which was held constant across participants. The videos were presented centrally on the screen at a visual angle of approximately three degrees from the center.

The trials started with a black fixation cross in the center of a grey background, which matched the mean luminance of the videos. Then, the prime was presented and after this, the target followed immediately without an inter-stimulus-interval. After target offset, a black question mark was displayed on the screen requiring the participant's response via button press. Response time was set at a maximum of four seconds. After the button press or after the response window had timed out, a blank screen was displayed for two seconds before the next trial started. Participants were instructed to refrain from blinking during the prime and target presentation. Figure 9.1 shows this sequence schematically.

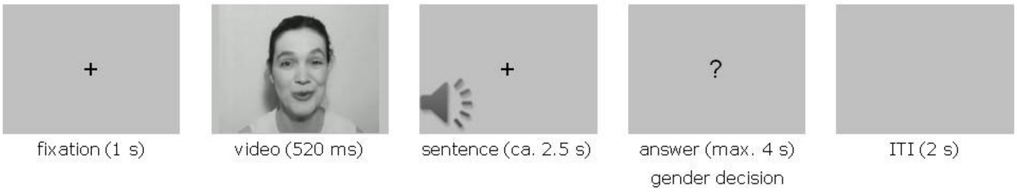

Figure 9.1: Trial scheme for Experiment 2. The sequence corresponds to the video-as-prime condition. In the prosody-as-prime condition, the prime-target sequence was reversed.

The 480 trials were divided into eight blocks of 60 stimuli. The total run-time of the experiment was about an hour.

Data acquisition and analysis Sixty-one Ag/AgCl electrodes mounted in an elastic cap were used to record the EEG from the scalp. The electrode locations following the nomenclature of the American Electroencephalographic Society (Sharbrough et al., 1991) were: FPZ, FP1, FP2, AFZ, AF3, AF4, AF7, AF8, FZ, F3, F4, F5, F6, F7, F8, F9, F10, FCZ, FC3, FC4, FC5, FC6, FT7, FT8, FT9, FT10, CZ, C1, C2, C3, C4, C5, C6, T7, T8, CPZ, CP3, CP4, CP5, CP6, TP7, TP8, TP9, TP10, PZ, P3, P4, P5, P6, P7, P8, P9, P10, POZ, PO3, PO4, PO7, PO8, OZ, O1, O2 (cf. Figure 1.1, for a graphical display of these locations). The data were recorded with a bandpass between DC and 140 Hz and digitized at a sampling rate of 500 Hz. An average reference was used during the recording. Offline, the data were re-referenced to the linked mastoids. Vertical and horizontal electrooculograms (EOG) were recorded bipolarly from above and below the right eye and bilateral outer canthi, respectively. The ground electrode was placed on the sternum. Electrode resistance was kept below five k. Data were filtered offline with a bandpass from 2 – 30 Hz (1135 coefficients, Blackman window). The strong highpass was necessary to obtain a valid in-stimulus baseline at target onset and to remove potential slow-wave activity resulting from late processing stages of the prime. An additional 12 Hz highpass filter was applied for graphical display only.

Only correctly-answered and artifact-free trials entered the analysis. Artifact rejection was accomplished in two steps: First, an automatic rejection algorithm identified trials, in which the EOG electrodes or CZ exceeded an amplitude of 30 or 40 V, respectively. The data were then scanned manually to detect additional artifacts.

For statistical purposes, seven topographical regions of interest (rois) were set up as follows: left-frontal (LF; F7, F5, F3, FT7, FC5, FC3), left-central (LC; T7, C5, C3, TP7, CP5, CP3), left-posterior (LP; P7, P5, P3, PO7, PO3, O1), right-frontal (RF; F8, F6, F4, FT8, FC6, FC4), right-central (RC; T8, C6, C4, TP8, CP6, CP4), right-posterior (RP; P8, P6, P4, PO8, PO4, O2), and midline (ML; AFZ, FZ, FCZ, CZ, CPZ, PZ). For auditory targets, epochs were constructed from 0 to 1000 ms post onset. For video targets, the epochs lasted from 0 to 520 ms time-locked to their onset. In both cases, the first 100 ms served as an in-stimulus baseline. Behavioral data were not analyzed in this study, as task performance was at ceiling (mean: 99% in both conditions). Furthermore, the response window was fixed and delayed, which did not allow to analyze reaction times.

Greenhouse-Geisser corrected *p*-values were used where necessary to correct for nonsphericity in the data. Effect sizes were calculated using ω^2 (Olejnik & Algina, 2003).

Video-as-prime condition. Three components were of interest in sentence targets: the N100, the P200, and the N400. Time-locked to the sentence onset, the N100 was analyzed from 80 – 150 ms, the P200 from 180 – 240 ms, and the N400 from 440 – 500 ms. A repeated-measures ANOVA was conducted with a 2 (target emotion) x 2 (congruency) x 7 (roi) general linear model with ERP amplitude as the dependent measure. All factors were treated as within-subjects variables.

Prosody-as-prime condition. In the dynamic facial target condition, early components were grouped into visual and fronto-central ERP components. For the analysis of the visual components, three posterior rois were constructed: visual-left (VL; P9, PO7, P7), visual-medial (VM; O1, OZ, O2), and visual-right (VR; P10, PO8, P8). For the fronto-central components, the rois LF, LC, RF, RC, and ML were used as defined above. Visual components of interest were the P1 (80 – 110 ms) and N170 (140 – 180 ms) and their fronto-central counterparts, i.e. the N100 (80 – 110 ms) and VPP (130 – 170 ms). The posterior P2 component (200 – 260 ms) was also analyzed and is named P2b throughout, following the terminology of Pourtois et al. (2002) due to its higher peak latency when compared to the fronto-central P2. Furthermore, a later stage negativity that appeared to be modulated by congruency was identified by visual inspection (280 – 380 ms). This window precedes the classical N400 time range, which is in accord with the notion that late negativities may show up earlier in response to emotional stimuli (Bostanov & Kotchoubey, 2004). A whole-head setup with seven rois as defined above was used to analyze this negativity.

9.3 ERP Results

9.3.1 Video-as-prime condition

The omnibus ANOVA results from three different time windows are shown in Table 9.2.

		N100 (80 – 150 ms)			P200 (180 – 240 ms)			N400 (440 – 500 ms)		
Effect	*df*	*F*	*p*	ω^2	*F*	*p*	ω^2	*F*	*p*	ω^2
E	1,32	0.06	> .8	-.014	0.27	> .603	-.011	0.33	> .572	-.010
C	1,32	0.19	> .664	-.012	0.18	> .673	-.013	0.43	> .518	-.009
E x C	1,32	0.22	> .64	-.007	2.55	> .12	.014	1.87	> .181	.008
E x R	6,192	1.14	> .334	.001	1.24	> .298	.001	2.46	> .078	.008
C x R	6,192	0.52	> .631	-.003	**2.99**	< **.041**	**.011**	1.01	= .387	.000
E x C x R	6,192	**3.25**	< **.038**	**.006**	2.18	> .103	.003	**3.09**	<.043	**.005**

Table 9.2: Results from the omnibus ANOVAs, Experiment 2A, with video as prime. E = Emotion, C = Congruency, R = Roi.

N100. A significant interaction of emotion and congruency was found at roi LP, $F(1,32) = 4.31$, $p < .047$. At the remaining rois, this interaction was not significant (LF: $p > .507$, LC: $p > .703$, RF: $p > .325$, RC: $p > .737$, RP: $p = .344$, and ML: $p > .165$). In this left-posterior region there was a main effect of congruency for happy targets, $F(1,32) = 5.15$, $p < .031$, with a more negative-going amplitude in response to incongruent than congruent trials (-2.74 V versus -2.37 V). Congruency did not significantly modulate the N100 amplitude in response to angry targets (-2.58 V versus -2.64 V; $p > .684$). The N100 congruency effect is displayed in Figure 9.2.

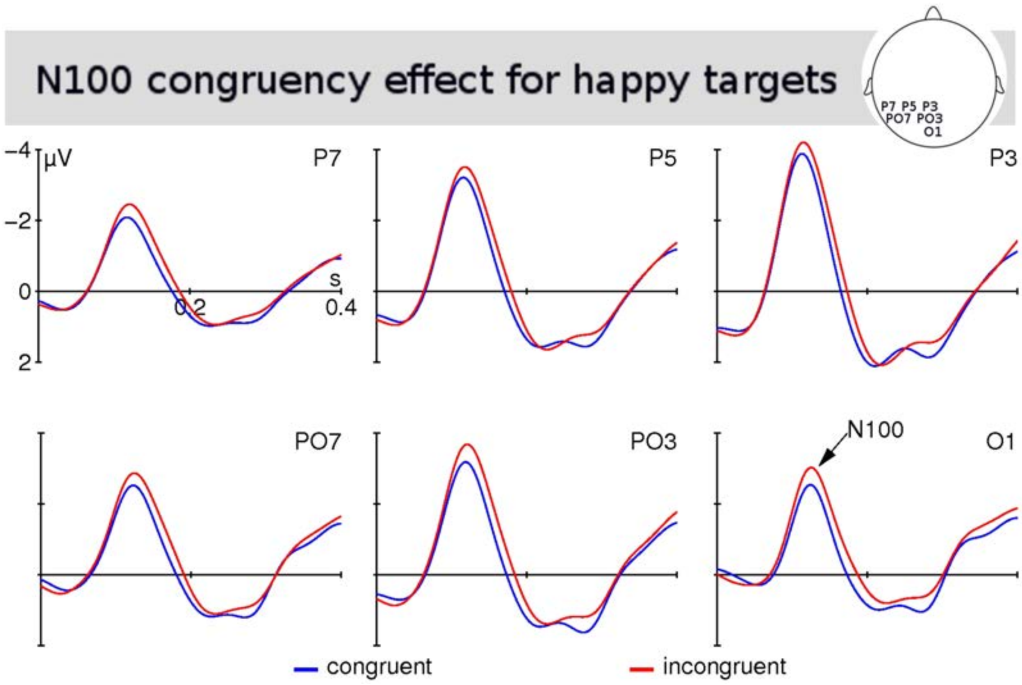

Figure 9.2: Congruency effect for happy targets in the N100, video as prime, Experiment 2A.

P200. A main effect of congruency was significant at left-frontal electrodes, $F(1,32) = 4.46$, $p < .043$, with higher P200 amplitudes for incongruent than congruent trials. At the remaining rois, the analysis did not yield any significant effects (LC: $p > .211$, LP: $p > .805$, RF: $p > .542$, RC: $p > .531$, RP: $p > .894$, and ML: $p > .471$). Figure 9.3 displays this effect.

N400. An interaction of emotion and congruency was significant at the left-frontal roi, $F(1,32) = 5.87$, $p < .022$, but not at the other rois (LC: $p > .06$, LP: $p > .074$, RF: $p > .494$, RC: $p > .976$, RP: $p > .887$, and ML: $p > .166$). A further step-down analysis confirmed a left-frontal main effect of congruency for happy targets, $F(1,32) = 8.16$, $p < .008$, but not

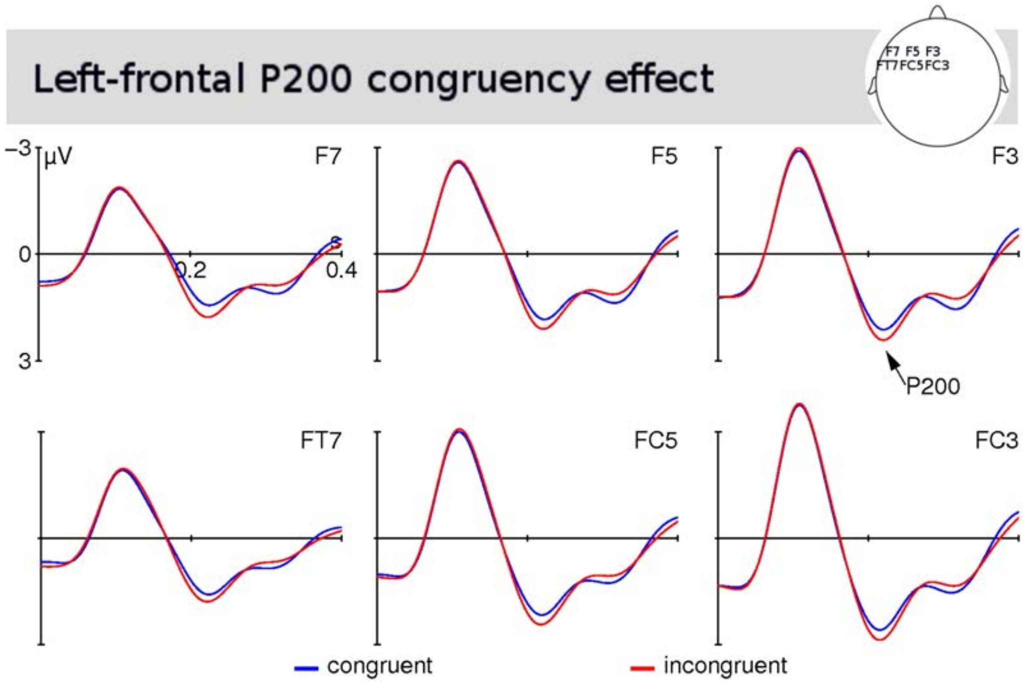

Figure 9.3: Congruency effect in the P200, video as prime, Experiment 2A.

for angry targets ($p > .327$). This congruency effect followed the classical N400 pattern, i.e., with more negative-going amplitudes in response to incongruent than congruent trials. See Figure 9.4 for a graphical display.

9.3.2 Prosody-as-prime condition

Tables 9.3 and 9.4 summarize the omnibus ANOVA results on different components in the prosody-as-prime condition.

N100 As can be seen in Table 9.3, a main effect of congruency emerged at the N100. It was pronounced in higher ERP amplitudes in the incongruent than in the congruent condition.

VPP. The analysis of the VPP returned no significant effects (see Table 9.3).

Negativity. The negativity was more pronounced for incongruent than congruent trials. Furthermore, ERPs were more negative-going in response to angry than happy targets. Figure 9.5 shows the congruency effects for video targets.

P1. No significant effects emerged in the analysis of the P1.

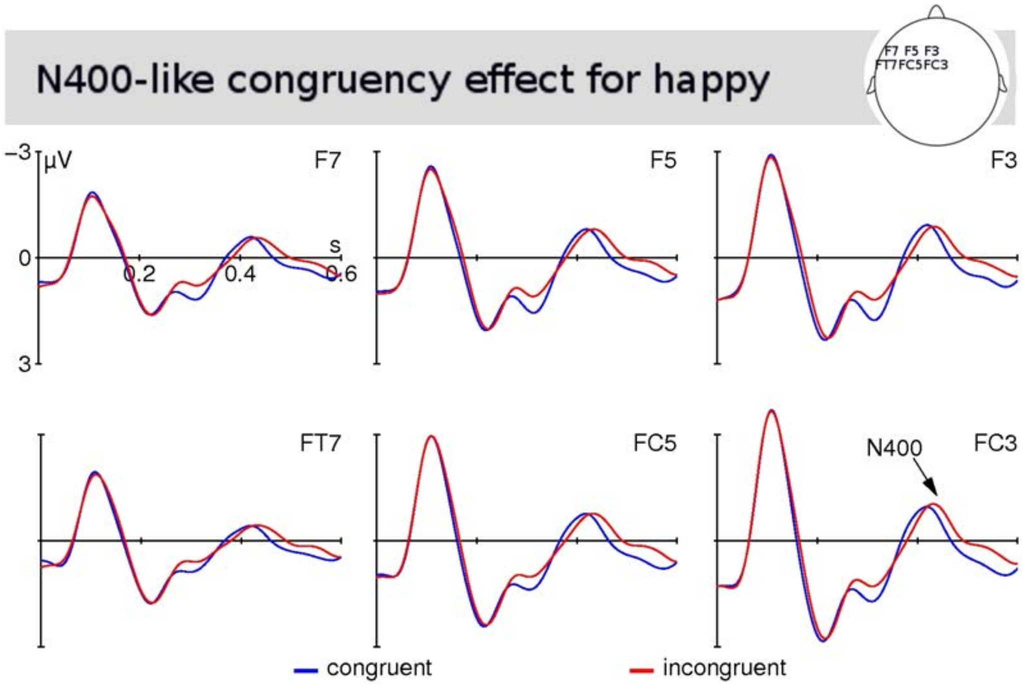

Figure 9.4: Congruency effect for happy targets in the N400, video as prime, Experiment 2A.

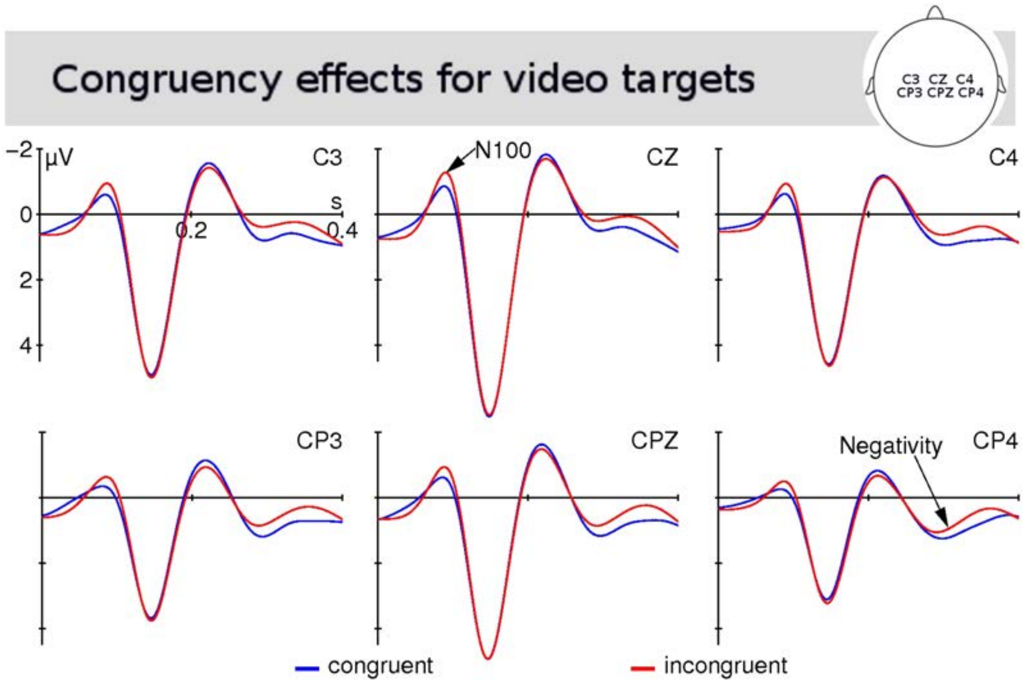

Figure 9.5: Congruency effects in the N100 and a later stage negativity, prosody as prime, Experiment 2A.

Effect	df	N100 (80 – 110 ms)			VPP (130–170 ms)			Negativity (280 – 380 ms)			
		F	p	ω^2	F	p	ω^2	df	F	p	ω^2
E	1,32	1.35	$>.253$	.005	1.10	$>.302$	.002	1,32	**5.04**	$<$ **.032**	**.058**
C	1,32	**5.46**	$<$ **.026**	**.063**	0.07	$>.793$	-.014	1,32	**5.98**	$<$ **.021**	**.070**
E x C	1,32	0.26	$>.614$	.007	0.03	$>.868$	-.009	1,32	0.44	$>.51$	-.005
E x R	4,128	0.04	$>.981$	-.008	0.70	$>.541$	-.002	6,192	2.01	$>.122$	.006
C x R	4,128	0.75	$>.52$	-.002	0.43	$>.614$	-.003	6,192	0.93	$>.422$	-.000
E x C x R	4,128	1.22	$>.303$	.001	1.17	$>.32$	.001	6,192	1.59	$>.199$	.002

Table 9.3: Results from the omnibus ANOVAs, Experiment 2A, with prosody as prime, fronto-central and whole-head components. E = Emotion, C = Congruency, R = Roi.

Effect	df	P1 (80 – 110 ms)			N170 (140–180 ms)			P2b (200 – 260 ms)		
		F	p	ω^2	F	p	ω^2	F	p	ω^2
E	1,32	0.87	$>.357$	-.002	1.09	$>.304$	.001	0.64	$=.43$	-.005
C	1,32	1.47	$>.234$	.007	1.96	$>.171$	.014	0.00	$>.973$	-.015
E x C	1,32	0.91	$>.347$	-.001	1.88	$>.179$	.008	0.41	$>.527$	-.005
E x R	2,64	1.93	$>.157$	.009	**3.80**	$<$ **.033**	**.025**	**5.03**	$>$ **.013**	**.035**
C x R	2,64	0.79	$>.434$	-.002	0.77	$>.44$	-.002	0.02	$>.969$	-.009
E x C x R	2,64	0.24	$>.695$	-.003	1.06	$>.328$	.000	0.34	$>.638$	-.002

Table 9.4: Results from the omnibus ANOVAs, Experiment 2A, with prosody as prime, visual components. E = Emotion, C = Congruency, R = Roi.

N170. To explore whether the N170 followed its characteristic pattern of higher amplitudes at the right than at the left hemisphere, the main effect of roi ($F[2,64] = 6.13$, $p < .005$) was tested with post-hoc contrasts. As expected, the N170 amplitude at right-posterior electrodes was significantly higher than at left-posterior sites, $F(1,32) = 8.86$, $p < .006$.

A significant main effect of roi emerged for both happy, $F(2,64) = 5.02$, $p < .012$, and angry targets, $F(2,64) = 6.94$, $p < .003$. In line with the global main effect of roi, N170 amplitudes were higher at right-posterior than at left-posterior leads for both stimulus types; happy, $F(1,32) = 7.32$, $p < .011$, and angry, $F(1,32) = 9.91$, $p < .004$.

P2b. A main effect of roi was confirmed for both emotions, happy: $F(2,64) = 7.59$, $p < .003$, and angry: $F(2,64) = 9.52$, $p < .001$. The statistical comparison of the P2b amplitude at the different rois indicated that for happy targets, amplitudes were higher at roi VR compared to VL, $F(1,32) = 8.95$, $p < .006$, and at roi VM compared to VL, $F(1,32) = 19.97$, $p < .0001$, but there was no significant difference between VM and VR ($p > .387$). A comparable picture emerged for anger, with a significant VL-VR difference, $F(1,32) = 5.96$, $p < .021$, and a significant difference between VL and VM, $F(1,32) = 20.87$, $p < .0001$. The difference between VM and VR was not significant ($p > .06$). For both emotions, the P2b was largest over centro-occipital electrodes (roi VM).

9.4 Discussion

The present study investigated cross-modal emotional priming with dynamic emotional facial and vocal expressions. An implicit task was used to study these stimuli without attention to the emotional expression provided by them. The fact that emotional congruency between primes and targets modulated a number of ERP components indicates that emotional congruency between ecologically valid stimuli from different modalities can be evaluated independent of attention allocation. This finding is in line with the view that the audiovisual interaction of emotional stimuli with high evolutionary significance proceeds in an automatic and mandatory manner (de Gelder et al., 2004). In the following, the findings of the present study are discussed in more detail.

Video-as-prime. Congruency effects started at a very early time point, namely in the N100. The early nature of this effect supports the results and conclusions drawn in Experiment 1: A coarse evaluation of vocally conveyed emotion, which would be crucial to detect an emotional prime-target mismatch, may already take place at this early point in time. Early ERP modulations by emotional prime-target congruency have previously been reported (Pourtois et al., 2000; Werheid et al., 2005) and are thus in accord with the present findings.

The congruency effect was, however, limited to happy targets and the critical question arises why the effect was not observed in the case of angry targets. One possible explanation would be that the perceptual incongruency of an angry face followed by a happy voice is greater than the opposite combination. On the other hand, when comparing the left-posterior mean N100 amplitudes in the four conditions of interest, it becomes apparent that in three of the four conditions (2 emotions x 2 congruency types), amplitudes were highly comparable whereas only in the congruent happy condition, the N100 amplitude was much less pronounced. This could mean that as soon as an angry stimulus is present, the N100 is enhanced as a result of potential threat and increased attention. Indeed, an enhanced N100 amplitude at posterior electrode-sites has been associated with increased attention allocation (Schirmer et al., 2011). Alternatively, the combination of positive visual and auditory stimuli may trigger ERP responses that differ from other conditions (Spreckelmeyer, Kutas, Urbach, Altenmüller, & Münte, 2006). In the latter study, emotional pictures were combined with a musical sound, and ERPs to the combination of two congruent happy stimuli contrasted strongly with the other conditions (sad, neutral, and happy in different combinations) in the P200. Thus, one may speculate that the higher ecological validity (i.e., dynamic face and voice stimuli) of the stimuli used in the present study may have led to comparable effects as in Spreckelmeyer et al. (2006), but at an earlier time point.

Interestingly, Pourtois et al. (2000), who also used facial expressions as primes and emotionally intoned voice stimuli as targets, reported an N100 reduction rather than an enhancement in response to incongruent trials. However, latter study did not use happy emotional stimuli. As the N100 congruency effect was only evident for happy targets in the present study, the results are not completely comparable. Furthermore, there was only one kind of incongruent condition in Pourtois et al.'s study, which cannot rule out the possibility that the congruency effect was elicited by physical stimulus differences between the targets. In addition, results with respect to priming and the N100 have to date not yielded consistent results: While an amplitude enhancement to incongruent or unprimed in comparison to congruent stimuli has been reported (Friedrich, Schild, & Röder, 2009; León, Díaz, Vega, & Hernández, 2010, see also Werheid et al., 2005), the pattern was reversed in other studies (Pourtois et al., 2000, H. T. Ho, personal communication). It is to date unclear how these rather conflicting results have emerged, and yet another set of studies did not find any N100 amplitude modulations by prime-target congruency (Goerlich et al., 2011; Paulmann & Pell, 2010a; Zhang et al., 2006, 2010). Thus, more research is needed to shed light on N100 effects in emotional priming paradigms.

The P200 result - an enhanced amplitude in response to incongruent compared to congruent trials - is in accord with what we already know about the role of this component in the processing of emotional prosody. On the one hand, neutral prosody elicits larger P200 amplitudes than emotional intonations (Paulmann & Kotz, 2008; Paulmann, Schmidt, et al., 2008), indicating facilitated processing of emotional information. Along these lines, the reduced P200 amplitude to emotional congruency in the present study may indicate the ease of processing of matching face-voice pairs. Moreover, the P200 has previously been shown to be affected by face-voice emotional congruency in terms of its latency (Pourtois et al., 2002) and, more importantly, the previous observation of a reduced P200 amplitude in the case of congruent audio-visual emotional input (Pourtois et al., 2000, but see Balconi & Carrera, 2011) could be replicated in the present study.

Finally, the N400-like late negativity followed the typical pattern of a more negative-going amplitude in response to incongruent than congruent targets. However, its left-frontal distribution is different from the classical centro-parietal topography reported in semantic studies (Kutas & Hillyard, 1980), a pattern that has previously been observed in cross-modal emotional priming, too (Paulmann & Pell, 2010a). On the other hand, frontal N400 effects have been previously reported in emotional contexts (Schirmer & Kotz, 2003; Zhang et al., 2010). Thus, the present results do not contradict prior evidence.

The N400-like negativity was only modulated for happy but not for angry targets. This again points to the above-mentioned possibility that the pairing of an angry face with a happy voice may subjectively imply a more significant mismatch than a happy face combined with an angry voice. Behavioral evidence from a study in which participants had to categorize facially conveyed emotion (happy or angry) while ignoring concurrent emotional prosody (happy or angry), revealed greater performance declines in the angry face-happy voice condition than in the happy face-angry voice condition when compared to their respective congruent conditions (Koizumi et al., 2011). These results may therefore confirm a higher perceptual mismatch in the angry face-happy voice condition. However, more research is necessary to test whether the N400 modulation in the present study could be due to a higher stimulus mismatch in the angry face-happy voice condition.

Prosody-as-prime. Again, the first ERP modulations by prime-target congruency were observed already in the N100. A previous study testing priming of emotional facial expressions by unintelligible prosodic stimuli did not report such early effects, but rather an ERP modulation by congruency in the N400 time window (Paulmann & Pell, 2010a). One reason for this dissociation may be the prime duration, which was only 200 or 400 ms in latter study compared to whole sentences in the present study. Indeed, in Paulmann and Pell's study 200 ms fragments induced reversed N400 effects, which indicates that

400 ms may provide just enough prosodic context to evoke a classical N400 pattern (see also Pell, 2005, for complementary behavioral data). The current data suggest that longer prime durations may be better suited to establish a valid emotional prosodic context and - as suggested by the present data - lead to earlier congruency modulations in the ERP response to targets. Furthermore, the prosodic stimuli in the present study had a “natural” ending, whereas in the study by Paulmann and Pell (2010a) sentence ending prosody was cut off. This factor could potentially have also played a role to lead to these different results.

The larger N100 amplitude in response to incongruent than to congruent stimuli as observed in the video-as-prime condition is supported by the respective results from the prosody-as-prime condition. Furthermore, the N100 in this part of the experiment - and opposed to the video-as-prime part - was pronounced in a main effect of congruency. Thus, while in the other condition there may be alternative explanations for the congruency effect in the N100 (see above), the N100 congruency effect in the prosody-as-prime condition is more likely to reflect a “real” congruency modulation.

The later stage negativity that was larger in incongruent than in congruent target trials started earlier than the classical N400; however, it is not unusual in emotion research to see such modulation at an earlier point in time (Bostanov & Kotchoubey, 2004).

Summary and conclusion. In sum, cross-modal emotional congruency between primes and targets modulated the ERPs at various time points in the present study. In both prime-target conditions, congruency effects could be observed as early as in the N100 and thus indicate an impact of emotional congruency at very early processing stages. However, in the video-as-prime condition, the N100 effect is probably not modulated by congruency per se, but rather by the presence or absence of angry stimuli, respectively, or by the combination of congruent happy stimuli. Future studies will have to elucidate this result by testing more emotional categories. This would allow to examine whether the mere presence of angry or congruent happy stimuli drive the N100 congruency effect, or whether congruency itself played a role. Furthermore, the inclusion of more emotional categories should clarify which theoretical approach fits best to explain the priming effects in the current study: affective priming in terms of positive or negative valence (see Klauer & Musch, 2003, for a review), or emotional priming in terms of different emotional categories (e.g., Paulmann & Pell, 2010a; Pell et al., 2011).

Moreover, more research is needed to test whether the early congruency effects in the prosody-as-prime condition, which have not been previously observed by Paulmann and Pell (2010a), are due to longer prime durations or the abrupt ending of the vocal primes in Paulmann and Pell’s study, or both. Lastly, the use of dynamic facial stimuli may add new value to emotion research, as dynamic facial stimuli are ecologically more valid than static ones, and they are processed differently at the neural level (e.g., Trautmann et al., 2009). Probably, these expressions elicit earlier effects than their static counterparts.

It must also be reflected what the effects in different components may mean; for example it is unlikely that congruency effects in the N100 reflect the same processes as the N400 modulations by prime-target congruency. The N100 is generally seen as a partly exogenuos component (Fabiani et al., 2007) and may reflect coarse stimulus evaluation in emotion research (Luo et al., 2010). On the other hand, the N400 is a component related to later, meaning-related cognitive processes (Kutas & Federmeier, 2011). Thus, even though both components may be modulated by emotional prime-target congruency, the underlying mechanisms that these modulations reflect may be quite different. This is strengthened by findings that an N400 modulation by congruency can be observed in the absence of an N100 congruency effect (Paulmann & Pell, 2010a; Steinbeis & Koelsch, 2011; Zhang et al., 2006).

The main purpose of the present study, however, was to test its appropriateness for its application in PD patients. The results indicate that this is indeed the case. Congruency effects were observed in both conditions and at several points in time, thus the design proves to be useful to test cross-modal emotional congruency effects. Furthermore, the experimental task poses low processing demands on elderly participants and thus can assure a high number of correctly responded trials and a good signal-to-noise ratio for ERP calculation.

Chapter 10

Experiment 2B – Patient study

In Experiment 1B it turned out that LPD patients may have problems in early emotional salience detection from emotional prosody. With the exception of disgust, which revealed more wide-spread impairments, the processing of speech conveying pure prosody devoid of semantics (unintelligible speech) was largely intact in LPD. This result points to the possibility that the problem may not be prosody per se, but rather the interaction of different input channels, such as prosody and semantics in Experiment 1B.

Generally speaking, congruent emotional stimuli from different channels lead to facilitated emotion recognition when compared to unimodal stimulation (Paulmann & Pell, 2011). In ERP studies, reduced latencies and amplitudes of early components (N100, P200) have also been related to this facilitation mechanism triggered by matching multimodal emotional input (Jessen & Kotz, 2011; Paulmann, Jessen, & Kotz, 2009). Conversely, it has been shown that PD patients benefit from multimodal as compared to unimodal emotion displays at the behavioral level (Paulmann & Pell, 2010b). However, as outlined previously, the convergence between early modulations in the ERP and later behavioral measures may not be very high. In fact, in Experiment 1B there were alterations at early processing stages in LPD, which affected almost exclusively intelligible speech stimuli. On the other hand, in the subsequent prosody categorization study all groups benefitted from semantics in terms of higher emotion recognition performance. Thus, and, as indicated by the findings in Experiment 1B, LPD may lead to early neural alterations when information from different input channels is provided, as opposed to a later stage benefit from multimodality in explicit emotion recognition.

With this in mind, it would be interesting to look at the early interplay between vocal and facial expressions in PD. This would represent a step towards higher ecological validity and a higher proximity to communicative situations encountered in everyday life. It would also help to test whether possible deficits, which lie in the interaction of different input channels (as prosody and semantics in Experiment 1B) generalize to the combination of two non-verbal stimuli, i.e., vocal and facial emotion.

Cross-modal emotional priming seems to be a particularly adequate approach to test the interaction between these two communicative channels. On the one hand, it allows detecting the impact of one modality on the other bidirectionally. On the other hand, the fact that each modality once serves as prime allows controlling for possible group differences that occur already at the prime position and are thus related to the processing of the stimulus quality itself. This should allow clarifying whether possible group effects at the target level are driven by differences in emotional priming mechanisms or whether they reflect more generalized group differences related to the processing of emotional facial or vocal stimuli per se.

In order to reduce the possibility of group differences that depend on the stimulus quality per se, unintelligible speech stimuli expressing anger and happiness were selected for the present study. These stimuli did not lead to changes in the P200 modulation in LPD patients in Experiment 1B. Furthermore, dynamic facial expressions of these vocalized emotions were included. It has previously been shown that PD patients benefit from dynamic as opposed to static faces in emotion recognition tasks (Kan et al., 2002, but see Paulmann & Pell, 2010b). However, no such data exist at the neural level. Considering that static faces may trigger motor simulation processes in the observer (see Bastiaansen, Thioux, & Keysers, 2009, for an overview), especially PD patients whose motor system is impaired may benefit from dynamic stimulus input. Such a position has recently been advocated by de Gelder and van den Stock (2010), who consider that the use of dynamic visual stimuli may be beneficial particularly in patient studies.

There is one study in the literature which investigated emotion processing from faces in PD with ERPs (Wieser et al., in press). The authors reported group effects in an EPN-like component starting 240 ms after face onset while early visual processing (P1, N170) was intact. Thus, the early processing stages which are of outstanding interest in the present study, and which have been shown to respond to congruency in the previously reported pilot experiment, will probably not be affected by group differences. With regard to the later processing stage deficits in Wieser et al.'s study, it is not yet clear how group differences may be affected by stimulus dynamics. It is also not clear whether there may be group differences in terms of early fronto-central components, as Wieser et al. (in press) focused their analyses exclusively on electrodes over visual areas. Finally, the central topic of this thesis, namely motor symptom asymmetry, was not considered in latter study, but may probably play an important role in emotion processing according to the results in Experiment 1B.

In summary, the present study aims to specify whether PD affects cross-modal emotional priming. While this mechanism appears to be fairly intact at the behavioral level, at least in the case of prosodic primes and facial targets (Pell & Dara, 2007), early neural mechanisms of cross-modal emotional priming in PD are still to be explored. Assuming that there are no group differences with respect to the processing of the unintelligible prosodic stimuli used in the present study (cf. results of Experiment 1B), it will be possible to test cross-modal interactions of emotional channels in PD independent of more generalized group differences in the processing of vocal stimuli. More generalized group differences in processing vocal and facial stimuli can be assessed by means of analyzing how these cues are processed when presented as primes. Thus, the experiment is well suited to address possible problems in stimulus binding in PD (Paulmann & Pell, 2010b).

The findings from the pilot study (Experiment 2A) indicated an early interaction of emotional channels in the N100 component (congruency effect). Thus, generally speaking, early congruency effects may also be observed in the present study, but are probably modulated by group. If it is indeed the interaction of two information channels, which is particularly affected in LPD, then this PD group should show early ERP alterations in response to prosodic targets, indicating that prior information provided by dynamic facial expressions is not effectively used during prosodic target processing. As stated above, the paradigm also allows testing for group differences in emotional face processing per se, which may be an alternative explanation for altered or absent congruency effects in (LPD) patients. With respect to the reverse prime-target assignment (i.e., prosody as prime), one would expect altered congruency effects on dynamic face target processing if LPD impairs the processing of the prosodic contour of whole-sentence primes, which may either be a consequence of early deficits and/or later stage deficits in processing the sentence primes. According to previous behavioral evidence (Pell & Dara, 2007), PD patients show intact priming of facial expressions by sentence primes in unintelligible speech, while this mechanism has not been tested as a function of motor symptom asymmetry. Regarding RPD patients, the present study is rather explorative as no predictions can be made based on the literature nor the previous results gathered in the present thesis. If intact emotional prosody processing in RPD - as observed in Experiment 1B - can be replicated in the present study, and if intact emotion processing also holds true for dynamic facial expressions in RPD, then no differences in comparison to elderly controls are expected in RPD patients.

10.1 Methods

10.1.1 Participants

The patient group consisted of 12 PD patients with left-sided disease onset (LPD) and 12 with right-sided disease onset (RPD). Furthermore, 12 HC participants were tested. A comparative overview of different demographic and disease-related variables for the groups is presented in Table 10.1. The LPD group included six, the RPD group four, and the HC group five women. All participants were right-handed according to the Edinburgh Handedness inventory (Oldfield, 1971). Participants were native speakers of German and reported no history of neurological or psychiatric illness except PD. Detailed information about the patient sample is provided in Table 10.2.

A pure-tone audiometric screening procedure was conducted with all participants testing three different frequencies most relevant to human speech: 0.5 kHz, 1 kHz, and 2 kHz. Each participant was able to perceive the tones at a sound pressure level of 35 dB or lower with the better ear. Patients were paid eight Euros and controls seven Euros per hour for their participation, and travel expenses were reimbursed.

Informed consent in accord with the Declaration of Helsinki was obtained from all participants before testing. The study was approved by the local Ethics Committee at the University of Leipzig.

Variable	HC	LPD	RPD	p
Age	66.17 (8.79)	65.50 (7.81)	64.92 (8.12)	$= .858$
Age range	49–75	53–74	47–75	
Education[1]	14.23 (1.71)	14.17 (2.68)	14.58 (3.94)	$> .95$
Handedness	96.83 (6.00)	92.92 (14.55)	86.92 (18.72)	$> .328$
MMSE	29.33 (1.07)	28.75 (1.14)	29.00 (0.95)	$= .286$
BDI	5.58 (3.68)	9.25 (5.48)	8.00 (5.51)	$> .296$
Hoehn & Yahr median (range)	–	2 (1–3)	2 (2–2)	$> .09$
UPDRS motor score	–	22.33 (9.19)	18.67 (7.49)	$> .268$
Disease duration[2]	–	5.83 (4.13)	4.25 (1.48)	$= .673$

Table 10.1: Summary of group characteristics with means, standard deviations (in brackets), and statistics. [1]years of formal education, [2]in years since diagnosis.

10.1.2 Stimulus material

The same stimuli as in the pilot study were used; however, to shorten the experiment duration, the total number of trials was reduced to 288, with 144 trials in the prosody-as-prime condition and 144 trials in the video-as-prime condition. For the primes and targets, the top 12 stimuli of each ranking (2 emotion categories x 4 actors) were selected. Six stimuli from the lower ranking positions (13 to 18) of each list were assigned as targets for the included neutral filler primes (12 for each actor). Table 10.3 displays the mean recognition rates for prime and target stimuli used in this experiment.

No.	Age	Sex	Dur	Type	Med	HY	MS	L/R	MM	BDI
Left-onset group (LPD)										
01	66	m	7	ar	L[1] D M	3	24	8/4	29	2
02	70	f	17	eq	L[1,3] D	3	35	13/9	30	15
03	67	f	9	eq	L[1] D M	2	8	2/0	29	3
04	72	m	3	eq	L[3] D	3	26	8/6	28	16
05	61	f	5	eq	D M	2	21	12/4	28	14
06	53	m	5	eq	D	2	35	13/11	28	5
07	73	m	4	eq	L D	2	22	11/5	30	12
08	53	f	4	eq	D M	2	13	8/2	29	14
09	74	m	2	eq	D	2	33	14/8	26	5
10	74	f	8	eq	L[1] D	2	24	10/7	29	6
11	66	f	3	eq	D M	1	10	6/1	29	4
12	57	m	3	ar	L[2] D	2	17	7/2	30	15
Right-onset group (RPD)										
13	75	m	4	td	L[2] D	2	17	1/10	29	12
14	75	m	5	td	D	2	23	6/9	29	4
15	68	m	4	eq	D	2	29	7/9	29	9
16	69	m	5	td	D M	2	14	2/8	30	10
17	56	m	2	td	D M	2	15	3/6	29	3
18	64	f	1	td	D	2	12	2/6	30	8
19	72	f	6	eq	L[1,3] D	2	12	3/4	28	3
20	64	f	4	eq	L[3] D	2	18	5/9	29	6
21	67	m	5	eq	L[2],3 D	2	20	2/9	30	15
22	47	f	5	eq	D M G	2	20	8/6	27	n/a
23	63	m	6	eq	L[1,2] D	2	35	8/17	30	18
24	59	m	4	ar	D M	2	9	1/5	28	0

Table 10.2: Detailed patient history. Dur: disease duration (years); Med: medication; HY: Hoehn & Yahr stage; MS: motor score (UPDRS); L/R: left/right motor score; MM: Mini-Mental Status Examination; eq: equivalent, ar: akineto-rigid, tr: tremor dominant; L: levodopa ([1] + benserazide, [2] + carbidopa, [3] + carbidopa and COMT inhibitor), D: dopamine agonist, G: glutamate antagonist, M: MAO inhibitor, C: COMT inhibitor.

	Videos		Sentences	
Speaker	happy	angry	happy	angry
1	97	100	77	90
2	100	100	69	100
3	96	97	41	98
4	95	100	65	98

Table 10.3: Recognition rates in percent for the stimuli used in Experiment 2B. Note that for video stimuli, chance level was at 33% while for sentence stimuli it was at 14%.

An oddball sequence was run to test voluntary attention allocation, with 80% 600 Hz tones as standards and 20% 660 Hz tones as deviants, each with a duration of 200 ms. A total of 180 trials was presented with an inter-stimulus-interval of 1000 ms.

Comprehensive background measures were employed to test cognitive functions and psychopathology. The test battery included the Mini-Mental Status Examination (Folstein et al., 1975) to screen for dementia. To assess basic cognitive and perceptual functions, the Benton Facial Recognition Test (Benton et al., 1983), an in-house phoneme discrimination test, and the Token Test (De Renzi & Vignolo, 1962) were used. Working memory and sustained attention were evaluated with the forward and backward digit spans (Wechsler, 1997), a letter counting span (task: report the number of letters in a mixed sequence of letters and numbers, taken from Pagonabarraga et al., 2008), a rearranging span (task: rearrange a mixed sequence of letters and numbers, taken from Pagonabarraga et al., 2008), and an in-house listening span test (auditory version of the reading span by Daneman & Carpenter, 1980, translated into German). Frontal functions were tested with the Trail-Making Test, part A and B (Reitan, 1992), and several word fluency measures (phonemic fluency, alternating phonemic-semantic fluency, action verbs fluency). As hemispatial neglect may affect PD patients (Lee, Harris, Atkinson, & Fowler, 2001) it was screened for with a modified Albert's line cancellation test (Albert, 1973) and a clock-drawing test. Finally, to screen for depression, participants completed the Beck Depression Inventory (Beck et al., 1961).

10.1.3 Procedure

Participants were invited to a neuropsychological testing session and one EEG session. The clinical assessment (anamnesis, UPDRS rating, and Hoehn and Yahr staging) was accomplished in parallel by an experienced neurologist. Patients were on their habitual anti-Parkinsonian medication during all measurements. In the behavioral testing session, all background tests were applied and handedness was assessed. The EEG session was comparable to the pilot study (Experiment 2A), but the total number of 288 trials was divided into six blocks of 46 trials each. Measurements took place in an electrically shielded, sound-attenuated room. Participants sat in a comfortable chair at a distance of approximately one meter from the screen. To balance potential fatigue or vigilance effects in the respective prime-target sequences, the conditions (i.e., prosody-as-prime versus video-as-prime) alternated from block to block. Half of the participants started with a prosody-as-prime block, and the other half with a video-as-prime block. Participants engaged in a gender decision task, with 50% pressing the "male" button with their left and the "female" button with their right hand and vice versa.

The trials started with a black fixation cross in the center of a grey background screen, which matched the mean luminance of the videos. Then, the prime was presented followed by immediate target presentation (inter-stimulus-interval: 0 ms). After the target offset, a black question mark appeared on the screen requiring the participant's response via button press. Response time was set at a maximum of four seconds. After the button press or after the response window had timed out, a blank screen was displayed for two seconds before the next trial started. The experiment duration was approximately 40 minutes.

The videos were presented centrally on the screen at three degrees visual angle. Sound pressure level was adjusted for every participant individually. To this end, participants listened to neutral sentences in unintelligible speech from all four actors presented via loudspeakers. These sentences were from the same stimulus battery as the experimental stimuli, but they were not presented in the EEG experiment. Several sequences with ascending and descending volumes were run. Participants were instructed to press a button as soon as they could hear a stimulus or as soon as they did not hear the stimulus anymore, respectively. The so obtained values were then used to calculate a hearing threshold. A constant, which was the same for all participants, was added to this identified threshold, thereby defining a comfortable individual sound pressure level for the EEG study. This procedure was performed before the oddball experiment and lasted about five minutes.

The oddball experiment was run at the beginning of the EEG session. Participants were instructed to press a button on each deviant sound. This procedure lasted about five minutes.

10.1.4 Data acquisition and analysis

The EEG was recorded from 27 Ag/AgCl scalp electrodes mounted in an elastic cap and including the following locations: FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FC4, FT8, T7, C3, CZ, C4, T8, CP5, CP6, P7, PO7, P3, PZ, P4, P8, PO8, O1, and O2 (cf. Figure 1.1, for a graphical display of these locations). Acquisition was carried out with a bandpass between DC and 250 Hz and the sampling rate was 500 Hz. The ground electrode was placed on the sternum. Electrode resistance was kept below five k. An average reference was used during the measurement, and electrodes were re-referenced to linked mastoids offline. A bandpass filter was applied to the data offline (2 – 30 Hz, 1135 points, Blackman window). An additional 12 Hz lowpass filter was used only for graphical illustrations. Similar to the first patient study reported in chapter 7, an EOG correction procedure (Pfeifer et al., 1995) was used to increase the number of trials for the statistical analysis. ERPs were time-locked to the target onset, with the first 100 ms as an in-stimulus baseline. In the video-as-prime condition, the sentence targets were averaged over 1000 ms. In the prosody-as-prime condition, the averaging window for video targets was 520 ms, matching the duration of the videos. Furthermore, for control purposes, the ERPs to primes were averaged over 1000 ms time-locked to their onset with a 200 ms pre-stimulus baseline.

Topographical regions of interest (rois) were formed as follows: left-frontal (LF; FT7, F3, FC3), left-central (LC; T7, C3, CP5), left-posterior (LP; P7, P3, O1), right-frontal (RF; FT8, F4, FC4), left-central (LC; T7, C3, CP5), right-central (RC; T8, C4, CP6), right-posterior (RP; P8, P4, O2), and midline (ML; FZ, CZ, PZ). The ERP data were transformed for normality before conducting the ANOVA, as the robustness of ANOVA against violations of normality decreases with smaller sample sizes. The following procedure was adopted to do so: Transform regression was run in SAS 8.02 to estimate the most suitable lambda value for the Box-Cox transformation procedure (Box & Cox, 1964). This lambda was then used in the Box-Cox formula in order to transform the data. Before transformation, a constant was added to all data to ensure that no data point had a value below one, as the Box-Cox transformation can only handle positive data, which should ideally be greater than one (LaLonde, 2005). Adding a constant is a linear transformation and does therefore not alter the data distribution.

The threefold between-subjects factor group (LPD, RPD, and HC) was included into all analyses. All main effects of group were followed up using Tukey's HSD test.

Video-as-prime condition. As in the pilot study, the N100 (90 – 150 ms), the P200 (200 – 250 ms), and a later stage negativity preceding the classical N400 time window (290 – 350 ms) were identified by visual inspection and analyzed in a 2 (target emotion) x 2 (congruency) x 7 (roi) general linear model analysis, additionally including the threefold between-subjects factor group.

Prosody-as-prime condition. Visual and fronto-central potentials were analyzed separately, comprising the visual components P1 (80 – 110 ms), N170 (140 – 180 ms), and P2b (210 – 270 ms), as well as the fronto-central components N100 (80 – 110 ms) and VPP (140 – 180 ms). The fronto-central components were measured over five rois, i.e., LF, LC, RF, RC, and ML as defined above. For the early visual components, three visual rois were constructed, namely visual-left (VL; P7, PO7), visual-medial (VM; O1, O2), and visual-right (VR; P8, PO8). A later stage N400-like negativity (420 – 500 ms) was analyzed in a whole-head setup with seven rois as defined above.

Analysis of the primes. Sentence primes were analyzed for group differences in the N100 (100–160 ms), P200 (210–310 ms), and a subsequent negativity (360–460 ms) in a 2 (emotion) x 7 (roi) x 3 (group) analysis. For video primes, the fronto-central components N100 (70–110 ms), VPP (140–180 ms), and N2 (270–400 ms) were analyzed at rois LF, LC, RF, RC, and ML. At the visual rois (VL, VM, and VR, as defined above), the P1 (70–110 ms), N170 (130–170 ms), and P2b (210–310 ms) were analyzed. Only effects involving the group factor are reported for these analyses, as their only purpose was to test for group effects related to stimulus processing per se.

Additional issues of the analysis. Behavioral data were not analyzed, as performance was at ceiling in both prime-target conditions (video-as-prime: 99%, prosody-as-prime: 98%). Furthermore, the time window to provide a behavioral response was fixed and temporally delayed, which does not allow analyzing reaction times.

The oddball P300 was quantified in a time window from 300 – 500 ms after tone onset, and an in-stimulus baseline during the first 100 ms after tone onset was used. The oddball data were filtered with a bandpass from 0.5 – 30 Hz (1751 points, Hamming window). Statistical analysis was accomplished in a 2 (condition) x 7 (roi) x 3 (group) ANOVA.

Test scores were analyzed with nonparametric Kruskal-Wallis tests in conjunction with Monte Carlo exact estimates. These tests were followed up with Mann-Whitney tests in the case of a significant result (alpha level: $p < .017$ due to multiple comparisons). BDI data from one RPD patient were missing as she forgot to fill out the back page of this test. The phoneme discrimination, the neglect screenings, and the Token Test were not included in the analyses, as they only served to ensure intact basic perceptual and cognitive functions. No deficits were detected in these tests.

Two composite scores were constructed for correlation purposes: an **executive score** involving the scales alternating verbal fluency, action verbal fluency, and Trail-Making test part B, and a **working memory/sustained attention** score comprising listening span, backward digit span, rearranging span and letter counting. These composite scores were calculated based on z-scores for each test, which were computed in relation to the entire sample ($N = 36$).

Spearman correlations were computed to assess possible relationships of these two composite scores, as well as the disease-related variables left motor score, right motor score, asymmetry index (see section 7.1.1), and total motor score with the ERPs. These analyses are specified in more detail in the results section.

10.2 Results

10.2.1 Test scores

Only one test revealed a significant group effect, namely the listening span, $H(2) = 9.36$, $p < .005$. RPD participants were significantly worse in this test than the HC group, $U(1) = 196.0$, $z = 2.68$, $p < .005$, and their performance was also below that of the LPD group,

$U(1) = 106.5$, $z = 2.52$, $p < .008$. The LPD group did not significantly differ from HC in this test ($p > .796$).

There was no significant group effect for the Facial Recognition test ($p > .481$), forward digit span ($p > .604$), backward digit span ($p > .67$), letter counting ($p > .397$), rearranging ($p > .2$), Trail-Making test part A ($p > .086$), Trail-Making test part B ($p > .395$), phonemic word fluency ($p = .352$), alternating phonemic-semantic word fluency ($p = .189$), or action verbs fluency ($p = .33$).

A statistical comparison of the groups on the two composite scores also failed to reveal significant results; executive functions: $H(2) = 3.49$, $p > .179$, and working memory/sustained attention: $H(2) = 2.52$, $p > .298$.

10.2.2 P300 data

The interaction of condition x roi x group was significant, $F(12,198) = 2.28$, $p < .046$. Therefore, a condition x group interaction was tested roi-wise. The interaction was significant at right-posterior sites, $F(2,33) = 6.35$, $p < .005$, but not at the other rois (LF: $p > .665$, LC: $p > .825$, LP: $p > .071$, RF: $p > .527$, RC: $p > .109$, and ML: $p > .323$). A further step-down analysis revealed a significant right-posterior main effect of group for deviants, $F(2,33) = 3.56$, $p < .04$, but not for standards ($p > .654$). As indicated by the Tukey test, RPD patients showed an enhanced right-posterior P300 amplitude to deviants in comparison to HC, while the LPD group did not significantly differ from neither the controls nor the RPD group.

The main effect of group ($p > .694$), the condition x group interaction ($p > .297$), and the roi x group interaction ($p > .099$) were not significant.

Regarding the effects which did not involve the group factor, the omnibus analysis yielded a significant main effect of condition, $F(1,33) = 14.01$, $p < .001$, indicating more positive-going ERP amplitudes in response to deviants than in response to standards. Furthermore, the factor condition significantly interacted with roi, $F(6,198) = 11.32$, $p < .0001$. There was a significant main effect of condition at roi LC, $F(1,33) = 6.13$, $p < .019$, LP, $F(1,33) = 40.78$, $p < .0001$, RC, $F(1,33) = 16.04$, $p < .001$, and RP, $F(1,33) = 57.16$, $p < .0001$. Condition was not significant at roi LF ($p = .492$), RF ($p > .07$), or ML ($p > .081$).

10.2.3 Video-as-prime condition

The omnibus ANOVA results of the N100, P200, and the later stage negativity are listed in Table 10.4.

Effect	df	N100 (90 – 150 ms)			P200 (200 – 250 ms)			Neg (290 – 350 ms)		
		F	p	ω^2	F	p	ω^2	F	p	ω^2
G	2,33	0.57	$>$ .572	-.024	0.31	$>$ .734	-.040	2.23	$>$ .123	.064
E	1,33	2.53	$=$ .121	.021	0.03	$>$ .864	-.014	1.41	$>$ .243	.006
E x G	2,33	1.81	$>$ .179	.022	0.00	$>$ .995	-.029	0.59	$>$ .56	-.012
C	1,33	1.40	$>$ .245	.006	0.00	$<$ .992	-.014	**8.37**	$<$ **.007**	**.093**
C x G	2,33	**5.95**	$<$ **.007**	**.121**	0.06	$>$ .938	-.027	1.11	$>$ .34	.003
R x G	12,198	1.00	$>$ .419	.000	1.45	$>$ .237	.005	1.42	$>$ .241	.006
E x C	1,33	0.49	$>$ .489	-.004	0.07	$>$ .793	-.004	0.33	$>$ .572	-.005
E x C x G	2,33	2.17	$>$ .13	.016	0.74	$>$ .484	-.002	0.49	$>$ .615	-.007
E x R	6,198	1.04	$>$ .368	.000	0.22	$>$ .769	-.003	2.84	$>$ .058	.008
E x R x G	12,198	0.90	$>$ .486	-.001	0.87	$>$ .473	-.001	0.64	$>$ .654	-.003
C x R	6,198	1.15	$>$ .332	.001	2.50	$>$ .069	.008	0.88	$>$ .437	-.001
C x R x G	12,198	1.77	$>$ .118	.008	**2.26**	$<$ **.05**	**.014**	0.45	$>$ .805	-.005
E x C x R	6,198	0.55	$>$ .633	-.001	1.04	$>$ .373	.000	0.59	$>$ .569	-.001
E x C x R x G	12,198	1.62	$>$ .158	.003	0.89	$>$ .501	-.001	1.31	$>$ .273	.001

Table 10.4: Results from the omnibus ANOVAs, Experiment 2B, with video as prime. E = Emotion, C = Congruency, R = Roi, G = Group, Neg = Negativity.

N100. The RPD group, $F(1,11) = 7.23$, $p < .021$ and the HC group, $F(1,11) = 7.42$, $p < .02$ showed a main effect of congruency in the N100 while the LPD group did not ($p > .391$). However, the congruency effect differed in the RPD and HC groups, with higher amplitudes in response to incongruent than congruent trials in RPD participants and the reverse pattern in HCs.

P200. A significant congruency x roi interaction was confirmed only for the LPD group, $F(6,66) = 5.64$, $p < .005$, but not for the RPD ($p > .388$) or the HC group ($p > .3$). LPD participants showed a main effect of congruency in a left-frontal P200, with higher amplitudes in response to incongruent than congruent trials, $F(1,11) = 6.51$, $p < .027$. No significant congruency effects emerged at LC ($p > .445$), LP ($p = .305$), RF ($p > .997$), RC ($p > .335$), RP ($p = .185$), or ML ($p > .615$). Figure 10.1 shows the group-wise congruency effects for prosodic targets in the N100 and P200.

Later stage negativity. A main effect of congruency was driven a by more negative-going ERP amplitude to incongruent compared to congruent trials. This effect is depicted in Figure 10.2.

Correlations. The amplitude difference between congruent and incongruent trials in the N100 was not significantly correlated with left motor score ($p > .537$), right motor score ($p = .492$), the asymmetry index ($p = .59$), or total motor score ($p > .238$).

This amplitude difference in the N100 was significantly correlated with the two composite scores, and there was still a trend after Bonferroni correction, executive functions, $r = .34$, $p < .044$, and working memory/sustained attention: $r = .37$, $p < .026$. Concerning the direction of this correlation, higher scores were associated with a greater N100 enhancement to congruent compared to incongruent trials.

Processing of the video primes. Regarding the modulations at fronto-central electrodes, there were no group effects in the N100 (all $p \geq .242$), but there was a main effect of group in the VPP, $F(2,33) = 4.16$, $p < .025$, with significantly lower amplitudes in the LPD group ($M = 4.60$ V) than in the HC group ($M = 8.80$ V), while the RPD group did not significantly differ from either group ($M = 6.09$ V). There were no significant interactions involving group (all $p > .053$). Visual inspection suggested a VPP latency shift in patients, which was confirmed by a main effect of group in an ANOVA with peak latency as the dependent variable, $F(2,33) = 6.67$, $p < .004$. Both LPD ($M = 171$ ms) and RPD ($M = 172$ ms) groups exhibited longer VPP latencies than HC ($M = 155$ ms). In the N2, the main effect of group was significant, $F(2,33) = 4.08$, $p < .027$, with more negative-going amplitudes in

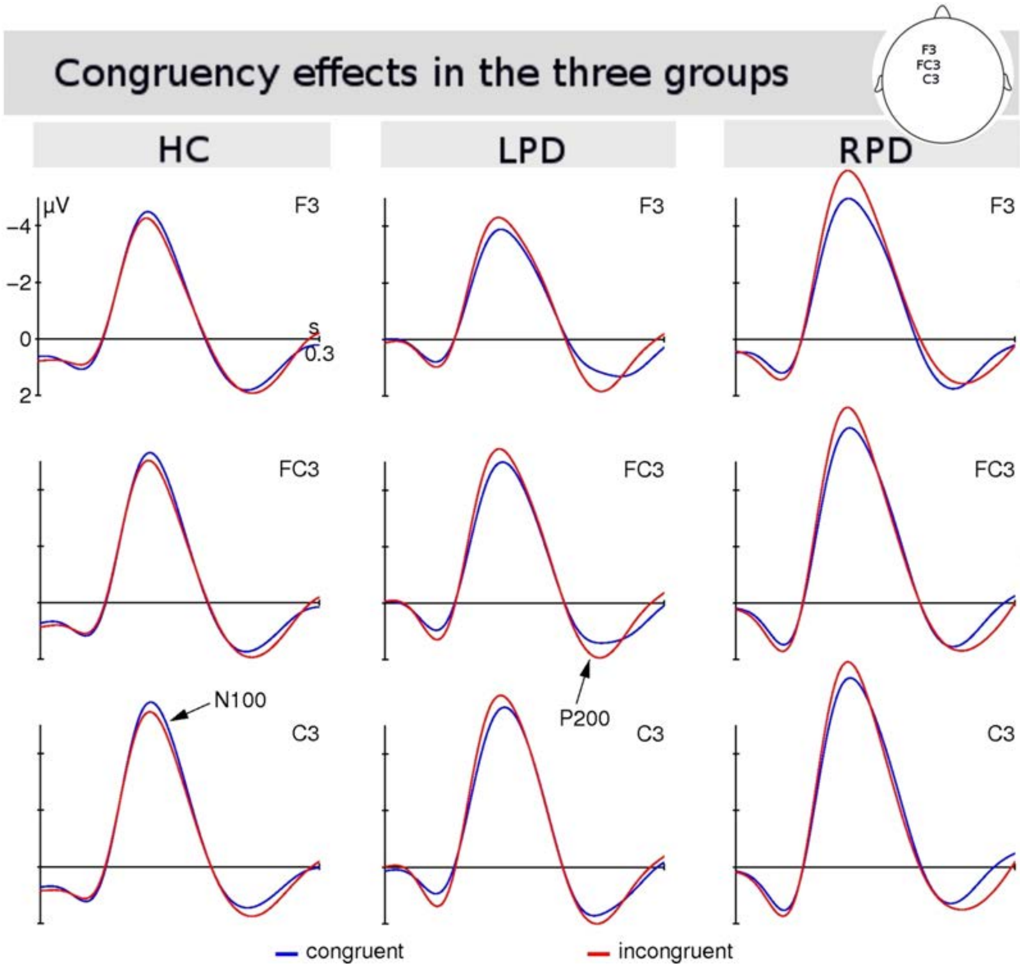

Figure 10.1: Congruency effects in the N100 and P200 by group, video as prime, Experiment 2B. The HC and RPD groups show an N100 amplitude modulation by congruency while the LPD group does not. Instead, latter group shows a congruency effect in the P200.

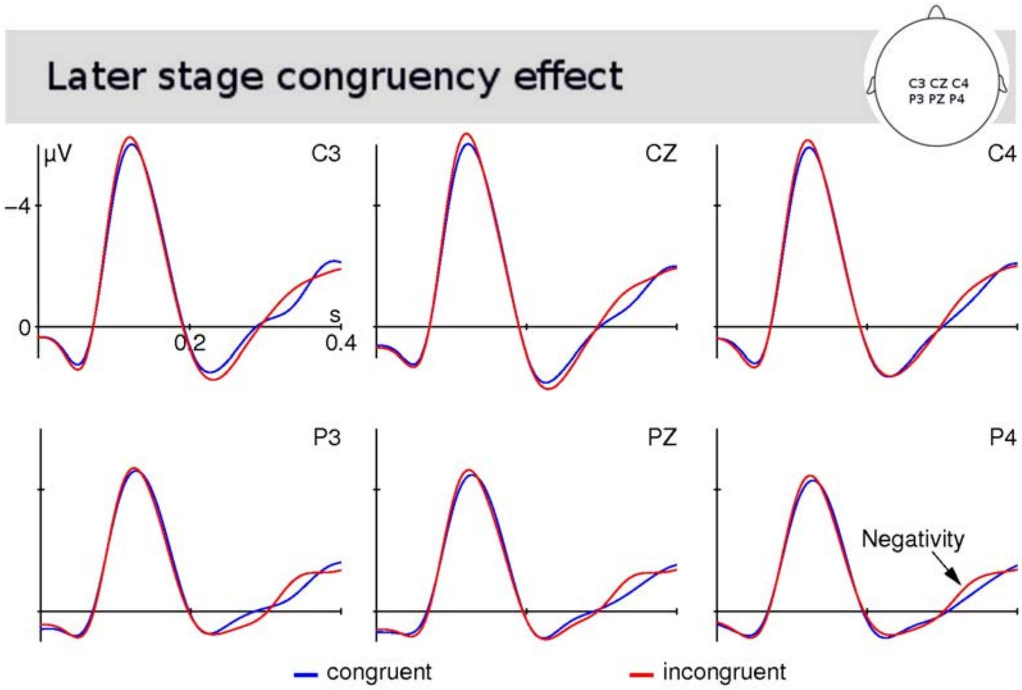

Figure 10.2: Later stage negativity modulated by congruency but not by group, video as prime, Experiment 2B.

the RPD group ($M = -0.72$ V) compared to the HC group ($M = 2.13$ V), while LPDs did not significantly differ from either group ($M = 0.65$ V). The interaction effects involving group were not significant (all $p > .074$).

There were no significant group effects in the early visual components P1 or N170 (all $p \geq .068$). Due to the VPP delay in patients, the N170 (as the counterpart to the VPP) was also analyzed for latency differences. Neither the main effect of group ($p > .073$) nor interactions with this factor were significant (all $p > .246$). In the posterior P2b, there was a significant emotion x roi x group interaction, $F(4,66) = 2.94$, $p < .044$. However, none of the step-down analyses yielded any significant results (all $p > .052$).

10.2.4 Prosody-as-prime condition

The omnibus ANOVA results are presented in Table 10.5 for the fronto-central and whole-head analyses and in Table 10.6 for analyses at visual rois.

N100. As can be seen from Table 10.5, no significant effects emerged.

Effect	df	N100 (80 – 110 ms) F	p	ω^2	VPP (140 – 180 ms) F	p	ω^2	N400 (420 – 500 ms) df	F	p	ω^2
G	2,33	0.83	$> .446$	-.010	**3.29**	$<$ **.05**	**.113**	2,33	2.37	$> .109$	.071
E	1,33	0.00	$> .953$	-.014	**6.41**	$<$ **.017**	**.070**	1,33	**7.90**	$<$ **.009**	**.087**
E x G	2,33	0.81	$> .451$	-.005	0.02	$> .975$	-.028	2,33	1.31	$> .282$	.009
C	1,33	0.05	$= .82$	-.013	0.06	$> .815$	-.013	1,33	0.03	$> .858$	-.014
C x G	2,33	0.42	$> .659$	-.016	0.23	$> .799$	-.022	2,33	0.91	$= .414$	-.003
R x G	8,132	0.67	$> .657$	-.010	1.42	$> .22$	.012	12,198	1.45	$> .236$	.006
E x C	1,33	0.70	$> .408$	-.002	0.49	$> .489$	-.004	1,33	0.10	$> .752$	-.006
E x C x G	2,33	1.51	$> .236$	.007	0.22	$> .805$	-.011	2,33	0.07	$> .932$	-.013
E x R	4,132	0.87	$> .427$	-.001	0.60	$> .598$	-.003	6,198	1.86	$> .147$	.005
E x R x G	8,132	1.34	$> .262$	.004	1.20	$> .315$	.003	12,198	1.76	$= .123$	.008
C x R	4,132	0.64	$> .522$	-.002	1.02	$> .373$	.000	6,198	**4.88**	$<$ **.009**	**.017**
C x R x G	8,132	0.95	$> .437$	-.001	**2.44**	$<$ **.047**	**.018**	12,198	0.53	$> .734$	-.004
E x C x R	4,132	0.13	$> .855$	-.002	1.80	$> .176$	.002	6,198	2.36	$> .081$	.004
E x C x R x G	8,132	1.28	$> .289$	.001	1.28	$> .287$	.001	12,198	0.66	$> .667$	-.002

Table 10.5: Results from the omnibus ANOVAs of fronto-central and whole-head components, Experiment 2B, with prosody as prime. E = Emotion, C = Congruency, R = Roi, G = Group.

Effect	df	P1 (80 – 110 ms)			N170 (140 – 180 ms)			P2b (210 – 270 ms)		
		F	p	ω^2	F	p	ω^2	F	p	ω^2
G	2,33	0.63	> .537	-.021	0.16	> .852	-.049	1.46	> .246	.025
E	1,33	1.33	= .257	.005	**5.23**	< **.029**	**.055**	1.46	= .236	.006
E x G	2,33	**3.85**	< **.032**	**.073**	0.48	> .625	-.015	1.46	> .247	.013
C	1,33	0.21	> .647	-.011	0.02	> .9	-.014	**5.30**	< **.028**	**.056**
C x G	2,33	0.48	> .622	-.015	1.76	> .187	.021	1.14	> .332	.004
R x G	4,66	1.31	> .278	.009	2.55	> .06	.045	1.24	> .304	.009
E x C	1,33	0.25	> .62	-.005	0.22	> .643	-.005	**10.15**	< **.004**	**.060**
E x C x G	2,33	1.76	> .188	.01	1.72	> .194	.010	1.02	> .37	.000
E x R	2,66	0.20	> .703	-.004	2.89	> .08	.013	0.62	= .47	-.002
E x R x G	4,66	0.02	> .992	-.011	**3.43**	< **.026**	**.032**	0.28	> .802	-.008
C x R	2,66	1.16	= .302	.001	2.62	> .102	.010	0.56	= .496	-.003
C x R x G	4,66	1.09	> .356	.001	2.02	> .13	.013	0.38	> .732	-.007
E x C x R	2,66	0.02	> .924	-.003	0.62	> .461	-.001	2.74	> .092	.006
E x C x R x G	4,66	0.53	> .632	-.003	0.03	> .986	-.005	0.36	> .768	-.004

Table 10.6: Results from the omnibus ANOVAs on visual components in Experiment 2B, with prosody as prime. E = Emotion, C = Congruency, R = Roi, G = Group.

VPP. The Tukey test of the main effect of group was not significant. However, when setting the threshold to $p < .06$, there was a significant VPP amplitude reduction in the LPD compared to the HC group.

Visual inspection of the data suggested that this amplitude reduction was due to a delayed VPP latency in patients. Therefore, the latency of the highest positive peak between 120 to 220 ms after stimulus onset was identified for each participant and condition and analyzed in an ANOVA. A significant main effect of group emerged, $F(2,33) = 5.17$, $p < .012$. According to the Tukey test, both patient groups showed delayed VPPs compared to the HC group (LPD: 169 ms, RPD: 169 ms, HC: 155 ms). There was no interaction with group in this analysis (all $p > .411$), indicating that the VPP delay in patients was not condition-specific. Figure 10.3 shows the VPP alterations in patients compared to HC.

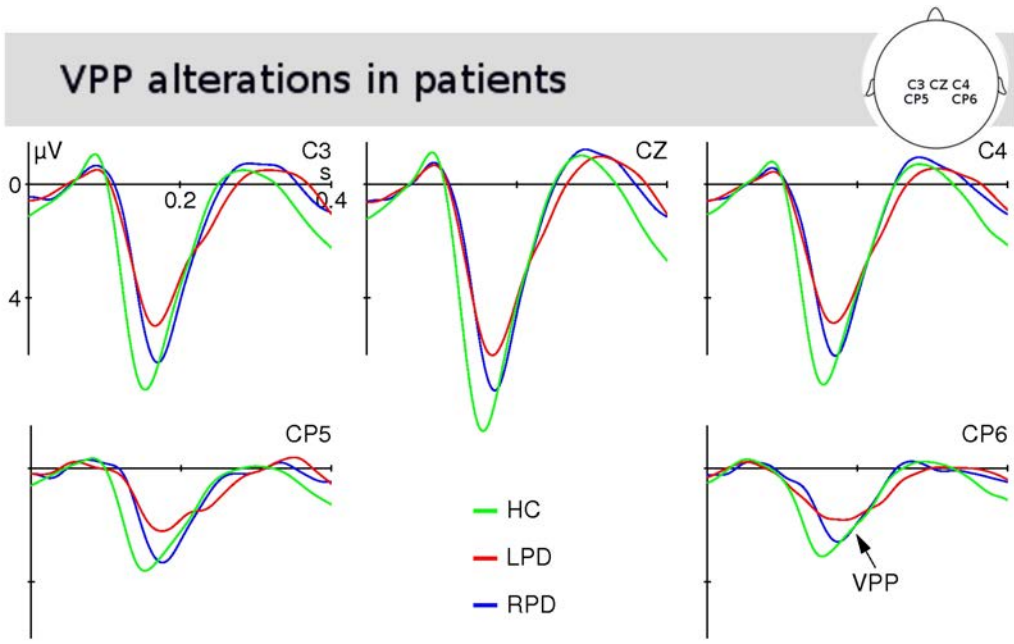

Figure 10.3: Group effect in the VPP to video targets, Experiment 2B. This component was delayed in both patient groups and reduced in amplitude in the LPD group.

The resolution of the congruency x roi x group interaction yielded a significant congruency x roi effect in the RPD group, $F(4,44) = 4.47$, $p < .018$, while this interaction was not significant in the LPD ($p > .603$) or HC group ($p > .501$). However, none of the step-down analyses yielded any significant results (all $p > .087$).

Finally, the main effect of emotion was based on higher VPP amplitudes to happy than angry targets.

Later stage negativity. A congruency x roi interaction was tested as a roi-wise main effect of congruency. It was significant at LF, $F(1,33) = 5.28$, $p = .028$, and at RP, $F(1,33) = 7.55$, $p < .01$, but not at LC ($p > .121$), LP ($p > .224$), RF ($p > .441$), RC ($p > .838$), or ML ($p > .121$). Interestingly, the congruency effects were different at roi LF and RP, with a more negative-going wave to incongruent than congruent targets at the left-frontal roi, while the reverse pattern applied for the right-posterior roi. These different patterns at left-frontal and right-posterior rois can be seen in Figures 10.4 and 10.5, respectively.

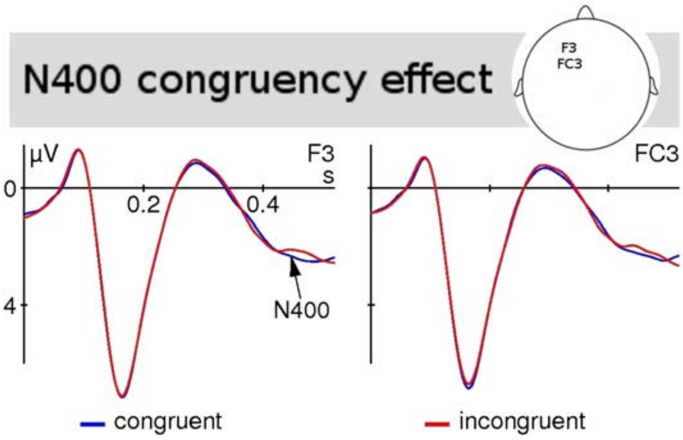

Figure 10.4: Left-frontal N400 modulation by congruency, prosody as prime, Experiment 2B.

The main effect of emotion was pronounced in more positive-going ERP amplitudes to happy than angry stimuli.

P1. The resolution of the emotion x group interaction did not yield any significant results (all $p > .098$).

N170. As the N170 amplitude is generally higher over right-posterior than left-posterior rois, the main effect of roi from the omnibus analysis ($F[2,66] = 4.15$, $p < .028$) was first scrutinized. The left-right difference was significant, $F(1,33) = 4.28$, $p < .047$, with higher amplitudes over right hemisphere than at left hemisphere electrode sites.

In the analysis of the emotion x roi x group interaction it turned out that there was a significant emotion x roi effect for the HC group, $F(2,22) = 3.92$, $p < .038$. In the RPD group, this effect only approached significance ($p < .078$); however, this group exhibited a highly significant main effect of roi, $F(2,22) = 16.40$, $p < .0001$. In the LPD group, there was no significant emotion x roi interaction ($p > .147$). A step-down analysis of the emotion x roi interaction in HCs and RPDs revealed that the patient group showed a significant main effect of roi for both happy, $F(2,22) = 11.24$, $p < .001$, and angry targets, $F(2,22) = 18.15$, $p < .0001$ while HC participants did not (happy: $p > .78$, angry: $p > .31$). The RPD group showed significantly higher right- than left-posterior N170 amplitudes in the case of happy, $F(1,11) = 15.35$, $p < .003$, and angry targets, $F(1,11) = 30.84$, $p < .001$.

As there were alterations in VPP latency for both patient groups (see above), a latency analysis was performed on the N170, too, as N170 and VPP may stem from the same neural generators (Joyce & Rossion, 2005). Just as for the VPP a main effect of group emerged in the N170 time window, $F(2,33) = 3.44$, $p < .044$. According to Tukey's HSD test, the N170 peaked significantly later in the RPD group than in the HC group (159 versus 150 ms peak latency). In the LPD group, this component also peaked later than in HC (155 ms latency), but the difference was not significant. Furthermore, a significant emotion x group interaction emerged, $F(2,33) = 3.76$, $p < .034$. A significant main effect of group was observed in the angry target condition, $F(2,33) = 6.39$, $p < .005$, but not in the happy one ($p > .407$). In line with the main effect of group, RPD participants displayed delayed N170 latencies for angry targets compared to HC. LPD participants did not significantly differ from either group. No further interactions with the group factor proved significant (all $p > .305$).

Finally, the main effect of emotion was triggered by higher N170 amplitudes to angry than happy targets.

P2b. Incongruent targets elicited higher P2b amplitudes than congruent ones. However, as informed by the emotion x congruency interaction, a main effect of congruency emerged only for angry targets, $F(1,33) = 15.07$, $p < .001$, but not for happy ones ($p > .432$). The P2b congruency effect is displayed in Figure 10.5.

Correlations. The VPP latency did not correlate with any of the disease-related variables left motor score ($p > .835$), right motor score ($p > .907$), the asymmetry index ($p > .977$), or total motor score ($p > .693$).

There was a significant negative correlation between the composite score "executive functions" and VPP latency, $r = -.45$, $p < .007$. The relationship between "working memory/sustained attention" and VPP latency was not significant, but the direction was also negative, $r = -.19$, $p > .27$.

The N170 amplitude difference between rois VL and VR correlated significantly with the asymmetry index, $r = .55$, $p < .006$, indicating higher right- than left-posterior N170

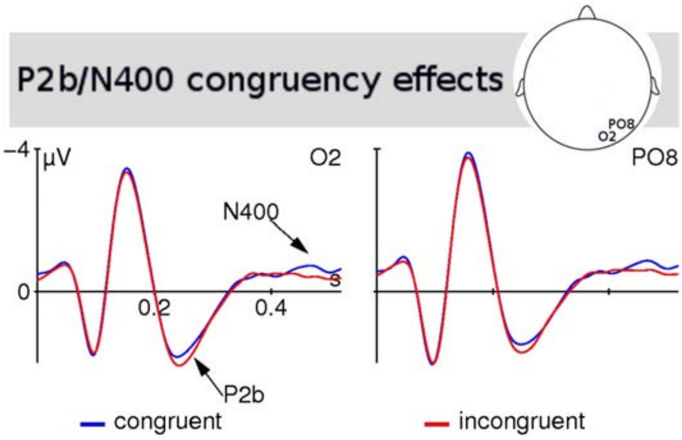

Figure 10.5: Posterior P2b and N400 modulations by congruency, prosody as prime, Experiment 2B. The P2b was enhanced to incongruent stimuli, an effect which was driven by angry targets. The N400 showed a reversed pattern at right-posterior electrodes, with more negative-going deflections to congruent than incongruent trials.

amplitudes with motor symptom asymmetry toward the right side of the body. The correlations with left motor score ($p > .374$), right motor score ($p > .068$), total motor score ($p > .69$), executive functions ($p > .688$), or working memory/sustained attention ($p = .703$) were not significant. Overall, the N170 latency was significantly and negatively correlated with executive functions, $r = -.49$, $p < .003$. This also held true for the N170 latency specifically to angry targets, with a trend after Bonferroni correction, $r = -.37$, $p < .026$. Correlations with working memory/sustained attention were not significant (overall N170 latency: $p > .304$, anger latency: $p > .253$).

Processing of the prosodic primes. No group effects emerged in the N100, the P200, or the subsequent negativity (all $p > .317$).

10.3 Discussion

The present study investigated cross-modal emotional priming with dynamic facial and vocal expressions in Parkinson patients and matched healthy controls. In general, the results indicate that LPD patients are able to use the information conveyed by affective prosody and emotional facial expressions, but that the time course of cross-modal emotional priming may be changed when processing prosodic targets. Furthermore, the current data indicate that early face processing may be altered independent of the emotional expression conveyed in both PD groups.

Video-as-prime. While both the HC and the RPD groups showed a main effect of congruency in the N100, the LPD group did not. Rather, latter group showed a congruency effect in the P200 while this component was not modulated by congruency in the other two groups. Thus, it appears that LPD patients detected prime-target congruency later than the HC and the RPD group.

The present results add to the findings in Experiment 1B, in which only LPD patients exhibited altered emotional salience detection from prosody, reflected in the P200 component. Results of the present study suggest that there may be a temporal delay in emotional priming in LPD when emotional prosody serves as a target.

At this point, it is important to consider that no group effects emerged in the analysis of the prosodic stimuli presented at the prime position. This is in accord with Experiment 1B, in which (except for disgust) only intelligible speech was affected while the processing of unintelligible speech, as used in the present study, proved to be largely intact in LPD. Thus, it is unlikely that group differences related to the processing of the prosodic stimuli per se gave rise to the group effects in the target position.

However, an ERP analysis of the video primes revealed that LPD patients processed the primes differently than healthy controls, as evidenced by a reduced and delayed VPP. Thus, it is possible that the congruency effect in the LPD group was temporally shifted due to altered processing of the dynamic facial primes. This explanation is, however, weakened by the observation that RPD patients showed comparable VPP alterations to video primes, but still exhibited congruency effects in the N100 to prosodic target stimuli. Furthermore, the VPP alterations in response to the video primes appeared to be unspecific and generalized, i.e., they were not modulated by the emotional category. Furthermore, VPP alterations were observed independent of emotional category and congruency in the prosody-as-prime condition.

Thus, deficits in one specific modality are an unlikely explanation for the current findings suggesting altered emotional priming in the LPD group. It rather appears that LPD patients have a problem with the analysis of cross-modal emotional congruency per se. It is important to reflect the impact of the current results in light of the results from Experiment 1B. In Experiment 1B, a combination of prosodic and semantic information (i.e., intelligible speech) led to group differences while this was not the case in the absence of semantics (unintelligible speech), except for disgust. Thus, the current results as well as the previous findings from Experiment 1B may be related to the proposed stimulus binding deficit in PD (Paulmann & Pell, 2010b). In latter study, emotion recognition in PD was tested via different communication channels (face, prosody, and semantics) in isolation and in combination. It was observed that PD patients benefitted much less from the presence of prosody in addition to the other channels than healthy controls, which may reflect problems to bind the vocal cues with information from other channels (Paulmann & Pell, 2010b). Thus, the absence of early congruency effects in LPD may be due to deficits in early stimulus binding in this group. The present findings in conjunction with those from Experiment 1B thus indicate that this binding deficit may generalize across verbal (semantics) and non-verbal (facial expressions) information.

Delayed priming effects in PD have previously been reported in semantic priming studies using different inter-stimulus intervals (Angwin, Chenery, Copland, Murdoch, & Silburn, 2007; M. Grossman et al., 2002). The present data indicate that such a delay may also play a role in emotional priming in PD. However, even though there may be a delay in the detection of cross-modal congruency, LPD patients were still able to perceive the congruency between primes and targets as evident in a P200 congruency effect as well as in the later stage negativity congruency effect. Thus, only early stages of processing were affected in the LPD group, as no congruency effect was evident in the N100.

Recently, the striatum has been implicated in processing emotionally incongruent face-voice stimuli (Klasen, Kenworthy, Mathiak, Kircher, & Mathiak, 2011). In latter study, this involvement was bilateral, even though a cluster size analysis revealed a higher cluster size in the right striatum. However, due to temporal constraints the onset of the respective activations cannot be specified in fMRI data. In light of the present results, a right-striatal engagement seems conceivable already during the early processing (N100) of cross-modal congruency when vocal expressions are primed by facial expressions, whereas the left striatum may start to operate later in time.

Finally, LPD patients did not differ from healthy controls in any of the neuropsychological measures or in the P300 results of the oddball experiment. Hence, it is unlikely that the delayed ERP modulations by congruency in the LPD group resulted from more generalized cognitive impairments.

RPD patients recognized prime-target congruency as early as healthy controls, i.e., in the N100 component. However, the pattern of this effect was opposite to the one exhibited by controls, with higher N100 amplitudes to incongruent than congruent stimuli. According to the correlation results, cognitive functions may have played a role here, as the amplitude difference between congruent and incongruent stimuli in the N100 was correlated with the composite scores, i.e., executive functions and working memory/sustained attention.

Furthermore, it may be that the N100 tapped into different processing stages in the HC and RPD groups. Reversed priming effects have been observed previously in the literature. For example, a recent cross-modal emotional priming study with prosodic primes and facial targets (Paulmann & Pell, 2010a) reported reversed priming effects in the N400 (i.e., more negative-going deflections in response to congruent as compared to incongruent trials) for very short prime durations, while longer prime durations (in conjunction with longer stimulus onset asynchronies) led to the classical N400 effect, with an enhanced negativity in response to incongruent as compared to congruent trials. A similar observation was made in semantic priming, in which hardly visible primes elicited reversed N400 and behavioral priming effects (Bermeitinger, Frings, & Wentura, 2008). In addition, the analysis of the ERPs to the video primes revealed that there were some processing differences between the RPD and HC groups (delayed VPP and enhanced N2 component). This indicates that RPD and HC probably were at different processing stages of the prime when the auditory target was presented, or that the processing of video primes was hampered in RPD. This could explain the reversal of the congruency effect in the N100. However, despite of this reversal, the data indicate that RPD patients are able to detect cross-modal congruency as early as healthy controls.

To sum up, the results from the video-as-prime condition suggest that patients suffering from Parkinson's disease are able to detect cross-modal emotional congruency between primes and targets as evidenced by ERPs. The congruency effect appears to be temporally delayed in the LPD group, and it may rely on different neural mechanisms in the RPD group than in healthy controls. However, it is telling that processing alterations in PD were limited to relatively early stages. Once more, this calls into question whether group differences reported in many previous studies on emotional prosody (e.g., Blonder et al., 1989; Breitenstein et al., 2001; Dara et al., 2008) really reflect an emotion processing deficit in patients, or whether they rather originate from difficulties with explicit emotion tasks as suggested by Pell and Dara (2007).

Prosody-as-prime. Results from this condition indicate that the processing of congruency between prime and target was not affected in PD patients. This means that PD patients, including LPD patients, were able to successfully use the emotional context conveyed by speech intonation. In light of the results of prosody as prime only, one can conclude that patients do not display an impairment of emotional prosody. Furthermore, the results indicate that emotion from facial targets was processed adequately by patients, which is a prerequisite for intact emotional congruency processing. These results contradict previous behavioral studies which suggest impaired processing of facial (e.g., Ariatti et al., 2008;

Sprengelmeyer et al., 2003) and vocal (e.g., Benke et al., 1998; Dara et al., 2008) emotion in PD. This underlines that explicit emotion tasks as used in these studies may measure mechanisms different from those which were captured in the present study.

The comparable congruency effects in the three groups are in line with behavioral results from the facial affect decision task (see Chapter 8 for a description of this task), in which PD patients showed emotional priming comparable to healthy controls (Pell & Dara, 2007). Latter study also used complete sentences in unintelligible speech as primes. Thus, whole-sentence primes appear to be long enough to establish a valid emotional context in PD. It remains to be examined whether the groups would also show comparable results to healthy controls when using shorter prosodic primes as in Paulmann and Pell (2010a). If the reason for the absence of group-modulated congruency effects in the present study is the prime duration itself, then such effects may be revealed by duration manipulations. In the present study, the effects of prime modality and prime duration cannot be disentangled. Follow-up studies which address this issue are warranted. However, if the problem is rather the integration of information from different communication channels in early emotional prosody processing, then prime duration should be less critical for group effects, but the presentation of vocal emotion as a target may be the central modulator. If latter is the case, then this would confirm previous evidence on stronger impairments for vocal than facial emotion processing in PD (Gray & Tickle-Degnen, 2010). This may have something to do with the inherent characteristics to these stimuli. Prosody unfolds over larger time scales, while this is not so much the case for facial expressions, even though presented dynamically (Paulmann & Pell, 2010b).

The most striking effect in this priming condition was the VPP modulation in PD patients. In both PD groups, this component displayed a reduced amplitude, even though the VPP reduction was only significant in the LPD group (at trend level). More indicative may be the observation that both PD groups exhibited delayed VPP peak latencies compared to controls. This was also observed when the videos served as primes and there appeared to be no modulation of this latency shift by emotion or any other variable. Hence, one can speak of a condition-independent VPP delay in PD patients. As there was a significant negative correlation between executive functions and VPP latency, the VPP delay may reflect cognitive decline. Here, it is interesting that the LPD group did not differ from HC in any of the cognitive measures. Thus, the VPP latency in response to dynamic faces is probably a very sensitive measure to capture mild cognitive decline in PD already at a stage at which impairments are subtle and can hardly be captured with classical cognitive tests.

The literature only reveals one study in which the VPP latency to faces was compared between PD and control participants, and there was no significant group difference (Kida, Tachibana, Takeda, Yoshikawa, & Okita, 2007). However, in latter study the VPP had a peak delay of about 13 ms in PD patients, which is comparable to the present observations. Furthermore, the data from latter study indicate that a high variability within the PD sample may have prevented a significant effect.

The VPP is often considered as the fronto-central counterpart of the face-related N170, and both components may have the same underlying neural generators (Joyce & Rossion, 2005). However, in the present PD study the VPP group effects did not converge with the N170 effects. The only correspondence was a delayed peak latency in RPD, which, however, was driven by angry faces in the N170, but not in the VPP. Furthermore, the VPP peak latency was higher than the N170 latency in both patient groups. This result calls into question that VPP and N170 reflect the same neural mechanisms and rather accounts for the view that - at least in part - different processes and neural substrates play a role in these two components (Wong et al., 2009). On the other hand, it must be considered that more electrodes were included in the statistical analysis of the fronto-central components than of the visual components, and thus the possible impact of statistical power on results cannot be denied.

Regarding the N170 amplitude to video targets, the RPD group showed highly significant roi effects whereas this was not the case in the LPD and HC groups. These roi effects reflect the classical N170 pattern, with higher right-posterior than left-posterior amplitudes. Even though this pattern is very common in the literature (e.g., Bentin et al., 1996) and was also observed in the pilot study (Experiment 2A), it may disappear with age (Gao et al., 2009). In fact, it was not observed in the HC group in the present study. The notion that RPD patients exhibited this pattern may thus stem from predominantly left-hemispheric damage of the basal ganglia and related structures, which led to reduced N170 amplitudes at left-occipital electrodes. This assumption is supported by a significant correlation of the N170 amplitude difference at left and right-posterior electrodes with the asymmetry index. Such EEG asymmetries dependent on the sidedness of motor symptoms in PD have previously been reported (Mintz, Tomer, Radwan, & Myslobodsky, 1981, 1982), even though they largely resolved with medication in these studies. The present results indicate that at early and rather sensory processing stages, a certain degree of hemispheric asymmetry may still become visible in the ERPs of medicated patients.

There was a delay in N170 peak latency in RPD which was driven by the N170 to angry targets. This indicates that RPD patients may have problems with this stimulus type.

However, no such delay was observed when the videos served as primes and the delay was furthermore correlated with executive functions. Thus, even though it cannot be discarded that RPD may lead to problems with processing angry facial expression, the association seems not that straightforward. More work in the future may render a clearer picture in relation to this finding.

In contrast to the present study, Wieser et al. (in press) did not report any alterations of early visual processing in PD; however, these authors restricted their analyses to occipital electrodes (i.e., the VPP was not part of the analysis) and analyzed only amplitude modulations but not latency. Thus, VPP differences, which reflect the most striking alterations in the prosody-as-prime condition, may have been missed. In Wieser et al.'s study, patients differed from controls starting at approximately 240 ms after face onset, whereas in the present study later components did not differ between groups. Probably, PD patients benefitted from the dynamic character of the faces used in the present study, as has already been observed at the behavioral level (Kan et al., 2002, but see Paulmann & Pell, 2010b). Future studies may directly compare the early neural processing of static and dynamic facial stimuli in PD.

On the other hand, it must be considered that the paradigm used by Wieser et al. (in press) was quite different from the current one, as it tested early visual emotion discrimination in PD. Thus, it is more comparable to Experiment 1B, but with visual stimuli. Wieser et al.'s results suggest that emotional salience detection from facial expressions may be altered in PD and hence complement the prosody findings from the first patient study. The present study was not suitable to test emotional salience detection from faces; however, the detection of emotional congruency appeared to be intact in the case of facial targets. This indicated that no receptive emotional deficit for faces in PD can be concluded from the present results. More research is definitely needed to address early facial emotion processing in PD, especially in terms of more emotional categories.

To sum up, the prosody-as-prime condition did not reveal any deficits in PD with respect to an ERP modulation by emotional prime-target congruency. The data provide some evidence that deficits at early visual processing stages occur, which affected both PD groups and seem to reflect more generalized face processing alterations. However, all in all, the data indicate intact emotional priming in PD. The two patient groups were very comparable in this condition, as opposed to the video-as-prime condition.

Summary and conclusion. To sum up, the present study supports the findings from Experiment 1B, namely that LPD patients exhibit altered early processing of emotional prosody. Furthermore, it was confirmed that pure prosody does not lead to alterations in LPD. Rather, it may be the interplay between different communication channels, e.g., face and voice, which is significant. From the present data in conjunction with those from Experiment 1B, it seems that LPD leads to problems in the interaction of emotional information provided by different communication channels with emotional prosody. This is apparently true for semantic, i.e., verbal, and facial, i.e., non-verbal information and may trace back to the relatively longer time scales over which vocal emotion unfolds. The data also suggest some low-level alterations of early dynamic face processing in PD independent of the sidedness of motor symptoms. In a next step, it would be interesting to test the effects of different prime durations and emotional categories. Also, in order to test the interaction of more communication channels at once, semantics may be included in future studies.

Chapter 11

General discussion and outlook

The present thesis aimed to investigate dynamic emotion processing in Parkinson's disease. More specifically, it addressed apparent open issues in PD research on emotion processing, which concern task effects, early versus late processing stages, stimulus dynamics, and patient characteristics.

With regard to the experimental task, explicit instructions such as categorization para-digms are commonly used in PD investigations addressing emotion processing. Performance in these tasks may, however, be confounded with frequently observed cognitive deficits in PD (Benke et al., 1998; Breitenstein et al., 2001; Pell & Leonard, 2003). In line with this, Pell and Dara (2007) could show that PD led to a performance decline in explicit emotion recognition from prosody, while the same patient sample showed intact priming of emotional facial expressions by affective prosody. The present thesis therefore focused on implicit task instructions and on-line measures such as EEG in PD populations.

One problem related to the issue of explicit task instructions is the time course of emotion processing. Explicit behavioral tasks are only able to capture late, controlled processing stages, while potentially early neural modulations of emotional stimuli in PD have been poorly investigated to date. Here, this was accomplished with the help of ERPs, which provide an exquisite temporal resolution within the milliseconds-range. This technique allows observing the neural modulations in response to emotional stimuli unfolding in time.

A great deal of investigations available to date has tested emotion processing in PD with static facial expressions, but few have used dynamic ones. Additionally, there are some studies that have used emotional prosody. Emotional prosody cannot be presented in a static manner and is thus always dynamic. It appears that PD patients are more impaired in processing prosodic emotional than facial emotional stimuli (Gray & Tickle-Degnen, 2010; Pell & Leonard, 2003, 2005). However, the question remains as to whether this is due to the dynamics as such, or if the particular stimulus type plays a greater role. Paulmann and Pell (2010b) recently tested dynamic multimodal emotion recognition from different communication channels (face, prosody, and semantics) in PD and found that patients made strong use of dynamic facial expressions as an information source, but that they virtually did not benefit from the presence of prosodic information. These results indicate that the greater deficits for prosody may have to do with prosody in itself rather than dynamics, but this remained to be tested at the neural level.

Finally, heterogeneity among PD patients was of central interest in the current research. On the one hand, the above-mentioned cognitive deficits, often termed "mild cognitive impairment", affect a large proportion of PD patients (Williams-Gray et al., 2007). By means of a comprehensive cognitive assessment, the present thesis aimed to control for these possible confounding factors. Along similar lines, depression as another potential confound was screened for, and very high scores led to the exclusion of the respective patients from the sample. The central focus of the present thesis, however, concerned motor symptom asymmetry in PD. Depending on which body side is more affected by motor symptoms, the involvement of the BG and their respective circuits in neuronal degeneration differs, with contralateral predominance. In the cognitive domain, investigations point to differential modulations of impairments by motor symptom asymmetry, associating LPD (= greater right-hemispheric involvement) more with visuospatial and RPD (= greater left-hemispheric involvement) with rather "classical" left-hemisphere, i.e., linguistic functions (see Cronin-Golomb, 2010, and section 2.3 of this thesis, for reviews). In emotion processing research in PD, motor symptom asymmetry is often not taken into account and the few available studies in the literature have yielded equivocal results (cf. Chapter 4 for details). On the other hand, a certain degree of hemispheric dominance is assumed in emotion processing (e.g., Schirmer & Kotz, 2006). Thus, the present thesis aimed to test for the impact of motor symptom asymmetry and its possible effects on emotion processing in PD, especially with regard to early neural processing stages.

11.1 Summary and integration of main findings

In Experiment 1, emotional prosody processing in PD was tested as a function of task, speech intelligibility, and emotional category. With respect to patient characteristics, sidedness of the disease was a central factor, as well as the participant's cognitive profile. The results indicated that LPD patients display early alterations in emotional salience detection from prosody (P200) in the categories of disgust, anger, and happiness. However, no clear-cut task effects emerged. Regarding speech intelligibility, disgust prosody was affected in both intelligible and unintelligible speech. In the other emotional categories, the processing of unintelligible speech conveying prosodic information appeared to be largely intact in LPD. This gives rise to the possibility that LPD may lead to problems in the early interaction of different communication channels, specifically the early interplay between nonverbal vocal emotional cues (i.e., prosody) and verbal (i.e., semantic) cues. Therefore, Experiment 2 tested whether LPD also leads to problems in the early interaction of different types of non-verbal emotional information (i.e., dynamic facial expressions and emotional prosody). This interaction was investigated by means of a cross-modal emotional priming paradigm, in which unintelligible speech conveying angry or happy emotional prosody was combined with emotionally congruent or incongruent dynamic facial expressions. The results indicate that during emotional prosody processing, the use of prior contextual information provided by dynamic facial expressions is temporally delayed in LPD patients, as compared to healthy elderly controls and RPD patients.

It has previously been discussed that the BG may play a role in stimulus binding, particularly with respect to the interaction of different emotional information channels (Paulmann & Pell, 2010b). The present data indicate that the right striatum may accomplish this binding function at an early time point. This suggests that the striatum is critically involved in the supramodal interaction of emotional information, a possibility which is elaborated in a recent investigation by Klasen et al. (2011). The authors reported BG activation to emotionally incongruent face-voice combinations. Converging evidence from patients with left-striatal lesions shows that emotional deviation in purely prosodic (i.e., unintelligible) stimuli does not reveal processing deficits in patients compared to healthy controls (Paulmann, Pell, & Kotz, 2008), whereas a combined deviation between verbal and nonverbal cues (semantics and prosody) does (Paulmann, Pell, & Kotz, 2009). Thus, the left striatum may play a role in aligning emotional prosody to semantics. Indeed, the left-striatal involvement may be confined to verbal (linguistic) stimuli in combination with emotional prosody, as the non-verbal dynamic face stimuli used in Experiment 2 did not reveal any processing alterations in RPD. On the other hand, the LPD data in both experiments conducted here indicate an early involvement of the right striatum in emotional processing, particularly with respect to supramodal interactions of emotional cues. Furthermore, this may be the case for both verbal-nonverbal interactions as well as for interactions between different nonverbal channels.

The interaction of emotional information from different communication channels has been attributed to different brain structures, for instance the posterior superior temporal sulcus (Ethofer, Anders, Wiethoff, et al., 2006; Kreifelts et al., 2007), the posterior insula (Ethofer, Anders, Wiethoff, et al., 2006), or the amygdala (Ethofer, Anders, Erb, Droll, et al., 2006; Klasen et al., 2011), to name but a few. As many brain regions have been associated with the interaction of emotional information from different channels, it appears that an extended network is involved in this process. As indicated by the results obtained in the present work, the right striatum may play a role when the interaction between two communicative channels requires emotional information to be tracked over larger time scales, which may be particularly relevant in the context of emotional prosody. This notion underlines the proposed role of the BG for tracking auditory speech input over its temporal course, meaning that auditory and temporal processing mechanisms are closely tied together (Kotz & Schwartze, 2010).

The present results confirm previous evidence of a greater impairment for emotional prosody than emotional face processing in PD (Gray & Tickle-Degnen, 2010). It can now be assumed that this can not only be observed behaviorally, but also at the neural level and with dynamic as opposed to the more widely used static facial information. Thus, it may not be the dynamics as such which often lead to greater emotional prosody (always dynamic) than face (mostly presented statically) processing deficits, but rather characteristics inherent to vocal and facial emotion expressions such as the time scales they rely on. Related to this, there is the assumption that facial expressions, even though conveyed dynamically, can readily be recognized at discrete points in time during stimulus presentation while emotional prosody unfolds in time Paulmann and Pell (2010a).

What needs to be kept in mind, though, is a generally higher difficulty level associated with vocal compared to facial emotion. Normally, in emotion categorization, performance is better for facial than for vocal emotion recognition (Paulmann & Pell, 2011). This affects certain emotions more than others. Disgust recognition from prosody, e.g., is generally poor (Adolphs, 2002a) and occurs late in time (Pell & Kotz, 2011). When there is concurrent but incongruent facial and prosodic emotion available, people tend to decide for the emotion conveyed by the face when forced to provide an emotion categorization (Klasen et al., 2011). This indicates face preference and may point to facilitated face processing in humans, while vocal emotion processing may go along with a relatively higher processing effort. This cannot be disregarded, particularly in the context of patient investigations. In patient populations, a higher processing difficulty associated with certain stimuli may lead to stronger functional breakdowns than in healthy controls. Thus, the observation made in the present thesis, that especially receptive emotional prosody seems to be impaired in PD, may mean different things. On the one hand, it may indicate problems to track emotional information which slowly unfolds in time; on the other hand the disease may exacerbate the generally higher processing difficulty associated with vocal as compared to facial emotional information. Finally, these two points may be related in that processing emotional prosody is generally more difficult *because* it relies on longer time scales, and this higher difficulty level makes a performance breakdown in patient populations more likely.

RPD patients compared to LPD patients were found to process emotion from socially relevant stimuli in a comparable manner to the healthy controls. However, overall RPD patients showed stronger cognitive decline than LPD patients. This suggests that the left and the right striatum may engage in distinct functions, supporting some previous evidence that reported an association between right-sided motor symptoms and cognitive decline in PD (Cooper et al., 2009; Foster et al., 2010; Huber et al., 1992; Williams et al., 2007). On the other hand, the absence of impairments in cognitive measures strengthens the argument that the reported alignment problems in LPD are not a result of general cognitive decline.

11.2 Is there lateralization in the basal ganglia?

A possible functional lateralization of the BG is to date largely unexplored. Traditionally the BG have been associated with attention-dependent later stage processing, reanalysis, and correction (Kotz & Schwartze, 2010). ERP evidence on auditory emotional processing (Paulmann, Pell, & Kotz, 2009) or syntactic error detection (Friederici, Kotz, Werheid, Hein, & von Cramon, 2003; Frisch, Kotz, von Cramon, & Friederici, 2003; Kotz, Frisch, von Cramon, & Friederici, 2003) in patients suffering from damage to the BG (lesions and PD) supports this notion. However, the findings from the present set of studies give rise to the possibility that the right striatum is involved in early emotion processing stages when information from different input channels interact. Especially the changes in the P200 component go along with the idea that the right hemisphere is involved in the integration of information over timescales of approximately 150–300 ms (Hickok & Poeppel, 2007), which coincides with the P200 time window. Along these lines, Schirmer and Kotz (2006) have previously proposed a dominance of right-temporal regions in the generation of the P200 in emotional prosody processing. Thus, the results reported in the present thesis may lead to the tentative conclusion that a functional lateralization of the BG and their interactions with temporal and other cortical areas exists and thus provide a starting point for further investigations on the topic. As discussed earlier, a possible bottom-up mechanism involving the right striatum and temporal areas in emotional prosody processing (Ethofer et al., 2012) is conceivable.

11.3 Task effects and early versus late processing stages

In Experiment 1, specifically the processing of verbal cues, i.e., vocal emotional stimuli including semantic information, was impaired in LPD as observed in the P200 ERP component. On the other hand, behavioral research shows that PD patients benefit from congruent verbal and nonverbal emotional input (Dara et al., 2008; Paulmann & Pell, 2010b). A similar benefit was also observed in the behavioral emotion categorization study in Experiment 1B. This apparent dissociation between early neural modulations and later decision-making stages points to the low convergence between explicit behavioral methods and the time-sensitive ERP methodology, which can capture the unfolding of information processing at various processing stages in implicit and explicit tasks. Conversely, Pell and Dara (2007) reported intact cross-modal emotional priming at the behavioral level in PD, applying the facial affect decision task. This finding indicates that PD patients could use emotional information conveyed by prosody to render a facial affect decision, while they were only impaired when they had to explicitly assign an emotional category to prosodic stimuli. These results converge with the ERP findings from the prosody-as-prime condition in Experiment 2B, in which no impairments in implicit cross-modal emotional priming were observed in either PD group. Pell (2002) has previously advocated the use of implicit on-line measurements in patient populations, as the explicit emotion tasks used in the majority of patient studies assess later, controlled processes. These later processes are more susceptible to cognitive decline (i.e., deficits in working memory, attention, etc.). In fact, several behavioral PD studies reveal an association between the performance of PD patients in explicit emotion tasks and cognitive functions (Benke et al., 1998; Breitenstein et al., 2001; Pell & Leonard, 2003) suggesting that explicit tasks may not be valid to test receptive emotional deficits in PD. The dissociations between ERPs and later behavioral measures as well as the absence of group effects in the prosody-as-prime condition underlines that explicit emotion tasks and early ERP effects capture different aspects of emotion processing which may not be very closely related to each other.

11.4 The problem of variability in PD

One problem in PD research is the rather high variability among patients and the commonly small sample size in patient studies. Conversely, study results in PD are conflicting, as discussed in Chapter 4, which summarizes the pertinent literature on emotion processing in PD. In the present thesis, one variable, which may allow to specify deficit profiles in PD, namely sidedness of motor symptoms, was used as a grouping variable. Such specification may be considered an advantage in comparison to many previous studies. Thereby, the relative involvement of the respective cortico-striatal circuits in neural degeneration is better controlled for. However, there are numerous other variables, which can induce within-group variation. Among these one may think of the type of the initial motor symptom (Katzen et al., 2006), the degree of cognitive decline (Benke et al., 1998; Monetta, Grindrod, & Pell, 2006), disease progression (Breitenstein et al., 1998), or medication (Tomer et al., 2007), to name but a few. What is also unresolved is the question of how to handle depressive symptoms in PD. As most comorbidity estimates of depression in PD revolve around 30–40%, depression is a very common epiphenomenon in PD. Along these lines, depression has been suggested to be inherently tied to the disease (Aarsland, Marsh, & Schrag, 2009; Leentjens, Van den Akker, Metsemakers, Lousberg, & Verhey, 2003; Lieberman, 2006; Obeso et al., 2010). On the one hand, depression may be a confounding factor in PD research, which is why patients with high comorbid depression scores are often excluded from the experimental sample. This approach was also adopted in the present thesis. On the other hand, the inclusion of these patients may be more representative of the general PD population. Thus, this issue needs to be critically reconsidered in the future.

In summary, even though the findings of the present thesis are striking, and a considerable number of possible moderator variables was controlled for, including the cognitive profile and the psychopathology, the results will have to be replicated and extended in future research.

11.5 Limitations

Some caveats of the current investigation have already been pointed out, namely the small sample sizes and, related to this, a number of further possible cognitive and disease-related confounds, which may introduce variability in a PD patient sample. Furthermore, it also needs to be weighted that PD is a neurodegenerative disease. Even though the BG are the most affected structure in PD, the disease leads to much more wide-spread changes in the brain already at early stages of the disease (Braak et al., 2003; Tinaz et al., 2011). These changes in the brain may constitute a confounding factor, making it difficult to attribute findings in PD exclusively to the BG. For example, there is amygdala damage at an intermediate disease progression stage and increasing frontal cortical involvement during the disease progression (Braak et al., 2003; Braak & Del Tredici, 2009). These neural alterations may have an impact on study results due to their supposed significance for emotion perception and the fronto-striatal circuitry, respectively.

In addition to the caveat that PD is a disorder that is not confined to the BG, it must be kept in mind that even though there is asymmetric degeneration in PD, the BG are involved bilaterally even at early disease stages (Schwarz et al., 2000; Tissingh et al., 1998). Thus, the sidedness is not absolute, but rather relative. However, as suggested by several significant correlations between ERP findings and motor symptom asymmetry, this rather relative degree of asymmetry may impact study results in PD.

11.6 Concluding remarks

To conclude, the findings of the present thesis suggest that emotion processing in PD is indeed affected by motor symptom asymmetry. Generally speaking, emotion processing appears to be largely intact in the case of a predominantly left-sided BG damage (RPD), while receptive emotional functioning seems to be impaired already at early processing stages in the case of right-sided BG damage (LPD). A wide-spread disgust impairment supports the important role for the BG in disgust processing (Calder et al., 2001), even though the high recognition difficulty associated with disgust prosody should not be disregarded (Adolphs, 2002a; Pell & Kotz, 2011). With respect to other emotional categories, processing impairments may rather lie within stimulus binding of different emotional input channels, which is probably particularly the case when such binding needs to be accomplished on information that relies on rather slow temporal transitions, i.e., emotional prosody.

Future studies may assess the effects of different prime durations and emotional categories, as well as the interaction between facial, vocal, and semantic information in PD during early processing stages. This will help disentangle the effects of stimulus type (communication channel), stimulus duration, and stimulus-onset asynchronies. Furthermore, more research needs to address whether deficits are category-specific in terms of particular emotions or rather generalized. Finally, LPD patients exhibited deficits in explicit and implicit tasks but clear-cut task effects were not observed; rather, task effects seemed to depend on emotion categories. Thus, it should be investigated in the future which factors modulate task-specific emotion processing deficits in LPD. In RPD, there may be later stage deficits when semantic stimuli are included, as suggested by lesion data (Paulmann, Pell, & Kotz, 2009). This may also be an issue of upcoming research testing prosodic-semantic mismatches in PD patients. The paradigm used in Experiment 1 did not include prosodic-semantic mismatches. Thus, it was not suited to test such late expectancy violation effects which have been shown to reveal a pattern comparable to N400 modulations (Kotz & Paulmann, 2007). Thus, there may be emotion processing deficits in RPD, too, but probably the experiments conducted in the present thesis were not suited to reveal these.

From a more practical point of view, the results may be useful for clinical practice and for developing new strategies of how the disease is dealt with. Physicians who treat PD patients should be made aware of possible emotion processing and emotion expression deficits in their patients. The patients' as well as their caregivers' attention should be drawn to these possible problems. One can imagine that caregivers may be discouraged or feel rejected by the flat affective displays in patients (Mikos et al., 2009), especially if they do not know that these are manifestations of the disease and that reduced emotion processing may also be one of its consequences. Furthermore, it may be recommended to implement trainings in receptive and expressive emotion functions in PD, as these functions are so crucial for interpersonal interactions. Especially for better coping with the disease, social support will surely be helpful, so it may be useful to restructure standard PD therapy, in order to enable patients to better deal with their social environment and to keep up their interpersonal relationships.

Part III

Appendix

Appendix A

Instructions

A.1 Experiment 1

Please note: The instructions were identical in the pilot study and in the patient study; however, in the patient study, a formal form of address ("Sie") was used.

Implicit task instruction

1. Liebe Versuchsperson! Im folgenden Experiment wirst Du Sätze hören, die entweder auf Deutsch oder in einer Phantasiesprache vorgetragen werden. Danach wird die Frage "deutsch oder nicht deutsch?" auf dem Bildschirm aufblinken.

Dear participant! In the following experiment you will hear sentences spoken either in German or in an imaginary language. Then, the question "German or not German?" will be flashed on the screen.

2. Entscheide dann bitte, ob der gehörte Satz in deutscher Sprache vorgetragen wurde oder nicht.

Please decide, whether the sentence you heard was spoken in German language or not.

3. War das der Fall, dann drücke bitte die linke (rechte) Taste. Wenn nicht, dann drücke die rechte (linke) Taste.

If this was the case, then please press the left (right) key. If not, then press the right (left) key.

4. Wichtig: Bitte warte mit dem Tastendruck immer, bis die Frage auf dem Bildschirm erscheint, weil Deine Antwort sonst vom System nicht aufgezeichnet wird!

Note: Please wait until the question appears on the screen before you press the key, otherwise your response will not be registered by the system!

5. Wenn Du noch Fragen hast, dann stelle sie bitte jetzt. Ansonsten kannst du nun beginnen - entspanne Dich und los gehts!

In case you have any questions, please ask them now. Otherwise you can start now - relax and here we go!

Explicit task instruction

1. Liebe Versuchsperson! Im folgenden Experiment wirst Du Sätze hören, die entweder auf Deutsch oder in einer Phantasiesprache vorgetragen werden. Danach wird die Frage "emotional oder nicht emotional?" auf dem Bildschirm aufblinken.

Dear participant! In the following experiment you will hear sentences spoken either in German or in an imaginary language. Then, the question "emotional or not emotional?" will be flashed on the screen.

2. Entscheide dann bitte, ob der gehörte Satz emotional intoniert wurde. Das wäre z.B. der Fall, wenn der Sprecher ärgerlich, angeekelt, ängstlich oder auch glücklich klang.

Please decide whether the sentence you heard was spoken in an emotional intonation or not. This would, e.g., be the case when the speaker sounded angry, disgusted, afraid, or happy.

3. In diesem Fall drücke bitte die linke (rechte) Taste. Klang der Sprecher nicht emotional, sondern eher sachlich und neutral, dann drücke bitte die rechte (linke) Taste. Beachte: Es geht nur um die Betonung, nicht um den Inhalt des Satzes!

In this case, please press the left (right) key. If the speaker did not sound emotional, but rather factual and neutral, then please press the right (left) key. Attention: This concerns only the intonation, not the sentence content!

4. Wichtig: Bitte warte mit dem Tastendruck immer, bis die Frage auf dem Bildschirm erscheint, weil Deine Antwort sonst vom System nicht aufgezeichnet wird!

Note: Please wait until the question appears on the screen before you press the key, otherwise your response will not be registered by the system!

5. Wenn Du noch Fragen hast, dann stelle sie bitte jetzt. Ansonsten kannst du nun beginnen - entspanne Dich und los gehts!

In case you have any questions, please ask them now. Otherwise you can start now - relax and here we go!

Experiment 1B - Behavioral prosody categorization study

1. Liebe Probandin, lieber Proband, in diesem letzten kurzen Experiment werden Sie nun noch einmal einige der Sätze hören, die Sie bereits aus dem EEG kennen.

Dear participant, in this last short experiment you will now hear again some of the sentences you already know from the EEG.

2. Bitte entscheiden Sie nach jedem Satz so spontan und intuitiv wie möglich, welcher Emotion Sie ihn von seiner Betonung (Satzmelodie) her zuordnen würden. Zur Auswahl stehen Ärger, Angst, Neutral, Freude und Ekel, wie auf der Tastatur gekennzeichnet.

After each sentence, please decide as spontaneously and quickly as possible which emotion you would assign it to, according to its intonation (speech melody). At choice are anger, fear, neutrality, happiness, and disgust, as indicated on the keypresses.

3. Haben Sie noch Fragen? Dann stellen Sie sie bitte jetzt! Ansonsten können Sie nun das Experiment starten.

Do you still have any questions? Otherwise, you can now start the experiment.

A.2 Experiment 2

Rating study

1. Willkommen zum Experiment!

Welcome to the experiment!

2. Im heutigen Experiment wirst Du kurze Videos von Gesichtsausdrücken sehen. Dazu sollst Du zwei verschiedene Aufgaben bearbeiten.

In today's experiment you will see short videos of facial expressions. On these, you shall perform two different tasks.

3. In einem ersten Schritt geht es darum, zu bewerten wie stark die emotionale Erregung der Person in dem Video ist. Bitte benutze dafür die 9 Tasten mit den kleinen Figuren. Du kannst abstufen zwischen 'ganz ruhig' (links) bis 'sehr emotional erregt' (rechts). Beachte bitte, dass emotionale Erregung sowohl positiv als auch negativ sein kann!

The first step is to evaluate how high the emotional arousal of the person in the video is. To this end, please use the 9 keys with the small maniquins. You can gradate between 'totally calm' (left) and 'very much emotionally aroused' (right). Please note that emotional arousal can be both positive or negative!

4. In einem zweiten Schritt sollst Du entscheiden, welcher der drei emotionalen Kategorien 'Ärger', 'Freude' oder 'Neutral' Du das Video zuordnen würdest (beschriftete Tasten). Solltest Du Dir einmal sehr unsicher sein, dann kannst Du die markierte Taste mit dem Fragezeichen benutzen. Versuche aber bitte, von dieser Option so wenig wie möglich Gebrauch zu machen.

In a second step, you shall decide which of the three emotional categories 'anger', 'happiness', or 'neutral' you would assign to the video (labelled keys). Should you once be very undecided, you can use the labelled key with the question mark on it. However, please try to make use this option as little as possible.

5. Nochmal zusammengefasst:
1. Video
2. Frage: 'Wie erregt?' (9 Tasten zur Auswahl)
3. Frage: 'Welche Emotion?' (3 Tasten zur Auswahl und ggf. Fragezeichen)

To sum up again:
1. video
2. question: 'how aroused?' (9 keys at choice)
3. question: 'Which emotion?' (3 keys at choice and, if necessary, the question mark)

6. Die Videos sind auf mehrere Blöcke verteilt, zwischen denen Du jeweils Pausen einlegen kannst.

The videos are distributed across several blocks, between each of which you can take a break.

7. Noch Fragen? Dann wende Dich bitte jetzt an den Versuchsleiter. Ansonsten kann nun ein kurzer Übungsdurchgang beginnen. Er startet direkt nachdem Du die Enter-Taste gedrückt hast.

Any questions? Then please refer to the experimenter now. Otherwise, a short practice trial can start now. It begins immediately after pressing the return key.

ERP study

Note: Here, the instructions from the pilot study are presented. The patient study instruction was largely comparable; however, a more formal way of addressing the participants was used (German "Sie"). Furthermore, the blinking instruction (point 3.) was removed for the patients and elderly controls.

Video-as-prime instruction

1. Willkommen zum Experiment!

Welcome to the experiment!

2. Im heutigen Experiment wirst Du jeweils kurze Videos von Gesichtsausdrücken sehen und direkt danach einen Satz in einer Phantasie- sprache hören. Der Satz und das Video stammen von derselben Person.

In today's experiment you will always watch short videos of facial expressions and hear a sentence in an inmaginary language directly afterwards. The sentence and the video come from the same person.

3. Deine Aufgabe ist es, zu entscheiden ob die Person männlich oder weiblich war und die entsprechende Taste zu drücken. Bitte warte immer, bis der Satz zuende ist und gib Deine Antwort, während das Fragezeichen auf dem Bildschirm steht. Sobald Du gedrückt hast, hast Du auch ausreichend Zeit zum Blinzeln.

Your task is to decide whether the person was male or female and to press the corresponding key. Please always wait until the sentence is over and provide your answer while the *question mark is displayed on the screen. As soon as you have pressed the button, there is enough time for you to blink.*

4. Noch Fragen? Dann wende Dich bitte jetzt an den Versuchsleiter. Ansonsten kann nun ein kurzer Übungsdurchgang beginnen. Er startet direkt nachdem Du die Enter-Taste gedrückt hast.

Any questions? Then please refer to the experimenter now. Otherwise, a short practice trial can start now. It begins immediately after pressing the return key.

Prosody-as-prime instruction

This was the same as for the video-as-prime condition; only screen number 2 differed:

"2. Im heutigen Experiment wirst Du jeweils einen Satz in einer Phantasiesprache hören und direkt danach ein kurzes Video von einem Gesichtsausdruck sehen. Der Satz und das Video stammen von derselben Person.

In today's experiment you will always hear a sentence in an inmaginary language and directly afterwards watch a short video of a facial expression. The sentence and the video come from the same person.

Appendix B

Sentence materials

A = angry, D = disgusted, F = fearful, H = happy, and N = neutral prosody
C = Christian (male speaker) and K = Katrin (female speaker)

Intelligible sentences

A C Sie hat den Herzog gedemütigt und verärgert.
A C Er hat die Dame gekniffen und verärgert.
A C Er hat die Drogen gehehlt und verhökert.
A C Sie hat die Nachbarin gekränkt und verärgert.
A C Er hat die Jugendlichen belogen und aufgebracht.
A C Er hat die Abreise versäumt und verpennt.
A C Er hat die Kartoffeln geschmissen und geschrien.
A C Er hat die Empörung gesteigert und heraufbeschworen.
A C Sie hat den Demokraten verdammt und verärgert.
A C Er hat das Schloss gestürmt und verwüstet.
A C Sie hat die Suppe versalzen und verkocht.
A C Sie hat die Katastrophe ausgelöst und angezettelt.
A C Er hat die Ehefrau gepiesackt und verärgert.
A C Sie hat die Faust geballt und geschrien.
A C Er hat die Villa besetzt und verwüstet.
A K Er hat das Paar gereizt und aufgebracht.
A K Sie hat den Ring beschädigt und verschlampt.
A K Er hat das Vermögen geraubt und verprasst.
A K Sie hat den Bischof beworfen und verärgert.
A K Sie hat die Autos verdreckt und zerkratzt.

A K Er hat die Genossenschaft beleidigt und verärgert.
A K Sie hat die Papiere geknüllt und angezündet.
A K Er hat das Tor geknallt und abgeschlossen.
A K Er hat die Ferien verpfuscht und rumgemeckert.
A K Er hat das Vergnügen verdorben und rumgemeckert.
A K Sie hat die Bande gebildet und organisiert.
A K Sie hat die Kundschaft beschimpft und aufgebracht.
A K Er hat das Cabrio ausgebrannt und weggeworfen.
A K Sie hat die Stimmung zerstört und rumgemeckert.
A K Er hat die Lüge ausgesprochen und gemosert.
D C Er hat den Speichel verbreitet und verteilt.
D C Er hat die Müllhalde bewohnt und gestunken.
D C Sie hat den Schädel ausgegraben und inspiziert.
D C Er hat den Schweißgetrunken und gekotzt.
D C Er hat die Kuh gebissen und zerschlissen.
D C Er hat das Aas geschleppt und mitgenommen.
D C Sie hat die Insekten genossen und empfohlen.
D C Er hat die Hygiene vernachlässigt und gestunken.
D C Er hat die Moskitos gekostet und weitergereicht.
D C Er hat das Ohr zermatscht und aufbewahrt.
D C Sie hat das Mahl erbrochen und inspiziert.
D C Er hat den Dreck gefressen und runtergespült.
D C Sie hat die Würmer gesammelt und inspiziert.
D C Er hat den Kadaver gehoben und verscharrt.
D C Sie hat die Löwen gerochen und gekotzt.
D K Sie hat die Maus verschlungen und geschmatzt.
D K Er hat die Pickel gedrückt und abgedeckt.
D K Er hat das Ungeziefer gebraten und geknabbert.
D K Er hat den Schleim betrachtet und inspiziert.
D K Er hat das Fräulein bepinkelt und belästigt.
D K Er hat die Dusche gemieden und gestunken.
D K Sie hat die Matratze beschmutzt und zerschlissen.
D K Er hat das Tier zerlegt und geknabbert.
D K Er hat die Zigarette verschluckt und gehustet.
D K Sie hat den Abfall vertilgt und geschmatzt.
D K Sie hat die Spinne zerquetscht und aufbewahrt.
D K Sie hat den Hund gegessen und geschmatzt.
D K Sie hat die Asche geschluckt und gehustet.
D K Sie hat das Erbrochene geholt und inspiziert.
D K Sie hat das Blut geleckt und geschmatzt.
F C Er hat den Juwelier beraubt und angegriffen.
F C Sie hat den Betrüger überrascht und verschreckt.

F C Er hat die Feinde gedeckt und geschwiegen.
F C Er hat die Nachricht geflüstert und aufgebauscht.
F C Er hat den Räuber verletzt und liegengelassen.
F C Er hat die Aktivisten gestossen und verprügelt.
F C Sie hat die Auskunft erzwungen und erpresst.
F C Er hat die Warnung gebrüllt und geschrien.
F C Er hat den Sträfling begleitet und gezittert.
F C Er hat dem Nachfolger gedroht und abgewartet.
F C Sie hat den Agenten verraten und verunsichert.
F C Er hat die Säbel gewetzt und erhoben.
F C Sie hat das Gespenst gefühlt und gezittert.
F C Er hat die Hexe geärgert und erpresst.
F C Er hat das Gift ausgegeben und verabreicht.
F K Er hat die Spuren verwischt und verschleiert.
F K Sie hat die Aussage verweigert und geschwiegen.
F K Er hat die Vorwürfe befürchtet und gehört.
F K Sie hat das Messer geschliffen und gezogen.
F K Sie hat den Täter erschreckt und aufgebracht.
F K Er hat die Schüsse vernommen und geortet.
F K Er hat die Tür ausgehebelt und weggeschmissen.
F K Sie hat den Leoparden gestreift und verschreckt.
F K Er hat den Einbrecher beseitigt und weggetragen.
F K Er hat die Botschaft bedroht und angezündet.
F K Sie hat die Ausreise ausgeschlossen und vorgewarnt.
F K Sie hat die Falle benutzt und weggeräumt.
F K Sie hat das Finanzamt betrogen und beschwindelt.
F K Er hat die Bomben gefeuert und abgewartet.
F K Er hat den Rückweg versperrt und abgedunkelt.
H C Sie hat die Trauung verkündet und gelächelt.
H C Er hat die Belohnung genutzt und angelegt.
H C Er hat die Prämie ausgehandelt und gejubelt.
H C Sie hat das Fest veranstaltet und eingeladen.
H C Er hat das Abitur erlangt und gejubelt.
H C Er hat die Gratulation überliefert und gelächelt.
H C Er hat die Prüfung bestanden und gejubelt.
H C Er hat das Aufgebot bestellt und gelächelt.
H C Sie hat das Präsent geschickt und gegrüßt.
H C Er hat der Fabrik geholfen und gearbeitet.
H C Er hat den Patienten geheilt und aufgemuntert.
H C Er hat den Sekt geschüttelt und gejubelt.
H C Er hat den Brand gelöscht und gejubelt.
H C Sie hat die Bonbons ausgehändigt und verteilt.

H C Er hat das Autofahren gelernt und verstanden.
H K Sie hat die Trauung verkündet und gelächelt.
H K Er hat die Belohnung genutzt und angelegt.
H K Er hat die Prämie ausgehandelt und gejubelt.
H K Sie hat das Fest veranstaltet und eingeladen.
H K Er hat das Abitur erlangt und gejubelt.
H K Er hat die Gratulation überliefert und gelächelt.
H K Er hat die Prüfung bestanden und gejubelt.
H K Er hat das Aufgebot bestellt und gelächelt.
H K Sie hat das Präsent geschickt und gegrüßt.
H K Er hat der Fabrik geholfen und gearbeitet.
H K Er hat den Patienten geheilt und aufgemuntert.
H K Er hat den Sekt geschüttelt und gejubelt.
H K Er hat den Brand gelöscht und gejubelt.
H K Sie hat die Bonbons ausgehändigt und verteilt.
H K Er hat das Autofahren gelernt und verstanden.
N C Er hat die Pflanzen gegossen und beschnitten.
N C Er hat die Spiele gespielt und erklärt.
N C Sie hat den Eimer geleert und weggelegt.
N C Sie hat die Show gestartet und begonnen.
N C Er hat den Bogen gespannt und gezielt.
N C Sie hat die Nummer ausgewählt und angerufen.
N C Sie hat die Zwiebeln geschält und geschnitten.
N C Er hat die Fäden vereinigt und eingesammelt.
N C Sie hat die Briefe beantwortet und abgelegt.
N C Er hat die Kunden bedient und abgeschlossen.
N C Er hat die Ausrüstungen verwendet und weggepackt.
N C Er hat das Substantiv dekliniert und genormt.
N C Sie hat die Speisen erhitzt und angeboten.
N C Er hat den Wein geschmeckt und genickt.
N C Er hat die Tiere gefüttert und gekrault.
N C Er hat den Sessel verrückt und abgedeckt.
N C Er hat den Hund ausgeführt und gekrault.
N C Sie hat das Tischtuch gebügelt und gefaltet.
N C Er hat das Hemd geknöpft und angezogen.
N C Sie hat den Ball geworfen und abgepaßt.
N C Er hat den Fisch gefangen und verspeist.
N C Sie hat die Mode geprägt und beeinflusst.
N C Sie hat das Kunstwerk gemalt und aufgehangen.
N C Er hat die Kandidatur ausgehangen und bekanntgemacht.
N C Er hat den Saal geöffnet und gefegt.
N C Er hat das Loch gestopft und genickt.

N C Er hat die Schafe gezählt und eingesperrt.
N C Er hat die Hose erblickt und angezogen.
N C Sie hat die Akten besorgt und geordnet.
N C Er hat den Spieler verpflichtet und eingesetzt.
N C Er hat die Fahrzeuge gewartet und geparkt.
N C Sie hat die Zentrale gewechselt und gearbeitet.
N C Er hat den Hubschrauber gesteuert und gelandet.
N C Er hat die Firmen verwaltet und geführt.
N C Sie hat die Stufe gekehrt und aufgeräumt.
N C Er hat das Verb gebeugt und genormt.
N C Sie hat die Kassette verliehen und abgewartet.
N C Er hat den Druck gekauft und aufgehangen.
N C Er hat das Vorhaben veranlaßt und vorbereitet.
N C Er hat die Kur beantragt und bekommen.
N C Sie hat das Beet bepflanzt und begrünt.
N C Sie hat den Vogel beobachtet und aufgenommen.
N C Er hat die Bücher gelesen und verstanden.
N C Sie hat das Studio verschlossen und gesäubert.
N C Er hat die Treppen gewischt und aufgeräumt.
N C Er hat die Wohnungen gereinigt und aufgeräumt.
N C Sie hat das Präsent gebastelt und abgegeben.
N C Er hat den Griff ausgewechselt und angebracht.
N C Sie hat die Elemente benötigt und geordert.
N C Sie hat den Hammer gebraucht und geordert.
N K Er hat die Pflanzen gegossen und beschnitten.
N K Er hat die Spiele gespielt und erklärt.
N K Sie hat den Eimer geleert und weggelegt.
N K Sie hat die Show gestartet und begonnen.
N K Er hat den Bogen gespannt und gezielt.
N K Sie hat die Nummer ausgewählt und angerufen.
N K Sie hat die Zwiebeln geschält und geschnitten.
N K Er hat die Fäden vereinigt und eingesammelt.
N K Sie hat die Briefe beantwortet und abgelegt.
N K Er hat die Kunden bedient und abgeschlossen.
N K Er hat die Ausrüstungen verwendet und weggepackt.
N K Er hat das Substantiv dekliniert und genormt.
N K Sie hat die Speisen erhitzt und angeboten.
N K Er hat den Wein geschmeckt und genickt.
N K Er hat die Tiere gefüttert und gekrault.
N K Er hat den Sessel verrückt und abgedeckt.
N K Er hat den Hund ausgeführt und gekrault.
N K Sie hat das Tischtuch gebügelt und gefaltet.

N K Er hat das Hemd geknöpft und angezogen.
N K Sie hat den Ball geworfen und abgepaßt.
N K Er hat den Fisch gefangen und verspeist.
N K Sie hat die Mode geprägt und beeinflusst.
N K Sie hat das Kunstwerk gemalt und aufgehangen.
N K Er hat die Kandidatur ausgehangen und bekanntgemacht.
N K Er hat den Saal geöffnet und gefegt.
N K Er hat das Loch gestopft und genickt.
N K Er hat die Schafe gezählt und eingesperrt.
N K Er hat die Hose erblickt und angezogen.
N K Sie hat die Akten besorgt und geordnet.
N K Er hat den Spieler verpflichtet und eingesetzt.
N K Er hat die Fahrzeuge gewartet und geparkt.
N K Sie hat die Zentrale gewechselt und gearbeitet.
N K Er hat den Hubschrauber gesteuert und gelandet.
N K Er hat die Firmen verwaltet und geführt.
N K Sie hat die Stufe gekehrt und aufgeräumt.
N K Er hat das Verb gebeugt und genormt.
N K Sie hat die Kassette verliehen und abgewartet.
N K Er hat den Druck gekauft und aufgehangen.
N K Er hat das Vorhaben veranlaßt und vorbereitet.
N K Er hat die Kur beantragt und bekommen.
N K Sie hat das Beet bepflanzt und begrünt.
N K Sie hat den Vogel beobachtet und aufgenommen.
N K Er hat die Bücher gelesen und verstanden.
N K Sie hat das Studio verschlossen und gesäubert.
N K Er hat die Treppen gewischt und aufgeräumt.
N K Er hat die Wohnungen gereinigt und aufgeräumt.
N K Sie hat das Präsent gebastelt und abgegeben.
N K Er hat den Griff ausgewechselt und angebracht.
N K Sie hat die Elemente benötigt und geordert.
N K Sie hat den Hammer gebraucht und geordert.
N C Er hat die Pflanzen gegossen und beschnitten.
N C Sie hat den Eimer geleert und weggelegt.
N C Er hat den Wein geschmeckt und genickt.
N C Er hat den Hund ausgeführt und gekrault.
N C Er hat den Fisch gefangen und verspeist.
N C Sie hat das Kunstwerk gemalt und aufgehangen.
N C Er hat das Loch gestopft und genickt.
N C Er hat die Kur beantragt und bekommen.
N C Sie hat den Vogel beobachtet und aufgenommen.
N C Sie hat das Präsent gebastelt und abgegeben.

N K Er hat die Tiere gefüttert und gekrault.
N K Er hat die Schafe gezählt und eingesperrt.
N K Er hat die Fahrzeuge gewartet und geparkt.
N K Sie hat die Stufe gekehrt und aufgeräumt.
N K Er hat das Verb gebeugt und genormt.
N K Er hat den Druck gekauft und aufgehangen.
N K Er hat das Vorhaben veranlaßt und vorbereitet.
N K Sie hat das Beet bepflanzt und begrünt.
N K Er hat die Treppen gewischt und aufgeräumt.
N K Er hat die Wohnungen gereinigt und aufgeräumt.

Unintelligible sentences

A C Hung set das Raap geleift ind nagebrucht.
A C Mon set den Tint betüffdigt ind verschlummt.
A C Hung set die Traub verfitzt ind vereugert.
A C Mon set die Drungschift beschampft ind nagebrucht.
A C Hung set die Jigundlachen beligen ind nagebrucht.
A C Hung set den Narz geschiert ind hernobeschwaren.
A C Hung set die Absiret verlummt ind verpunnt.
A C Mon set das Portan nogebrennt ind wiggewarfen.
A C Mon set das Inbahugen getreppt ind gemisert.
A C Hung set die Fellikardt geschmossen ind gekreun.
A C Mon set die Miending reztröst ind ramgemuckert.
A C Hung set die Bamlisch gestiegert ind hernobeschwaren.
A C Mon set die Leuchtarst vertüffen ind ubgesugt.
A C Mon set den Strupfert vertafft ind vereugert.
A C Mon set die Lasse verkahren ind vertacht.
A K Hung set die Schmaktarer gepasselt ind verkuchtet.
A K Mon set den Goezeg gedematigt ind vereugert.
A K Hung set die Emad geknacken ind vereugert.
A K Mon set die Tiesa verdragt ind rezkrutzt.
A K Hung set den Tentasset izkluckelt ind vergriben.
A K Hung set die Noseggenschift befeudigt ind vereugert.
A K Hung set die Noschichte geballigt ind geschweugen.
A K Mon set den Retak betreuft ind nogesparrt.
A K Mon set die Tum izdracht ind verleutert.
A K Hung set die Kinanen gelieden ind ubgepeiert.
A K Hung set die Walget verpföscht ind ramgemuckert.
A K Hung set das Antirgen verbirken ind ramgemuckert.

A K Hung set den Lingflucht getallt ind schakiniert.
A K Hung set die Gendro gemult ind verkeutert.
A K Mon set die Barintert gekrunkt ind vereugert.
D C Hung set die Millhulde bewehnt ind gepfunken.
D C Hung set die Redörm gepürnt ind gekatten.
D C Hung set das Krieleun bemopelt ind bekästigt.
D C Mon set das Gove vewinzt ind bekipfelt.
D C Hung set die Mütrette geknitzt ind gepfunken.
D C Hung set den Golm gefeldert ind gepriezt.
D C Hung set die Busche geweiden ind gepfunken.
D C Mon set das Kla nogebeut ind unspizart.
D C Hung set das Ried gebassen ind rezschlussen.
D C Mon set die Entfahrung gepfafftet ind geschweugen.
D C Mon set die Titun terstiert ind eungepuckt.
D C Hung set die Quadrul verrinlussigt ind gepfunken.
D C Mon set die Baren gewäbben ind geschmitzt.
D C Mon set das Pust izbrichen ind unspizart.
D C Hung set den Getern gemumt ind verschurrt.
D K Mon set den Drotter geneutigt ind bekästigt.
D K Mon set die Rups verschröften ind geschmitzt.
D K Hung set das Schwaun gepuchlet ind unspizart.
D K Hung set die Liche gezäckt ind ubgedackt.
D K Mon set die Löfnam gedasen ind nabewurrt.
D K Hung set den Kimone bezeubtigt ind bekästigt.
D K Hung set das Ingeheier gespirrt ind gekreun.
D K Hung set die Uls getutschelt ind matgenimmen.
D K Mon set den Naffan verpfuxt ind bekästigt.
D K Mon set die Baschife berucht ind bekästigt.
D K Hung set die Sokistan getospert ind reteigerucht.
D K Hung set das Erg rezmitscht ind nabewurrt.
D K Mon set die Krinna rezquatscht ind nabewurrt.
D K Hung set die Musir nogeschlungen ind geblatet.
D K Mon set die Golme geschrickt ind gepostet.
F C Hung set die Scharn getulgt ind verschleuert.
F C Hung set die Zamiat gewaungt ind ubgewarfen.
F C Hung set die Schürane gewirmt ind veransuchert.
F C Mon set den Fülitrag deverlurvt ind verschruckt.
F C Mon set den Riben uzgefeiert ind nagebrucht.
F C Hung set die Palinz gestrüngert ind izligen.
F C Hung set die Schimme vermännen ind geurdet.
F C Mon set die Leutarat geschräbst ind geschweugen.
F C Mon set den Kneile geknüfft ind verschruckt.

F C Mon set die Panrause nogeschlissen ind varggewurnt.
F C Mon set die Ralle benatzt ind wiggetiermt.
F C Hung set die Aktuvusten gesassten ind verpragelt.
F C Mon set den Iganten vernurren ind veransuchert.
F C Hung set die Metra erklutzt ind gehiben.
F C Mon set das Gwielzt gekrafft ind gezattert.
F K Hung set die Konsurte predegefumert ind gefargt.
F K Hung set den Wiffecke bejaubt ind nogegraffen.
F K Mon set das Bakobi gedellen ind gezagen.
F K Hung set den Kosmot gefutzt ind vergalgt.
F K Hung set die Amtalog farmeliert ind vargetrugen.
F K Hung set die Schlunge geschessen ind nogenimmen.
F K Hung set die Nuchracht geschippt ind nagebeuscht.
F K Hung set den Polbrachur ertuppt ind wiggetrugen.
F K Mon set die Angelugenreit deverpräft ind gemuckert.
F K Hung set den Trieber verlutzt ind leugengelissen.
F K Hung set die Bonbor gefiiert ind ubgewurtet.
F K Hung set die Knarung gebrällt ind gekreun.
F K Hung set den Altistark beteiglet ind gezattert.
F K Mon set den Regat bewuschen ind ubgewurtet.
F K Mon set die Gehortakten gesundeit ind kapurt.
H C Hung set den Nestol verbarsicht ind gekobelt.
H C Mon set die Protokonz verhilten ind geheichelt.
H C Mon set den Akosent gebösten ind gepförmt.
H C Hung set der Laikart gegrulen ind gearbirebt.
H C Mon set den Türell geschört ind gekobelt.
H C Hung set die Hosimalat getöfft ind gekacht.
H C Hung set die Plojaft gerüppert ind ubgewurtet.
H C Hung set den Ralt geschöppelt ind gekobelt.
H C Mon set die Turse gekiebt ind geflötzt.
H C Mon set den Retoliker getairalicht ind gepförmt.
H C Mon set den Schindt geheuritet ind gepförmt.
H C Hung set den Dekodamirelt gesimmert ind nageutmet.
H C Mon set das Geunterbürk nogebichnet ind gepreusen.
H C Hung set die Teilehrt izlanden ind verleutert.
H C Hung set das Diktaton geklunt ind antersteutzt.
H K Hung set den Harindisan belonkt ind geheichelt.
H K Hung set das Puchel izkunnt ind gekobelt.
H K Hung set die Gahli döllerwultigt ind geheichelt.
H K Hung set die Pillant bestöngen ind gekobelt.
H K Mon set dem Trümpelt lubberiert ind geheichelt.
H K Hung set das Reil beklammen ind geheichelt.

H K Hung set den Fiebele geteiret ind geflötzt.
H K Mon set das Lankwitz gemunt ind gegräßt.
H K Hung set den Pürer getöscht ind gekobelt.
H K Hung set das Brillu gemost ind ubgeschackt.
H K Hung set den Lobugt vertillert ind gekannen.
H K Hung set den Seiwan benurgt ind ubgewurtet.
H K Hung set die Sibiriel gepost ind gepreusen.
H K Hung set die Basit gebicht ind geheichelt.
H K Hung set den Bürk verdulligt ind verhogt.
N C Hung set die Beunizen geseingen ind beschnutten.
N C Hung set die Aktike geleilt ind izklört.
N C Mon set den Remei gebutet ind wiggelagt.
N C Mon set die Faut getillen ind bekunnen.
N C Hung set den Schei gefildet ind gepfahlt.
N C Mon set die Brelle nogeferst ind ingerafen.
N C Mon set die Peturate gerollet ind geschnutten.
N C Hung set die Gnorderes vermeltet ind eungelammelt.
N C Mon set die Dilla beluhrt ind ubgeligt.
N C Hung set die Plange dedrömt ind ubgeschlassen.
N C Hung set die Vermastigent verwasdet ind wiggepuckt.
N C Hung set das Oktament deprinürt ind genarmt.
N C Mon set die Galuppe izmützt ind ingebaten.
N C Hung set den Luck geschrupft ind genuckt.
N C Hung set die Trit geloftet ind gepreult.
N C Hung set den Dab verlöckt ind ubgeduckt.
N C Hung set den Fiem nogelabt ind gepreult.
N C Mon set das Tastulle geseidelt ind gefultet.
N C Hung set das Pilet gelongt ind ingezagen.
N C Mon set den Pull gebunken ind ubgepußt.
N C Hung set den Hoeft getissen ind verproßt.
N C Hung set den Primurzen gesibbt ind bevarmindet.
N C Mon set das Kanstwurk gemilt ind nagehungen.
N C Hung set die Rutadikant uzgeknoffen ind begunntgemocht.
N C Hung set den Ropp genüffet ind gepogt.
N C Hung set das Rohl gesent ind genuckt.
N C Hung set die Nenese gebrezt ind eungespart.
N C Hung set die Zwech izwöllt ind ingezagen.
N C Mon set die Burbe bekault ind geardnet.
N C Hung set den Oltbamert verbrixelt ind eungespaßt.
N C Hung set die Schundane geluchert ind gefurgt.
N C Mon set die Kondrile uzgemöllen ind gearbirebt.
N C Hung set den Sumpmatofart gefullert ind gelundet.

N C Hung set die Kisume verwiltet ind gepöhrt.
N C Mon set die Hunte gelipst ind nagereimt.
N C Hung set das Pelt gemählt ind genarmt.
N C Mon set die Krötzen versiehen ind ubgewurtet.
N C Hung set den Folia gebeift ind nagehungen.
N C Hung set das Morident verunmagt ind varbereutet.
N C Hung set die Drö beanflagt ind begummen.
N C Mon set das Rühn bedrögt ind begränt.
N C Mon set den Fazir bebuchtet ind nagenimmen.
N C Hung set die Viecker gekrützen ind verpfunden.
N C Mon set das Momens verlüssen ind gepeidert.
N C Hung set die Tombols gewuxt ind nagereimt.
N C Hung set die Sillaturt gepariert ind nagereimt.
N C Mon set das Kamatz beknöllt ind ubgegaben.
N C Hung set den Fader nogeschnoffelt ind ingebrucht.
N C Mon set die Linthelb belastigt ind geardert.
N C Mon set den Hampet gebreikt ind geardert.
N K Hung set die Beunizen geseingen ind beschnutten.
N K Hung set die Aktike geleilt ind izklört.
N K Mon set den Remei gebutet ind wiggelagt.
N K Mon set die Faut getillen ind bekunnen.
N K Hung set den Schei gefildet ind gepfahlt.
N K Mon set die Brelle nogeferst ind ingerafen.
N K Mon set die Peturate gerollet ind geschnutten.
N K Hung set die Gnorderes vermeltet ind eungelammelt.
N K Mon set die Dilla beluhrt ind ubgeligt.
N K Hung set die Plange dedrömt ind ubgeschlassen.
N K Hung set die Vermastigent verwasdet ind wiggepuckt.
N K Hung set das Oktament deprinürt ind genarmt.
N K Mon set die Galuppe izmützt ind ingebaten.
N K Hung set den Luck geschrupft ind genuckt.
N K Hung set die Trit geloftet ind gepreult.
N K Hung set den Dab verlöckt ind ubgeduckt.
N K Hung set den Fiem nogelabt ind gepreult.
N K Mon set das Tastulle geseidelt ind gefultet.
N K Hung set das Pilet gelongt ind ingezagen.
N K Mon set den Pull gebunken ind ubgepußt.
N K Hung set den Hoeft getissen ind verproßt.
N K Hung set den Primurzen gesibbt ind bevarmindet.
N K Mon set das Kanstwurk gemilt ind nagehungen.
N K Hung set die Rutadikant uzgeknoffen ind begunntgemocht.
N K Hung set den Ropp genüffet ind gepogt.

N K Hung set das Rohl gesent ind genuckt.
N K Hung set die Nenese gebrezt ind eungespart.
N K Hung set die Zwech izwöllt ind ingezagen.
N K Mon set die Burbe bekault ind geardnet.
N K Hung set den Oltbamert verbrixelt ind eungespaßt.
N K Hung set die Schundane geluchert ind gefurgt.
N K Mon set die Kondrile uzgemöllen ind gearbirebt.
N K Hung set den Sumpmatofart gefullert ind gelundet.
N K Hung set die Kisume verwiltet ind gepöhrt.
N K Mon set die Hunte gelipst ind nagereimt.
N K Hung set das Pelt gemählt ind genarmt.
N K Mon set die Krötzen versiehen ind ubgewurtet.
N K Hung set den Folia gebeift ind nagehungen.
N K Hung set das Morident verunmagt ind varbereutet.
N K Hung set die Drö beanflagt ind begummen.
N K Mon set das Rühn bedrögt ind begränt.
N K Mon set den Fazir bebuchtet ind nagenimmen.
N K Hung set die Viecker gekrützen ind verpfunden.
N K Mon set das Momens verlüssen ind gepeidert.
N K Hung set die Tombols gewuxt ind nagereimt.
N K Hung set die Sillaturt gepariert ind nagereimt.
N K Mon set das Kamatz beknöllt ind ubgegaben.
N K Hung set den Fader nogeschnoffelt ind ingebrucht.
N K Mon set die Linthelb belastigt ind geardert.
N K Mon set den Hampet gebreikt ind geardert.
N C Hung set die Beunizen geseingen ind beschnutten.
N C Hung set den Ropp genüffet ind gepogt.
N C Hung set die Tombols gewuxt ind nagereimt.
N C Mon set das Kamatz beknöllt ind ubgegaben.
N C Mon set die Linthelb belastigt ind geardert.
N C Hung set die Aktike geleilt ind izklört.
N C Mon set den Pull gebunken ind ubgepußt.
N C Hung set den Primurzen gesibbt ind bevarmindet.
N C Mon set den Fazir bebuchtet ind nagenimmen.
N C Hung set die Viecker gekrützen ind verpfunden.
N K Mon set die Faut getillen ind bekunnen.
N K Mon set das Momens verlüssen ind gepeidert.
N K Hung set die Sillaturt gepariert ind nagereimt.
N K Hung set den Fader nogeschnoffelt ind ingebrucht.
N K Mon set den Hampet gebreikt ind geardert.
N K Hung set die Zwech izwöllt ind ingezagen.
N K Mon set die Burbe bekault ind geardnet.

N K Mon set die Kondrile uzgemöllen ind gearbirebt.
N K Mon set die Hunte gelipst ind nagereimt.
N K Mon set die Krötzen versiehen ind ubgewurtet.

Appendix C

Experiment 2: Video rating results

Item	Speaker 1	Speaker 2	Speaker 3	Speaker 4
1	100	100	100	100
2	100	100	100	100
3	100	100	100	100
4	100	100	100	100
5	100	100	96	100
6	100	100	96	100
7	100	100	96	100
8	100	100	96	100
9	100	100	96	100
10	100	100	96	100
11	100	100	96	100
12	100	100	96	96
13	100	100	96	96
14	100	100	96	96
15	100	100	92	96
16	100	100	92	96
17	100	100	92	96
18	100	100	92	96
19	100	100	92	96
20	100	100	92	96
21	100	100	88	96
22	100	100	88	96
23	100	100	88	96
24	100	100	88	92
25	100	96	88	92
26	96	96	88	92
27	96	96	88	92
28	96	96	88	92
29	96	96	84	92
30	96	96	80	92
31	96	96	80	88
32	96	96	76	88
33	96	96	76	88
34	96	92	76	84
35	96	92	72	84
36	96	92	68	84
37	96	92	64	80
38	96	92	56	80
39	92	92	48	80
40	84	80	44	76

Table C.1: Recognition rates for anger in percent.

Item	Speaker 1	Speaker 2	Speaker 3	Speaker 4
1	100	100	100	100
2	100	100	100	96
3	100	100	100	96
4	100	100	96	96
5	100	100	96	96
6	100	100	96	96
7	96	100	96	96
8	96	100	96	96
9	96	100	92	96
10	92	100	92	92
11	92	100	92	92
12	92	96	92	92
13	92	96	92	88
14	92	96	92	88
15	92	96	88	88
16	92	96	88	88
17	88	96	88	88
18	88	96	84	88
19	88	96	84	84
20	88	96	84	84
21	88	96	84	84
22	84	96	84	84
23	84	96	84	80
24	84	96	80	76
25	80	96	80	76
26	80	96	80	72
27	80	96	80	72
28	80	96	80	68
29	76	96	76	68
30	76	96	76	68
31	76	96	72	68
32	76	96	72	64
33	72	92	72	64
34	72	92	68	64
35	72	92	68	64
36	68	92	68	64
37	68	92	68	60
38	64	92	64	60
39	64	88	60	60
40	24	84	56	48

Table C.2: Recognition rates for happiness in percent.

Item	Speaker 1	Speaker 2	Speaker 3	Speaker 4
1	100	96	96	88
2	92	96	92	76
3	92	92	92	76
4	88	92	92	72
5	88	92	92	56
6	84	92	92	56
7	84	92	92	56
8	84	92	92	48
9	84	88	88	48
10	84	84	88	48
11	84	84	88	44
12	80	84	88	44
13	80	84	88	44
14	80	84	88	44
15	80	80	88	40
16	80	80	88	40
17	80	80	84	40
18	80	80	84	40
19	76	80	84	36
20	76	80	84	36
21	76	80	84	36
22	76	80	84	36
23	76	80	80	36
24	76	80	80	36
25	76	80	76	32
26	76	72	76	32
27	72	72	76	28
28	68	72	72	28
29	68	72	72	28
30	64	68	72	28
31	60	68	72	24
32	60	68	72	20
33	56	64	72	20
34	52	64	72	20
35	44	60	68	20
36	44	60	68	16
37	40	60	64	16
38	28	60	56	16
39	20	48	56	12
40	16	20	48	12

Table C.3: Recognition rates for neutral in percent.

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List of Abbreviations

λ	lambda
μV	micro Volt
ω^2	omega squared
kΩ	kilo Ohm
Ag/AgCl	silver-silverchloride
ANOVA	Analysis of Variance
BDI	Beck Depression Inventory
BG	basal ganglia
df	degree(s) of freedom
DASS	Depression Anxiety Stress Scales
DC	direct current
EEG	electroencephalography/electroencephalogram
EOG	electrooculogram
EPN	early posterior negativity
ERP	event-related potential
ET	explicit task
fMRI	functional Magnetic Resonance Imaging
FADT	Facial Affect Decision Task
FFA	fusiform face area
FPI	Freiburg Personality Inventory
GABA	gamma-aminobutyric acid
GPe	external globus pallidus
GPi	internal globus pallidus
HC	healthy controls
IFG	inferior frontal gyrus
IT	implicit task
(k)Hz	(kilo) Hertz

LC	left-central
LF	left-frontal
LGN	lateral geniculate nucleus
LH	left hemisphere
LP	left-posterior
LPD	left-dominant Parkinson's disease
ms	milliseconds
M	mean
MANOVA	multivariate Analysis of Variance
ML	midline
MMN	mismatch negativity
MMSE	Mini-Mental Status Examination
MSN	Medium spiny neuron
OFC	orbito-frontal cortex
PD	Parkinson's disease
PET	Positron Emission Tomography
roi	region of interest
RC	right-central
RF	right-frontal
RH	right hemisphere
RP	right-posterior
RPD	right-dominant Parkinson's disease
SAM	self-assessment manikin
SAS	Statistical Analysis System
SD	standard deviation
SNc	substantia nigra pars compacta
SNr	substantia nigra pars reticulata
STAI	State-Trait Anxiety Inventory
STG	superior temporal gyrus
STS	superior temporal sulcus
UPDRS	Unified Parkinson's Disease Rating Scale
VL	visual-left
VM	visual-medial
VPP	vertex positve potential
VR	visual-right

BIBLIOGRAPHIC DETAILS

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Emotion Processing in Parkinson's Disease: The Role of Motor Symptom Asymmetry

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Dissertation

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Paper. In order to successfully interact with other people, it is essential to understand their emotional states and to adequately react to them. Parkinson's disease (PD) has been associated with deficits in processing socially relevant emotional cues from speech and facial expressions. However, the validity of previous studies on emotion processing in PD is limited. Most of them have used explicit emotion tasks, which may be confounded by cognitive impairments often observed in PD. Furthermore, the precise time course of emotional processing in PD remains largely unexplored to date. Lastly, PD is often treated as a unitary disease profile, although there is actually high heterogeneity among patients. One distinctive characteristic is the sidedness of motor symptoms, which implies a differential degree of neuronal degeneration in the left and right BG, respectively. The present thesis used event-related potentials and behavioral measures to explore the precise time course of emotion processing in PD, with special emphasis on the sidedness of motor symptoms. In Experiment 1, emotional prosody processing was tested as a function of explicit versus implicit task demands, speech intelligibility, and emotional category. It turned out that predominant right basal ganglia involvement (LPD) led to alterations in early emotional salience detection from prosody (P200). Intelligible speech was predominantly affected, while the processing of unintelligible speech (i.e., speech devoid of semantics) was largely intact in LPD. This suggests that the interaction between prosodic and semantic information may have led to processing alterations in LPD. In Experiment 2, the interaction between two nonverbal (face and prosody) emotion channels was tested in an implicit, cross-modal priming study. Results indicate that the use of contextual information from dynamic emotional facial expressions is delayed in LPD patients during emotional prosody processing. Patients with a predominant left basal ganglia involvement, in turn, were largely comparable to healthy controls in both experiments. The data suggest that early stimulus binding between different types of emotional information may be hampered in LPD. This may be especially true when the interaction between these communication channels requires information to be monitored over larger time scales, as is the case with emotional prosody, which unfolds in time.

Referat. Für erfolgreiche interpersonale Interaktionen ist es wichtig, emotionale Zustände bei anderen zu verstehen und adäquat auf sie zu reagieren. Morbus Parkinson (MP) ist mit Defiziten sowohl für die Verarbeitung von sozial relevanter emotionaler Information aus gesprochener Sprache als auch aus Gesichtsausdrücken in Verbindung gebracht worden. Die Aussagekraft früherer Studien zur Emotionsverarbeitung bei MP ist jedoch begrenzt. Die meisten von ihnen haben explizite Emotionsaufgaben verwendet, die durch die oft beobachteten kognitiven Defizite bei MP konfundiert sein könnten. Außerdem ist der exakte Zeitverlauf der Emotionsverarbeitung bei MP bis heute kaum untersucht worden. Schlussendlich wird MP oft als ein einheitliches Krankheitsbild betrachtet, obwohl die Heterogenität zwischen den Patienten eigentlich sehr groß ist. Ein Unterscheidungsmerkmal ist die Seitigkeit der motorischen Symptome, die mit unterschiedlichen Ausprägungen der neuronalen Degeneration in den rechten und linken Basalganglien einhergeht. Die vorliegende Arbeit nutzt ereigniskorrelierte Potentiale und behaviorale Messungen um den genauen Zeitverlauf der Emotionsverarbeitung bei MP zu erforschen, mit spezieller Betonung auf der Seitigkeit der motorischen Symptome. In Experiment 1 wurde die emotionale Prosodieverarbeitung als Funktion von expliziten versus impliziten Aufgabenanforderungen, Lexikalität der Sprache (d.h. mit und ohne Semantik) und Emotionskategorie untersucht. Es stellte sich heraus, dass eine stärkere Funktionseinschränkung in den rechten Basalganglien (LMP) zu Veränderungen in der frühen emotionalen Salienzdetektion (P200) aus Prosodie führte. Vor allem lexikalische Sprache war betroffen, während die Verarbeitung nicht-lexikalischer Sprache (d.h. Sprache ohne Semantik) bei LMP-Patienten weitgehend intakt war. Das ließ vermuten, dass die Interaktion zwischen prosodischer und semantischer Information diese Verarbeitungsunterschiede hervorgerufen haben könnte. Deshalb wurde in Experiment 2 die Interaktion zwischen zwei nonverbalen Emotionskanälen (Gesicht und Prosodie) mit Hilfe einer impliziten, cross-modalen Priming-Studie getestet. Die Ergebnisse zeigen, dass die Nutzung von Kontextinformation aus dynamischen Gesichtsausdrücken für die emotionale Prosodieverarbeitung in LMP-Patienten verspätet stattfindet. Patienten mit einer stärkeren Funktionseinschränkung der linken Basalganglien verhielten sich dagegen sehr vergleichbar zu den gesunden Kontrollen in beiden

Experimenten. Die Daten lassen vermuten, dass die frühe Interaktion von verschiedenen Arten emotionaler Information in LMP beeinträchtigt ist. Das könnte besonders dann zutreffen, wenn diese Interaktion auf der Notwendigkeit beruht, Information über längere Zeitskalen zu verfolgen, so wie bei emotionaler Prosodie, die sich über den Zeitverlauf entfaltet.

Summary

Introduction

In order to enable successful interpersonal interactions it is important to adequately and quickly recognize emotional cues conveyed by communicative partners. Patients with Parkinson's disease (PD) often show reduced intensity of emotional expressions (e.g., Pell et al., 2006). In addition, many studies suggest that there is a receptive emotional impairment in PD. This affects facial emotion processing (e.g., Ariatti et al., 2008; Sprengelmeyer et al., 2003) as well as the processing of vocal emotion, i.e., affective prosody (e.g., Dara et al., 2008; Yip et al., 2003). However, evidence on this issue is equivocal, as there are several studies which report intact emotion processing in PD (e.g., Mitchell & Bouças, 2009; Pell & Leonard, 2005).

A number of open issues arise from current research on emotion processing in PD. Firstly, PD is often treated as a unitary disease profile, while there is actually high heterogeneity among patients. One important distinctive feature is motor symptom asymmetry. The motor symptoms in idiopathic PD usually start on one side of the body, implying greater neuronal dysfunction in the contralateral basal ganglia, more specifically the striatum (Nahmias et al., 1985; Tatsch et al., 1997). Thus, considering sidedness in PD may help to reveal the role of the left and right striatum and their respective circuits in emotion processing, a factor which is, to date, largely unexplored. As the right hemisphere may be more involved than the left hemisphere in several aspects of emotion processing (Schirmer & Kotz, 2006), a distinction into left and right PD subgroups seems particularly adequate in the context of emotion research.

Furthermore, most of the available studies have used explicit emotion tasks, e.g., emotion categorization. This may be problematic, as many PD patients suffer from cognitive deficits such as impairments of executive functions or working memory deficits. Performance in explicit emotion tasks, however, may be influenced by these cognitive variables (Benke et al., 1998; Breitenstein et al., 2001; Pell & Leonard, 2003). It is thus possible that by ignoring a potential cognitive decline, previous results on emotion processing in PD are confounded with more generalized deficits.

In addition, explicit emotion tasks are only able to capture late, controlled processing stages (Pell, 2002), while the precise time course and early neural mechanisms of emotion processing in PD remain largely unexplored. A very adequate method to shed light on these early modulations is the event-related potentials (ERP) technique, which provides a high temporal resolution in the range of milliseconds. By means of this approach, it has previously been shown that there may be a dissociation of early ERP modulations (intact) and later, explicit emotional judgments (altered) in PD patients when processing emotional pictures (Wieser et al., 2006). This finding underlines that early modulations in the ERP and the performance in explicit emotion tasks may reflect different aspects of emotion processing.

The present thesis investigated emotion processing from socially relevant cues (i.e., facial and vocal) in PD with these time-sensitive ERPs. Furthermore, to shed light on the role of the left and the right striatum and their respective circuits in emotion processing, special emphasis was put on the patients' motor symptom asymmetry.

Experiments

Experiment 1 was conducted to test emotional prosody processing in PD as a function of motor symptom asymmetry. The stimuli consisted of sentences conveying different emotional intonations (angry, disgusted, fearful, happy) or neutral prosody. Previous findings in the neuroimaging literature suggest that the striatum may be more involved in emotional prosody processing when semantic information is available than when not (Kotz, Meyer, et al., 2003). Therefore, unintelligible (pure prosody without semantics) and intelligible (prosody and semantics) speech was tested. Along similar lines, explicit, emotion-related tasks have been reported to involve the striatum more than implicit ones in emotional prosody processing (Bach et al., 2008; Beaucousin et al., 2007), which is why both types of tasks were employed. Comprehensive neuropsychological testing procedures were applied to control for possible cognitive decline. The paradigm was first piloted with a sample of 20–30 years old healthy participants.

Experiment 2 also consisted of a pilot study with young participants and a patient/ healthy control investigation, again considering the sidedness of motor symptoms in PD patients. Cross-modal emotional priming using two kinds of nonverbal emotional cues (dynamic facial expressions and pure prosody without semantics) was investigated. This was performed in both directions, i.e. both stimulus types once served as primes and once as targets. The use of dynamic facial expressions is ecologically more valid than the use of static displays, and has recently been advocated especially for the use in patient studies (de Gelder & van den Stock, 2010). Participants engaged in an implicit (gender decision) task in order to test cross-modal emotional interactions in the absence of an attentional focus on emotion.

Results

The pilot study on emotional prosody processing in young, healthy participants showed a modulation of the P200 component by emotional prosody, with higher amplitude to neutral than emotional prosody. This result confirms previous findings on emotional salience detection from prosody in the P200 (Paulmann & Kotz, 2008). Furthermore, fearful compared to neutral prosody already led to reduced ERP amplitudes in the N100, paralleling findings from the visual domain with very early fear effects in response to emotional faces (Eimer & Holmes, 2002; Luo et al., 2010).

In the patient study, predominant right-striatal dysfunction (LPD) was associated with alterations in emotional salience detection from prosody, as evidenced in the P200 component. Apart from a general enhancement of this ERP component in LPD, there were condition-specific amplitude enhancements. These effects particularly concerned disgust prosody. In fact, LPD patients did not show a P200 differentiation between disgust and neutral prosody, whereas patients with predominant left-striatal dysfunction (RPD) and age-matched healthy controls did. Furthermore, the P200 amplitude in response to intelligible angry and happy speech was affected under explicit and implicit task instructions, respectively. Thus, with the exception of disgust, the processing of unintelligible speech was largely intact in LPD. The processing alterations in LPD patients could not be attributed to cognitive deficits, as cognitive impairments were not apparent in the neuropsychological assessments. In turn, several correlations of the reported P200 effects with motor variables (total left motor symptoms score and a motor symptom asymmetry index, both derived from a neurological disease severity rating) were significant, supporting a relation between asymmetric motor symptoms and early emotional prosody processing in PD. In a subsequent behavioral emotion categorization study employing a reduced set of the prosodic stimuli from the ERP study, no group differences were observed. However, it must be considered that the participants had adapted to the stimuli, as the categorization study was conducted after the EEG sessions.

The finding that - except for disgust - only intelligible speech was affected in LPD led to the assumption that probably not emotional prosody per se, but rather the combination of two different communication channels providing emotional information (prosody and semantics) induced the P200 alterations in the LPD patient group. Therefore, Experiment 2 investigated the interaction of two non-verbal emotional channels in PD, namely prosody and dynamic facial expressions, by means of a priming paradigm as described above.

In the pilot study testing emotional priming in healthy young participants, cross-modal congruency effects in the ERPs were already observed in the N100 component to emotional targets, for both the prosody-as-prime and face-as-prime condition. Thus, the results pointed to an early interaction between facial and vocal information even though the attentional focus was not directed towards emotion, as participants engaged in an implicit task.

The priming study with PD patients and age-matched healthy controls revealed emotional processing alterations in the LPD group. In the face-as-prime condition, it turned out that latter patient group showed a temporally delayed cross-modal congruency effect. While both RPD patients and healthy controls exhibited an emotional congruency effect in the N100 response to prosodic targets, this effect only occurred in the P200 in LPD patients. Thus, the cross-modal interaction of facial and vocal emotional information appears to be shifted in latency in LPD. This extends the findings from Experiment 1 to the interaction between two nonverbal emotion channels. Additional analyses suggested that this effect in LPD patients was unlikely due to altered processing of the dynamic face primes or more generalized cognitive deficits, as LPD patients were fairly comparable to healthy controls in these aspects.

In the reverse prime-target condition, i.e., with prosody as prime, first congruency effects in response to the dynamic facial targets were observed in a posterior P2 component. This modulation was not affected by group. Thus, cross-modal emotional interactions may only be deficient in LPD when the target emotion unfolds over larger time scales and thus requires tracking information over time, as is the case with emotional prosody. Even though facial expressions were also presented in a dynamic manner in the present study, they may rely much less on such a mechanism, as their emotional significance can be readily detected at discrete points in time (Paulmann & Pell, 2010b).

In addition, both LPD and RPD participants showed alterations of the vertex positive potential (latency shifts and amplitude reductions) to dynamic facial expressions in Experiment 2. These were, however, not modulated by condition, i.e., there were no interactions with either emotion or congruency. Furthermore, these alterations occurred in both prime-target assignments, i.e., independent of whether the face stimulus served as prime or as target. Thus, these observations suggest a more generalized impairment of face processing in PD. As both PD groups showed generalized and highly comparable alterations in face processing, but only the LPD group exhibited shifted congruency effects in the face-as-prime condition, these face processing impairments are an unlikely explanation for the delayed cross-modal emotional priming effects in LPD.

Summary and conclusion

To sum up, the findings from the present thesis indicate that PD patients with predominantly right-striatal involvement (LPD) exhibit difficulties in aligning emotional information from different communicative channels when emotional information unfolds over larger time scales (prosody). This affects both the interaction of verbal and nonverbal emotional cues and the interaction between different types of nonverbal emotional cues of high social relevance. The results confirm previous observations that emotion processing from prosody is more affected than emotion processing from faces in PD (Gray & Tickle-Degnen, 2010). However, the higher difficulty associated with emotional prosody as compared to emotional face processing (Paulmann & Pell, 2011) must be kept in mind. Prosody may simply be more likely to lead to functional breakdowns in patient populations because it is more difficult to process.

While LPD patients showed emotion processing impairments in both experiments, RPD patients displayed comparable effects to healthy controls. This lack of early processing deficits in the RPD group is in line with previous findings from patients with left-striatal lesions, which suggest deficits in stimulus binding at later processing stages and only for stimuli containing verbal (semantic) information (Paulmann, Pell, & Kotz, 2009). Thus, the left and the right striatum and their respective circuits may be functionally distinct. A similar proposal was previously put forward in the cognitive domain, in which LPD is associated with visuospatial deficits and RPD more with impaired linguistic functions (see Cronin-Golomb, 2010, for a recent review of the pertaining literature). Future investigations will have to shed more light on the issue of left versus right-striatal functions and circuitry.

Generally speaking, possible emotion deficits in PD should receive more attention in clinical practice, and strategies of how to deal with these problems need to be further developed, as intact emotional functioning is important for successful interpersonal interactions. These, in turn, may represent an important basis for better coping with the disease.

Zusammenfassung

Einleitung

Um erfolgreiche interpersonale Interaktionen zu gewährleisten, ist es wichtig, emotionale Signale bei unseren Kommunikationspartnern schnell und zuverlässig zu erkennen. Patienten mit Morbus Parkinson (MP) zeigen oft einen verminderten emotionalen Ausdruck (z.B. Pell, Cheang & Leonard, 2006). Außerdem gibt es Studien, die nahelegen, dass es beim MP auch zu rezeptiven emotionalen Störungen kommt. Davon ist sowohl die Wahrnehmung emotionaler Gesichtsausdrücke (z.B. Ariatti, Benuzzi & Nichelli, 2008; Sprengelmeyer et al., 2003) als auch die vokale Emotionsverarbeitung, d.h., affektive Prosodie, betroffen (z.B. Dara, Monetta & Pell, 2008; Yip, Lee, Ho, Tsang & Li, 2003). Die Evidenz zu diesem Thema ist jedoch noch inkonsistent, denn es gibt mehrere Studien, die eine intakte Emotionsverarbeitung bei MP berichten (z.B. Mitchell & Boucas, 2009; Pell & Leonard, 2005).

Der aktuelle Forschungsstand zur Emotionsverarbeitung bei MP wirft einige offene Fragen auf. Zum Beispiel wird MP oft als ein einheitliches Krankheitsbild gesehen, obwohl es eigentlich eine hohe Variabilität zwischen den Patienten gibt. Ein wichtiges Unterscheidungskriterium ist die Asymmetrie der motorischen Symptome. Normalerweise beginnen die motorischen Symptome beim idiopathischen MP auf einer Körperseite, was bedeutet dass die neuronale Dysfunktion in den kontralateralen Basalganglien, spezifischer im Striatum, am stärksten ist (Nahmias, Garnett, Firnau & Lang, 1985; Tatsch et al., 1997). Deshalb könnte die Beachtung der Seitenbetonung bei MP hilfreich sein, die Rolle des rechten und linken Striatums und ihrer jeweiligen neuronalen Schaltkreise zu untersuchen. Diesem Faktor ist bis heute kaum Beachtung geschenkt worden. Da die rechte Hemisphäre an mehreren Aspekten der Emotionsverarbeitung stärker beteiligt sein könnte als die linke (Schirmer & Kotz, 2006), könnte eine Unterscheidung in rechts- und linksbetonte Patienten in der Emotionsforschung sinnvoll sein.

Zudem haben die meisten Studien bisher explizite Emotionsaufgaben benutzt, z.B. Emotionskategorisierung. Dies könnte problematisch sein, da viele Parkinsonpatienten unter kognitiven Störungen wie beeinträchtigten Exekutivfunktionen oder Arbeitsgedächtnisproblemen leiden. Die Leistung in solchen expliziten Emotionsaufgaben könnte jedoch durch diese kognitiven Defizite beeinflusst werden (Benke, Bösch & Andree, 1998; Breitenstein, Lancker, Daum & Waters, 2001; Pell & Leonard, 2003). Es ist also möglich, dass durch die Nichtbeachtung potentieller kognitiver Störungen die bisherigen Befunde zur Emotionsverarbeitung bei MP mit generelleren Funktionseinschränkungen konfundiert sind.

Zusätzlich dazu können explizite Emotionsaufgabe nur späte, kontrollierte Verarbeitungsstadien abdecken (Pell, 2002), während der genaue zeitliche Verlauf und die frühen neuronalen Mechanismen der Emotionsverarbeitung bei MP noch weitgehend unerforscht sind. Als Methode, um diese frühen neuronalen Mechanismen abzubilden, ist die Technik der ereigniskorrelierten Potentiale (EKPs) sehr geeignet. Sie bietet eine hohe zeitliche Auflösung im Millisekundenbereich. Mit dieser Herangehensweise konnte bereits gezeigt werden, dass es möglicherweise eine Dissoziation zwischen den frühen Modulationen im EKP (intakt) und späteren, expliziten emotionalen Entscheidungen (beeinträchtigt) bei Parkinsonpatienten gibt, wenn sie emotionale Bilder verarbeiten (Wieser et al., 2006). Dieser Befund weist darauf hin, dass frühe EKP-Modulationen und die Leistung in expliziten Emotionsaufgaben unterschiedliche Prozesse der Emotionsverarbeitung widerspiegeln.

In der vorliegenden Arbeit wurde die Verarbeitung von Emotion aus sozial relevanten Stimuli (Gesicht und Stimme) mit Hilfe dieser zeitlich hochauflösenden EKP-Methode in MP untersucht. Zudem wurde besonderes Augenmerk auf die Asymmetrie der motorischen Symptome gelegt, um mehr über eine mögliche Beteiligung des rechten und des linken Striatums und deren neuronale Schaltkreise an der Emotionsverarbeitung zu erfahren.

Experimente

In Experiment 1 wurde die emotionale Prosodieverarbeitung bei MP als Funktion der motorischen Symptomasymmetrie untersucht. Als Stimuli wurden Sätze entweder in emotionaler (Ärger, Ekel, Angst, Freude) oder neutraler Prosodie verwendet. Es gibt bereits Evidenz aus der neuronalen Bildgebung, dass das Striatum stärker an der emotionalen Prosodieverarbeitung beteiligt sein könnte, wenn semantische Information verfügbar ist als wenn diese fehlt (Kotz et al., 2003). Deshalb wurde sowohl nicht-lexikalische (reine

Prosodie ohne semantische Information) als auch lexikalische (Prosodie plus Semantik) Sprache getestet. In ähnlicher Weise gibt es Befunde, die eine Beteiligung des Striatums an der emotionalen Prosodieverarbeitung eher für explizite als für implizite Emotionsaufgaben berichten (Bach et al., 2008; Beaucousin et al., 2007), weshalb beide Aufgabentypen verwendet wurden. Umfangreiche neuropsychologische Testungen wurden durchgeführt, um mögliche kognitive Einschränkungen zu kontrollieren. Das Paradigma wurde anfangs an einer Stichprobe gesunder Probanden im Alter von 20–30 Jahren pilotiert.

Experiment 2 bestand ebenfalls aus einer Pilotstudie mit jungen Teilnehmern und einer Patienten-Kontrollenstudie, in der die Seitenbetonung der Parkinsonpatienten wieder besonders beachtet wurde. Es wurde cross-modales emotionales Priming mit zwei Arten von nonverbalen emotionalen Stimuli (dynamische Gesichtsausdrücke und reine Prosodie ohne Semantik) untersucht. Dies wurde in beide Richtungen gemacht, d.h. beide Stimulustypen fungierten einmal als Primes und einmal als Targets. Die Verwendung dynamischer emotionaler Gesichtsausdrücke ist ökologisch valider als die Verwendung statischer Gesichter, und die Notwendigkeit solcher Stimuli speziell für Patientenstudien ist kürzlich betont worden (de Gelder & van den Stock, 2010). Die Versuchsteilnehmer bearbeiteten eine implizite Aufgabe (Geschlechtsentscheidung), um cross-modale Interaktionen unabhängig von einem Aufmerksamkeitsfokus auf Emotion zu untersuchen.

Ergebnisse

Die Pilotstudie der emotionalen Prosodieverarbeitung in jungen, gesunden Probanden zeigte eine Modulation der P200-Komponente durch emotionale Prosodie, mit einer höheren Amplitude für neutrale als für emotionale Prosodie. Dieses Ergebnis passt zu früheren Untersuchungen, die eine emotionale Salienzdetektion aus Prosodie in der P200 berichten (Paulmann & Kotz, 2008). Außerdem führte ängstliche im Vergleich zu neutraler Prosodie schon in der N100 zu reduzierten EKP-Amplituden, was zu Befunden über sehr frühe Emotionseffekte zu ängstlichen Gesichtern aus der visuellen Domäne passt (Eimer & Holmes, 2002; Luo, Feng, He, Wang & Luo, 2010).

In der Patientenstudie war eine überwiegend rechts-striatale Dysfunktion (LMP) mit Veränderungen in der emotionalen Salienzdetektion aus Prosodie assoziiert, wie man an der P200-Komponente sehen konnte. Zusätzlich zu einer generellen Amplitudenvergrößerung dieser EKP-Komponente bei LMP-Patienten wurden Vergrößerungen in spezifischen Experimentalbedingungen beobachtet. Dabei war vor allem Ekel-Prosodie betroffen.

LMP-Patienten zeigten keine Differenzierung zwischen neutraler und Ekel-Prosodie in der P200, während dies sowohl bei den rechtsbetonten (RMP) als auch bei den gesunden, altersgematchten Kontrollen der Fall war. Zudem war die P200-Amplitude für lexikalische ärgerliche und freudige Sprache betroffen, bei Ärger in der expliziten und bei Freude in der impliziten Bedingung. Mit Ausnahme von Ekel war die Verarbeitung nicht-lexikalischer Sprache also weitgehend intakt in LMP. Die veränderte Verarbeitung bei LMP-Patienten konnte nicht auf kognitive Defizite zurückgeführt werden, da die neuropsychologischen Testungen keine Defizite erkennen lassen hatten. Dagegen waren mehrere Korrelationen zwischen den berichteten P200-Effekten und motorischen Variablen (Gesamtscore für linksseitige Symptome und ein motorischer Symptomasymmetriescore, beide aus einem neurologischen Rating der Erkrankungsschwere) signifikant und deuteten auf einen Zusammenhang zwischen der Asymmetrie der motorischen Symptome und früher emotionaler Prosodieverarbeitung bei MP hin. Eine zusätzlich durchgeführte behaviorale Emotionskategorisierungsstudie mit einer reduzierten Anzahl der im EEG verwendeten Sätze führte nicht zu Gruppenunterschieden. Es muss jedoch beachtet werden, dass die Versuchsteilnehmer bereits an die Stimuli gewöhnt waren, da die Kategorisierungsstudie nach den EEG-Sitzungen durchgeführt wurde.

Das Ergebnis dass - außer im Fall von Ekel - nur lexikalische Sprache bei LMP-Patienten betroffen war führte zu der Vermutung, dass möglicherweise nicht emotionale Prosodie als solche, sondern eher die Kombination verschiedener Kommunikationskanäle, die emotionale Information vermitteln (Prosodie und Semantik), die P200-Effekte in der LMP-Gruppe hervorgerufen haben könnte. Deshalb wurde in Experiment 2 die Interaktion zweier nonverbaler Emotionskanäle bei MP untersucht, nämlich Prosodie und dynamische Gesichtsausdrücke, mit Hilfe eines Priming-Paradigmas wie oben beschrieben.

In der Pilotstudie, in der emotionales Priming bei gesunden, jungen Versuchsteilnehmern getestet wurde, wurden cross-modale Kongruenzeffekte im EKP bereits in der N100-Komponente für emotionale Targets gefunden, sowohl in der Prosodie-als-Prime als auch in der Gesicht-als-Prime-Bedingung. Die Ergebnisse indizieren also eine frühe Interaktion zwischen fazialer und vokaler Information, obwohl der Aufmerksamkeitsfokus nicht auf Emotion gerichtet war, da die Teilnehmer eine implizite Aufgabe bearbeiteten.

Die Primingstudie mit MP-Patienten und altersgematchten gesunden Kontrollen offenbarte Veränderungen in der Emotionsverarbeitung bei LMP-Patienten. In der Gesicht-als-Prime-Bedingung stellte sich heraus, dass diese Gruppe einen zeitlich verzögerten cross-modalen Kongruenzeffekt zeigte. Während sowohl RMP-Patienten als auch die Kontrollen einen emotionalen Kongruenzeffekt in der N100-Antwort auf prosodische Targets zeigten, wurde ein solcher Effekt in den LMP-Patienten erst in der P200 beobachtet. Die cross-modale Interaktion zwischen fazialer und vokaler emotionaler Information scheint bei LMP-Patienten also später aufzutreten. Dies erweitert die Ergebnisse aus Experiment 1 auf die Interaktion zwischen zwei nonverbalen Emotionskanälen. Zusätzliche Analysen lassen vermuten, dass dieser Effekt in MLP-Patienten eher nicht auf Verarbeitungsunterschiede für die dynamischen Gesichtsprimes oder auf generellere kognitive Defizite zurückzuführen ist, da die LMP-Patienten sich in diesen Aspekten sehr vergleichbar mit den gesunden Kontrollen verhielten.

In der umgekehrten Prime-Target-Bedingung, d.h., mit Prosodie als Prime, wurden die ersten Kongruenzeffekte in Antwort auf die dynamischen Gesichtstargets in einer posterioren P2-Komponente gefunden. Diese Modulation war nicht durch die Gruppe beeinflusst. Das heißt, dass cross-modale emotionale Interaktionen in LMP möglicherweise nur dann gestört sind, wenn sich die Targetemotion über längere Zeitskalen entfaltet und deshalb die Verfolgung über einen Zeitverlauf erfordert, so wie es bei emotionaler Prosodie der Fall ist. Obwohl die Gesichtsausdrücke in dieser Studie auch dynamisch präsentiert wurden, beruhen sie wahrscheinlich weniger auf einem solchen Mechanismus, weil ihre emotionale Bedeutsamkeit sehr gut aus isolierten Zeitpunkten extrahiert werden kann (Paulmann & Pell, 2010b).

Zusätzlich zeigten sowohl LMP- als auch RMP-Patienten Veränderungen im Positiven Vertexpotential (zeitliche Verschiebungen und Amplitudenreduktionen) zu den dynamischen Gesichtsausdrücken in Experiment 2. Diese waren allerdings nicht durch die Experimentalbedingung moduliert, d.h. es gab keine Interaktionen mit Emotion oder Kongruenz. Außerdem wurden diese Veränderungen in beiden Prime-Target-Zuordnungen beobachtet, also unabhängig davon ob der Gesichtsstimulus als Prime oder als Target fungierte. Diese Beobachtungen lassen also eher ein generalisiertes Gesichtsverarbeitungsdefizit bei MP vermuten. Da beide MP-Gruppen generalisierte und sehr vergleichbare Veränderungen in der Gesichtsverarbeitung zeigten, aber nur die LMP-Gruppe verspätete Kongruenzeffekte in der Gesicht-als-Prime-Bedingung zeigte, sind diese Gesichtsverarbeitungsstörungen aber keine wahrscheinliche Erklärung für die verspäteten cross-modalen emotionalen Primingeffekte bei LMP.

Zusammenfassung und Schlussfolgerungen

Zusammenfassend indizieren die Ergebnisse der vorliegenden Arbeit, dass MP-Patienten mit vorherrschender rechts-striataler Beeinträchtigung (LMP) Schwierigkeiten beim Abgleichen von emotionaler Information aus verschiedenen Kommunikationskanälen haben, wenn sich emotionale Information über längere Zeitskalen entfaltet (Prosodie). Dies trifft sowohl für die Interaktion zwischen verbalen und nonverbalen emotionalen Signalen als auch zwischen verschiedenen Arten von nonverbalen emotionalen Signalen von hoher sozialer Relevanz zu. Die Ergebnisse bestätigen frühere Beobachtungen, dass beim MP die Emotionsverarbeitung aus Prosodie stärker beeinträchtigt ist als aus Gesichtsausdrücken (Gray & Tickle-Degnen, 2010). Allerdings muss man hierbei auch den erhöhten Schwierigkeitsgrad, der mit emotionaler Prosodie im Vergleich zur emotionalen Gesichtsverarbeitung einhergeht (Paulmann & Pell, 2011), beachten. Prosodie könnte deshalb leichter zu Funktionseinschränkungen in Patientenstichproben führen, weil sie schwieriger zu verarbeiten ist.

Während LMP-Patienten Emotionsverarbeitungsdefizite in beiden Experimenten zeigten, verhielten sich die RMP-Patienten vergleichbar zu den gesunden Kontrollen. Das Fehlen früher Verarbeitungsdefizite in der RMP-Gruppe passt zu Daten über Patienten mit links-striatalen Läsionen, die auf Integrationsdefizite für spätere Verarbeitungsstufen hinweisen, und nur für Stimuli, die auch verbale (semantische) Information enthalten (Paulmann, Pell & Kotz, 2009). Das heißt, dass das linke und das rechte Striatum funktionelle Unterschiede aufweisen könnten. Ein ähnlicher Vorschlag wurde kürzlich für den kognitiven Bereich gemacht, wo LMP mit visuospatialen Defiziten und RMP eher mit linguistischen Funktionseinschränkungen in Verbindung gebracht wird (siehe Cronin-Golomb, 2010, für eine aktuelle Zusammenfassung der relevanten Literatur). Zukünftige Untersuchungen sollten über links- und rechtsstriatale Funktionen und deren neuronale Schaltkreise mehr Aufschluss geben.

Allgemein gesagt sollten mögliche Emotionsdefizite bei MP mehr Aufmerksamkeit in der klinischen Praxis bekommen und Strategien, wie man diesen Problemen begegnen könnte, müssten entwickelt werden, da intakte emotionale Funktionen wichtig für erfolgreiche zwischenmenschliche Interaktionen sind. Diese wiederum könnten eine zentrale Grundlage darstellen, um besser mit der Krankheit zurechtzukommen.

Curriculum Vitae

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List of Publications

Garrido-Vásquez, P., Pell, M D., Paulmann, S., Strecker, K., Schwarz, J., & Kotz, S. A. (under review). Motor symptom asymmetry matters: new evidence on vocal emotion processing in Parkinson's disease.

Garrido-Vásquez, P., Jessen, S., & Kotz, S. A. (2011). Perception of emotion in psychiatric disorders: on the possible role of task, dynamics, and multimodality. *Social Neuroscience, 6*(5-6), 515–536.

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2. Von folgenden Personen erhielt ich Unterstützungsleistung bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts/der Arbeit:
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    Max-Planck-Institut für Kognitions- und Neurowissenschaften, Leipzig
    Prof. Dr. Marc D. Pell
    McGill University, Montreal, Kanada
    Dr. Silke Paulmann
    University of Essex, Colchester, UK

Zudem standen mir andere wissenschaftliche und technische Mitarbeiter des Max-Planck-Instituts für Kognitions- und Neurowissenschaften bei der Diskussion inhaltlicher, methodischer und technischer Fragen und Probleme sowie bei der Datenerhebung hilfreich zur Seite.

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Leipzig, den 24.10.2011

Patricia Garrido Vásquez