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Recognition of affective prosody in brain-damaged patients and healthy controls: A neurophysiological study using EEG and whole-head MEG

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A passive oddball experiment was used in which stimuli were emotional exclamations differing in their affective tone. In both electroencephalography (EEG) and magnetoencephalography (MEG), deviants elicited an N300 component, sometimes accompanied by a slow wave. Both components had a symmetrical distribution, but the former was more posterior than the latter. The same responses to prosodic stimuli were significant in 6 of 27 patients with severe disorders of consciousness (persistent vegetative state and minimally conscious state) and in all 3 of the examined locked-in patients, indicating that the procedure can be applied for testing neurological patients. The occurrence of significant responses depended on the presence or absence of a lesion to the right temporal lobe. Obviously, the N300 depends on the activity of the right temporal cortex but does not originate there. We suggest that the component is related not to the recognition of affective prosody as such, but to the following detection of affective mismatch due to violations of emotional context of stimulation.

Whereas brain mechanisms and electrophysiological correlates of semantic processing have been studied extensively during the past decades, less attention has been paid to the electrophysiology of *speech prosody*. This term denotes those aspects related to intonation (melody) of spoken language and subsumes two functionally different components: linguistic prosody, which helps the perceiver to perform segmentation of the stream of spoken sentences and plays a role equivalent to punctuation in a written text; and emotional prosody, which expresses the emotions of the speaker (Scherer, 1986). The former is perceived on a rather large time scale, including whole words or phrases, on the basis of periodical changes in voice pitch, timbre, and loudness. The latter, in contrast, is perceived on a shorter time scale (e.g., phonemes) on the basis of an acoustical parameter called *voice quality* (Laver, 1980).

It is well known (see Kutas & Hillyard, 1980, for written language; Connolly, Stewart, & Phillips, 1990, for spoken language) that words not strongly semantically primed typically elicit a central or parietocentral event-related brain potential (ERP) component, N400. In contrast, syntactic violations or syntactically difficult constructions frequently yield other ERP components, such as the left anterior negativity (LAN) or a parietal positivity P600 (Friederici, Hahne, & Mecklinger, 1996; Friederici, Pfeifer, & Hahne, 1993). There is a controversy about the specificity of these effects; the P600, for example, can be found after all kinds of violations of language rules (Kotchoubey & Lang, 2003; Münte, Heinze, Matzke, & Wieringa, & Johannes, 1998). Similar positive components also appear after key words in sentences, which dissolve uncertainty produced by an equivocal context (Friederici et al., 1996; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Osterhout, Holcomb, & Swinney, 1994). One may, therefore, wonder whether such a late positivity would also occur when a resolution of uncertainty was

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attained not by a particular syntactical structure, but because of prosodic accents (e.g., "the workers considered the last offer from the management of the factory" vs. "the workers considered the last offer from the management was a real insult" [Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992]). Several studies have indicated that this is, indeed, the case (Kerkhofs, Vonk, Schriefers, & Chwilla, 2007; Mietz, Toepel, Ischebeck, & Alter, 2008; Steinhauer, 2003; Steinhauer, Alter, & Friederici, 1999; Steinhauer & Friederici, 2001). A slow positivity whose latency depended on the localization of the prosodic shift in a sentence was also obtained in senseless "sentences" consisting of pseudowords, and even in hummed sentence-like sequences (Pannekamp, Toepel, Alter, Hahne, & Friederici, 2005). On the other hand, considerable semantic or pragmatic uncertainty caused by prosodic manipulations can elicit N400-like effects (e.g., Eckstein & Friederici, 2005; Magne et al., 2005; Mietz et al., 2008, for electroencephalography [EEG] studies; Hayashi, Imaizumi, Mori, Niimi, & Ueno, 2001; Imaizumi, Mori, Kiritani, Hosoi, & Tonoike, 1998, for magnetoencephalography [MEG] studies). Also, the N400 to semantic mismatch can be modified by preceding prosodic information (Isel, Alter, & Friederici, 2005). Whereas prosodic incongruence in the middle of the sentence tends to elicit a central or centroparietal negativity, similar manipulations with final words lead to a late positivity and a right anterior negativity (Eckstein & Friederici, 2005; Magne et al., 2005).

Much less is known about electrophysiological effects of emotional prosody. Schirmer, Kotz, and Friederici (2002) described an emotional prosodic priming effect on word targets that was similar to the corresponding semantic priming effect (in both cases, the ERP component N400 is less in primed than in nonprimed words) but whose time course revealed gender differences unusual for semantic priming (i.e., women exhibited faster emotional priming than did men). However, when subjects had to pay attention to prosody and judge its congruence, the difference between men and women disappeared (Schirmer, Kotz, & Friederici, 2005). Wambacq, Shea-Miller, and Abubakr (2004) reported an increased ERP positivity to spoken words with negative affective prosody (as compared with words with neutral prosody), whose latency varied as a function of attention; no interaction between the consecutive words (i.e., priming) was reported. Recently, Kotz and Paulmann (2007) and Paulmann and Kotz (2008b) used a set of sentences containing violations of emotional and semantic context. They found a late right-lateralized positivity in response to purely emotional violations and a broadly distributed negativity around 300 msec to combined emotional and semantic violations.

All these studies employed emotionally colored spoken words that always possess some referential context regardless of their prosodic tone. This context is an additional factor, because the emotional content of a word can interact with emotional prosody in an a priori unpredictable way. To avoid this additional effect, Bostanov and Kotchoubey (2004) used emotional exclamations instead of words. Such exclamations are phylogenetically primary and still are the most powerful means for communication of purely affective contents (Goffman, 1978; Scherer & Kappas, 1988). Most humans can recognize them almost without errors and within a very short time on the basis of the voice quality (Scherer, 1986).

Using an oddball paradigm without explicit instruction with four different emotionally positive (happy) exclamations and one emotionally negative (sad) one, Bostanov and Kotchoubey (2004) obtained an ERP negativity with a central maximum peaking about 300 msec poststimulus as a response to violations of the actual affective context. An acoustical analysis of the exclamations and a control priming experiment revealed that this ERP component was unrelated to simple physical stimulus features such as fundamental frequency (F0) and intensity. Likewise, it cannot be attributed solely to the contrast between positive and negative affects, because a similar effect was also observed in response to a negative emotion (e.g., disgust) presented on the background of another negative emotion (e.g., fear). This component, called N300, might, therefore, be putatively regarded as an electrophysiological marker for recognition of changes in emotional prosody (Figure 1).

The significance of such a marker is determined by the fact that perception of prosody is a separate (modular) brain function largely unrelated to other aspects of spoken language processing. Double dissociations between deficient prosody recognition and other, superficially similar functional disturbances revealed an independent type of neuropsychological dysfunction, the sensory *aprosodia* (Adolphs, Damasio, & Tranel, 2002; Anderson & Phelps, 1998; Perry et al., 2001). Such patients, typically with a lesion in the right temporal lobe (RTL; Adolphs et al., 2002; Ross, Orbelo, Burgard, & Hansel, 1998), cannot recognize the intonation of speech, although they can comprehend semantic and syntactical aspects of language. Interestingly, the aprosodia test battery developed for the assessment of this disorder comprises both linguistic and emotional aspects of prosody (Ross, 1981), and no strong evidence exists that the two can be affected independently of each other (Seddoh, 2002).

If the recognition of prosody can be disturbed while everything else works correctly, the opposite condition is also possible; that is, the recognition of prosody (possibly, of affective prosody, which is simpler than linguistic prosody) may remain the only (or one of only a few) intact cortical function(s) in a patient with otherwise severely disturbed mental capacities. Being completely unable to understand the semantic content of spoken words and sentences, such a patient might be diagnosed as being in a persistent vegetative state (PVS; Jennett, 2002; Kotchoubey, in press; Royal Colleges of Physicians, 2003). An electrophysiological test procedure, such as the passive emotional oddball described above, might reveal that some of these patients are nevertheless able to adequately perceive some nonverbal aspects of speech.

Bostanov and Kotchoubey (2004) hypothesized that their N300 elicited by prosodic mismatch may be equivalent to the N400 to semantic mismatch, but this interpretation is based mostly on the functional justification, rather than the specific spatiotemporal characteristics of the

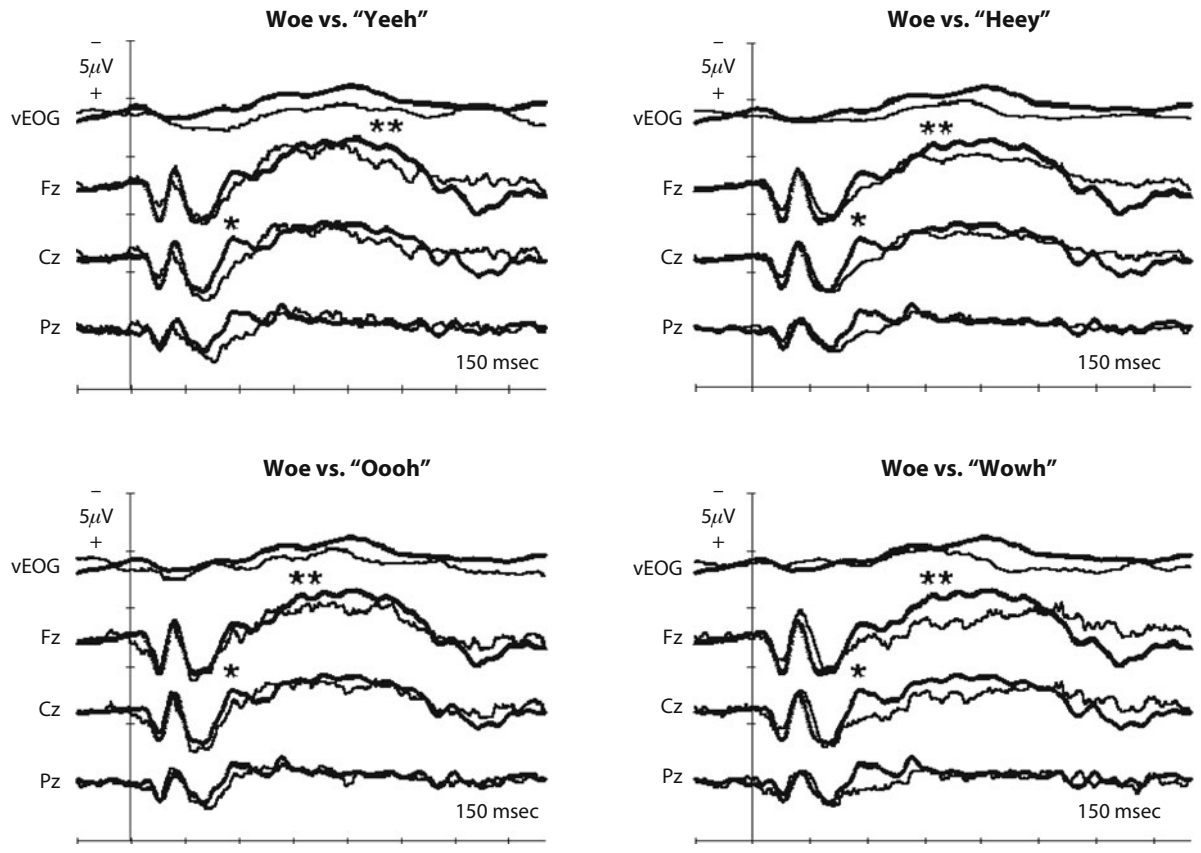

Figure 1. Event-related brain potentials to the woe exclamation (bold line) compared with the four joyful exclamations "heey," "oooh," "yeeh," and "wowh" (thin line), at midline electrode sites, based on the data of Bostanov and Kotchoubey (2004). Negativity is up. Each tick on the *x*-axis stands for 150 msec, each tick on the *y* axis, for 5 μV. Note that in contrast to the figures in Bostanov and Kotchoubey, the waveforms presented here contain an equal number of standards and deviants (i.e., 60 per subject). The N300 (marked *) is accompanied by a slow negative wave (marked **). The slow wave appears to have a more anterior distribution than the N300 and is completely absent over the parietal cortex. However, the condition × topography interaction was not significant.

component. Given a low spatial resolution in that study, alternative accounts could not be ruled out. The N300 might, for instance, belong to the family of mismatch negativities (MMNs) elicited by any acoustical deviation (Näätänen, 1992). The contemporary literature clearly indicates that MMN is produced not only by deviations in simple physical features but also by changes in very complex acoustical patterns (e.g., List, Justus, Robertson, & Bentin, 2007; Näätänen & Winkler, 1999; Pulvermüller, Shtyrov, Hasting, & Carlyon, 2008; Schröger, 1997).

The aims of the present study were (1) to further explore the brain activity involved in the analysis of emotional prosodic stimulus features, and (2) to use this experimental procedure for the assessment of prosodic comprehension in neurological patients to whom the standard neuropsychological techniques cannot be applied, because of either a disorder of consciousness or severe motor paralysis. Concerning (1), we hoped that the whole-head MEG technique, with its high spatial resolution, would shed more light on the origin of the N300. As regards (2), the EEG recordings were carried out in a group of patients with extremely severe disorders of consciousness, as well as in 3 severely paralyzed patients, 2 of whom were in a complete locked-in state. During the last few years, several research groups have developed batteries of ERP tests designed for assessment of cognitive information processing, including complex memory and semantic processing, in patients with severe paralysis, disorders of consciousness, or severe aphasia (e.g., Becker & Reinvang, 2007; Connolly & D'Arcy, 2000; Connolly, Mate-Kole, & Joyce, 1999; D'Arcy et al., 2003; Kotchoubey et al., 2005; Neumann & Kotchoubey, 2004; Reinvang, 1999). However, to the best of our knowledge, these methods have never been applied for assessment of prosodic functions in the severely disabled. Evidence from both ERP (e.g., Kotchoubey et al., 2005; Wijnen, van Boxtel, Eilander, & de Gelder, 2007) and imaging (e.g., Laureys, Giacino, Schiff, Schabus, & Owen, 2006; Owen et al., 2006) experiments has accumulated that even patients diagnosed as being in a PVS can exhibit signs of cortical stimulus processing at different levels of complexity. We expected that the processing of affective prosody would also be present in some of these patients. Particularly, on the basis of previous lesion studies (e.g., Ross et al., 1998), better results may be expected in patients with an intact RTL.

Table 1
Patient Data

Initials	Age (years)	Gender	Diagnosis	Etiology	Duration (months)	BAEPs	Scan Method	Main Lesion	RTL Damage
A.O.	37	F	GBS		70	normal	no		
J.B.	52	M	ALS		79	normal	no		
J.W.	55	M	ALS		83	normal	no		
B.K.	64	M	PVS	SAH	4	normal right	CT	Diffuse cortical atrophy	Yes
G.R.	35	M	PVS	TBI	2.5	normal	CT	Frontotemporal left	No
H.S.	20	M	PVS	TBI	2	normal	CT	Frontotemporal right	Yes
K.B.	63	M	PVS	stroke	1.5	normal	CT	Thalamus, capsula interna	No
L.M.	35	M	PVS	SAH	8	normal right	CT	Diffuse cortical atrophy	Yes
M.R.	37	M	PVS	anoxia	9	normal	CT	Frontotemporal left	No
N.J.	18	M	PVS	TBI	2.5	normal	MRT	Parietooccipital bilateral	No
P.C.	33	F	PVS	TBI	11	normal right	CT	Temporal left	No
R.G.	43	F	PVS	anoxia	2	normal	CT	Diffuse cortical atrophy	Yes
R.J.	38	F	PVS	anoxia	3	normal	CT	Diffuse cortical atrophy	Yes
R.T.	18	M	PVS	TBI	4	normal left	CT	Frontotemporal right	Yes
R.U.	19	F	PVS	stroke	26	normal	MRT	Frontal, temporal, parietal right	Yes
V.G.	54	M	PVS	SAH	6	normal	CT	Frontotemporal bilateral	Yes
W.J.	55	M	PVS	TBI	3	normal	CT	Diffuse cortical atrophy	Yes
W.U.	45	M	PVS	TBI	7	normal	MRT	Parietotemporal left	No
B.U.	50	F	MCS	SAH	2	normal	CT	Frontal bilateral, temporal right	Yes
G.E.	68	M	MCS	anoxia	5.5	normal	CT	Diffuse cortical atrophy	Yes
H.A.	53	M	MCS	anoxia	6	normal	CT	Diffuse cortical atrophy	Yes
H.K.	32	M	MCS	TBI	108	normal	MRT	Diffuse subcortical	No
H.T.	54	F	MCS	anoxia	5	normal	CT	Diffuse cortical atrophy	Yes
J.M.	30	M	MCS	SAH	4	normal left	CT	Frontal bilateral	No
L.A.	55	M	MCS	anoxia	2	normal left	MRT	Diffuse cortical atrophy	Yes
O.T.	67	M	MCS	stroke	2	normal right	CT	Frontotemporal left	No
R.F.	24	F	MCS	TBI	45	normal	MRT	Frontal left, posterior bilateral	No
S.B.	59	M	MCS	SAH	8	normal	CT	Diffuse cortical atrophy	Yes
S.I.	50	F	MCS	SAH	4.5	normal	CT	Diffuse cortical atrophy	Yes
T.Y.	27	M	MCS	TBI	57	normal	CT	Mostly thalamic bilateral	No

Note—ALS, amyotrophic lateral sclerosis; GBS, Guillain-Barré syndrome; MCS, minimally conscious state; PVS, persistent vegetative state; SAH, subarachnoidal hemorrhage; TBI, traumatic brain injury; CT, computer tomography; MRT, magnetic resonance tomography; RTL, right temporal lobe. Boldface initials are those of patients who exhibited significant responses to prosodic stimuli.

The study was approved by the ethical committee of the University of Tübingen Medical School. Patients were examined, with the informed consent of their legal representatives.

METHOD

Subjects

Eight men and 8 women, age range 26–40 years, took part in the MEG experiment. All subjects were right-handed. None had a history of any neurological or psychiatric disease. All subjects were paid €8/h.

A total of 29 patients with severe disorders of consciousness were examined; the data of 2 patients were dismissed due to excessive movement artifacts. The remaining group consisted of patients in PVS or minimally conscious state (MCS).[1] Inclusion criteria for this group were: age >16; normal brainstem auditory evoked potentials (BAEPs) at least on one side with possibly delayed, but not absent, BAEPs on the other side; no flat EEG; and no diffuse delta waves in the EEG. All patients were examBined during waking. The cortical N1 component of the auditory evoked potentials was present in all of them.

Additionally, 3 patients with severe motor disability were examined, 2 of them totally paralyzed (including a complete gaze paralysis), and the 3rd with tetraplegia and speech paralysis. The data of all patients are summarized in Table 1. Below we describe in more detail the data of those patients whose electrophysiological data will be presented in Figures 4 and 5.

1. Patient K.B.: male, 63, diagnosed as PVS after a parenchymal hemorrhage with extensive lesions in the thalamus and capsula interna. Coma duration was 12 days. EEG examination on Day 50 (when the prosody experiment was carried out) showed regular symmetrical fast theta oscillations of 6–7 Hz, without a response to light, normal BAEPs and slightly delayed somatosensory evoked potentials (SSEPs).

2. Patient J.M.: male, 30, admitted at the neurosurgical hospital with a subarachnoidal hemorrhage from the ramus communicans anterior. Angiographic examination demonstrated an aneurysm in this artery. An attempt to close this aneurysm with endovascular coils resulted in a transient closure of both anterior cerebral arteries, leading to a severe generalized swelling. Computer tomography (CT) showed severe malresorptive hydrocephalus. Therefore, a ventriculoperitoneal shunt was installed, resulting in the improvement of liquor circulation. Coma duration was 24 days. EEG examination took place on Day 131. The patient was awake and capable of short-time visual fixation. The diagnosis was MCS or suspected PVS. The EEG was characterized by the predominant symmetrical theta rhythm, without a consistent response to stimulation. BAEPs and SSEPs were intact.

3. Patient M.R.: male, 37, survived brain anoxia brought on by prolonged cardiac arrest. He was in a coma for 3 weeks. CT demonstrated a diffuse atrophy of cortical gray matter, predominantly in the left frontal, temporal, and parietal lobes. The diagnosis was PVS. The prosody experiment was carried out on Day 294. The EEG was mainly characterized by theta activity at 5–6 Hz, which was not suppressed by light. SSEPs were delayed and decreased in amplitude. BAEPs were slightly delayed on the right side and normal on the left side.

4. Patient J.B.: male, 52. Five years prior to participation in the present study, he was diagnosed with amyotrophic lateral sclerosis (ALS) with a pseudobulbar syndrome. Difficulties in swallowing and

speech (dysarthria) dramatically increased within a few weeks after diagnosis. After 1.5 years, a paresis in the extremities developed, finally leading to complete paralysis. The patient was tracheostomized after acute respiratory failure. During the next 3 years he communicated using eye movements. He also was trained, with considerable success, to use a brain–computer interface (Kübler et al., 1999). After pneumonia and subsequent sepsis lasting for about 5 weeks, any communication abilities were lost. The patient was artificially ventilated and fed. The EEG demonstrated a regular alpha rhythm, reactivity to light stimulation, and normal BAEPs and SSEPs.

5. Patient J.W.: male, 55, had suffered from ALS for 7 years. The onset of the disease was marked by slowly developing weakness in the legs accompanied by paresthesias. This progressive weakness resulted in a complete paraplegia within 3 years, followed by a similar symptom development in the upper extremities. During the time of examination, the patient's status was characterized by tetraplegia with hypotonia in the legs and hypertonia and hyperreflexia in the arms. Breathing was spontaneous, but speech and swallowing were impossible. The patient communicated using eye movements, mimicry, and vocalizations. No abnormality was found in the rest EEG or in sensory evoked potentials.

6. Patient A.O.: female, 37, suffered from chronic polyradiculoneuropathy with Guillain-Barré syndrome (GBS) for almost 6 years. Her clinical condition and the results of her first ERP examination have been reported elsewhere (Kotchoubey, Lang, Bostanov, & Birbaumer, 2003). Here, a result of the second examination is presented, 8 months after the first one. The patient was completely unresponsive, with eyes closed and depressed muscle tone. The EEG showed an occipital alpha rhythm of very low amplitude (8 Hz, 5–10 μV), decreasing with stimulation. BAEPs and SSEPs were completely normal. As with J.B., no communication using eye movements was possible.

Procedure

Five emotional vocalizations were presented, four of them being exclamations of joy: "Yeeh!," "Heey!," "Wow!," and "Oooh!" A single exclamation of woe, "Oooh!," served as a deviant stimulus. The duration of both "Ooohs" was 840 msec; that of the other joyful stimuli, 750, 800, and 870 msec, respectively. All five stimuli had the same occurrence frequency of 20%. The vowel /o/ was purposely chosen for both the sad exclamation and one of the joyful exclamations. The stimuli were identical to those used in Bostanov and Kotchoubey (2004) and Kotchoubey, Lang, Bostanov, and Birbaumer (2003). In the former article, spectrograms are presented, and it was shown that the difference between the ERPs to "Oooh!" (woe) and Oooh!" (joy) was the same as that between "Oooh!" (woe) and the average of all joyful stimuli, thus demonstrating that this difference cannot be attributed to a particular vowel. However, it would be incorrect to compare the sad stimulus only with "Oooh!" (joy), because different standards matched different features of the deviant. The sad exclamation was adjusted so that it was close to the mean of the four joyful exclamations in terms of F0 and average intensity. Control experiments (which cannot be reported here in detail) showed that whenever the deviant, whether an emotional or tonal stimulus, differed from standards in a simple acoustical property such as F0 or intensity, it elicited a completely different response, dominated by a parietal P300. Only emotional deviants matched to standards—at least with respect to the perceived pitch and loudness—elicit a pattern presented in Figure 1.

All exclamations were uttered by a male speaker who was not a professional actor, and were recorded digitally at a 22-kHz/16-bit sampling rate. The sounds had been tested on several groups of young healthy individuals in Germany, France, England, Italy, and Israel, with the recognition rate being 92%–95% in all groups—except the French, whose recognition rate was 80%. During the experiment, each of the five stimuli occurred 60 times in a randomized sequence of 300 sounds binaurally presented at a rate of 1 stimulus/1.1 sec. All healthy subjects in the present experiment reported that they recognized one (infrequent) woe stimulus among several joyful stimuli.

All subjects were told to avoid movements and to listen to the stimuli. They were not instructed to make an overt or covert response to any stimulus, mainly because the procedure was designed for patients who cannot make any response (see Bostanov & Kotchoubey, 2004; Kotchoubey et al., 2005; Neumann & Kotchoubey, 2004). Additionally, an active instruction, such as making a motor response or mental count, might activate processes of "perceptual closure" (e.g., Verleger, 1988), resulting in a P300 to the deviant.

Data Acquisition and Analysis

Healthy subjects. MEG was recorded from 151 first-order magnetic gradiometers (CTF Inc., Vancouver, BC) and was digitized at 250/sec. The subject's head position was determined using localization coils at the nasion and preauricular points and repeatedly controlled after the end of the experimental procedure. Artifactual trials (no more than five per subject) were defined according to the amplitude criterion >1.3 pT in frontal channels and were dismissed. The data were subdivided into epochs from -100 to $+1{,}000$ msec around stimulus onset. After this, they were digitally filtered with a high pass of 0.5 Hz and a low pass of 40 Hz. Difference fields were computed by subtracting the waveforms produced by the sad exclamation from the mean waveforms produced by the joyful exclamations.

The mean amplitudes of event-related magnetic fields were determined for each channel in the intervals from 200 to 300 msec and from 300 to 500 msec, which corresponds approximately to the N300 and the following slow negative component. Additionally, an interval of 80–140 msec (N1) was measured. The absolute values of these amplitudes (regardless of the sign) were compared between joyful and sad exclamations in each channel, using a *t* test. Furthermore, means were calculated for the following groups of sensors: frontal right, frontal left (16 sensors each); central right, central left (16 sensors each); parietal right, parietal left (9 sensors each); anteriotemporal right, anteriotemporal left (10 sensors each); and posteriotemporal right, posteriotemporal left (11 sensors each). The sensors at the midline were excluded. A repeated measures ANOVA was then performed with factors of region (five levels), side (two levels: right vs. left) and stimulus (five levels), and time window (two levels: 200–300 vs. 300–500 msec). The last factor was not included in the ANOVA for N1. When appropriate, Greenhouse–Geisser epsilon (ε) correction for nonsphericity was applied. When the main effect of the factor stimulus or its interactions were significant, *t* tests were conducted to compare responses to individual stimuli pairwise.

Patients. EEG was recorded using nine sintered Ag/AgCl electrodes attached at scalp positions F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4, according to the 10–20 system. Two mastoid electrodes connected via a 15-kΩ shunt served as reference. Two vertical (above and below one eye) and horizontal ocular electrodes (at the outer corners of both eyes) were used to record the electrooculogram (EOG). The signals were digitized at 512/sec and filtered with a high-pass filter of 0.3 Hz and a low-pass filter of 70 Hz (12 dB/octave). Additionally, a notch filter was set around 50 Hz. Epochs were chosen from 100 msec before to 1 sec after stimulus onset. A regression procedure (Gratton, Coles, & Donchin, 1983) was employed to correct blink and eye movement artifacts. The remaining artifacts (1–3 trials per patient/condition) were dismissed according to the ± 150 μV amplitude criterion.

For statistical analysis, the ERPs were first averaged for each individual patient across all responses, irrespective of condition: the so-called total average, which was then wavelet transformed using the continuous wavelet "Mexican Hat." In this total-average scalogram, wavelet measures for the N300 were identified as described in Bostanov and Kotchoubey (2004). Thus defined, N300 amplitudes were then measured in each single trial and grouped into five conditions according to the five stimuli presented. The following statistical evaluation was carried out by means of ANOVAs with topography

(nine electrodes) as a repeated measures factor and stimulus (two levels, with each stimulus being compared with all the remaining stimuli) as a "between-trial" factor. The alpha level was set at .05, one-tailed, because a one-sided hypothesis (i.e., the potential would be more negative to deviants than to standards) was tested.

RESULTS

Healthy Subjects

The time course of MEG responses to emotionally positive and negative exclamations is shown in selected channels in Figure 2. A comparison between Figures 1 and 2 reveals similarity of the waveforms recorded in EEG and MEG. The most prominent component common to all responses and channels was the N1 with a latency of about 100 msec. As shown in Figure 3, this component was localized in the temporal lobes of both hemispheres. Moreover, the difference map (Figure 3C) did not show substantial differences between the two conditions. This visual impression was further supported by the statistical analysis. Of the total of 151 MEG channels, a larger absolute N1 amplitude to sad than to joyful stimuli was found in 70 channels; the opposite was true for 81 channels. The ANOVA showed that neither the main effect of stimulus nor its interactions were significant; however, as expected, the main effect of region was highly significant [$F(4,60) = 7.92, p < .001, \varepsilon = .718$].

In contrast to the N1, the subsequent negativities appeared to differ between standards and deviants. In the ANOVA, the main effect of stimulus [$F(4,60) = 4.97, p = .007, \varepsilon = .645$] was significant in both the 200–300 msec window [$F(4,60) = 3.85, p = .037, \varepsilon = .454$] and the 300–500 msec window [$F(4,60) = 5.64, p = .01, \varepsilon = .462$]. Obviously, the activity differed among the regions [main effect of region: $F(4,60) = 19.44, p < .001, \varepsilon = .718$]. More importantly, the stimulus effect also varied as a function of region [region × stimulus interaction: $F(16,240) = 6.71, p = .001, \varepsilon = .193$]. Although this interaction was significant in both time windows [$F(16,240) = 3.20, p = .019, \varepsilon = .263$; and $F(16,240) = 3.96, p = .007, \varepsilon = .249$, for 200–300 and 300–500 msec, respectively], the triple interaction between region, stimulus, and time window also attained significance [$F(16,240) = 2.02, p = .048, \varepsilon = .321$].

No effect containing the factor of side approached significance. Therefore, in the further analysis, the data were collapsed over the symmetric regions in the two hemispheres. In the 200- to 300-msec window, the response to the deviant was generally larger than that to the standards "Yeeh!" ($t = 4.85, p < .001$) and "Heey!" ($t = 2.19, p = .044$). Particularly over the parietal regions, the deviant response was larger than responses to "Yeeh!" ($t = 5.49, p < .001$) and "Heey!" ($t = 4.25, p = .004$), and the difference to joyful "Oooh" approached significance ($t = 1.87, p = .081$). The same pattern was found for the posteriotemporal cortex (deviant minus "Yeeh!": $t = 10.44, p < .001$; deviant minus "Heey!": $t = 7.05, p < .001$; deviant minus joyful "Oooh!": $t = 1.94, p = .068$).

In the 300–500-msec window, the deviant elicited a larger response than did "Yeeh" ($t = 8.81, p < .001$), "Wow" ($t = 3.70, p = .002$), and joyful "Oooh" ($t = 2.35, p = .033$). Particularly, significant differences were obtained for central (deviant minus "Yeeh!": $t = 3.08, p = .008$; deviant minus "Wow!": $t = 2.69, p = .017$), anteriotemporal (deviant minus "Yeeh!": $t = 7.19$; deviant minus "Wow!": $t = 7.22$; deviant minus joyful "Oooh!": $t = 6.81$, all ps $< .001$), posteriotemporal (deviant minus "Yeeh!": $t = 6.08$; deviant minus "Wow!": $t = 5.50$; deviant minus joyful "Oooh!": $t = 5.93$, all ps $< .001$), and frontal (deviant minus "Yeeh!": $t = 3.50, p = .003$; deviant minus "Oooh!": $t = 1.93, p = .073$) regions. No pairwise comparison between responses to any two joyful stimuli attained significance at any region.

Thus, from the analysis above, it appears that the difference between standards and deviants had a more anterior distribution in the 300- to 500-msec time window than in the 200- to 300-msec time window. To further test this impression, we built new sensor groups according to the distribution of the magnetic fields apparent in Figure 3. Specifically, the anterior group included 50 sensors: MLC11, MLC12, MLC13, MLC14, MLC15, MLC21, MLC22, MLC23, MLC24, MLC31, MLC32, MLC33, MLC41, MLC42, MLC43, MLT21, MLT11, MLT31, MLT22, MLT41, MLT12, MLT32, MLT23, MLT13, MLT42, and the symmetrical sensors on the right side, with the nasion–inion coordinates from −0.21 to +0.63, where nasion = +1 and inion = −1. The posterior group included 40 sensors: MLP11, MLP12, MLP13, MLP21, MLP22, MLP31, MLP32, MLP33, MLP34, MLT33, MLT24, MLT14, MLT43, MLT34, MLT25, MLT15, MLT44, MLT16, MLT35, MLT26, and the symmetrical sensors on the right side, with the nasion–inion coordinates from −0.27 to −0.72. An ANOVA was then performed with factors of anterior/posterior (AP: two levels), stimulus, and time window (two levels). Because the responses to standard stimuli did not differ, the stimulus factor was simply taken as having two levels, standards versus deviants. The ANOVA revealed a significant triple AP × stimulus × time window interaction [$F(1,15) = 6.14, p = .026$]. Post hoc t tests indicated a significantly larger difference between standards and deviants over anterior sensors in the later, as compared with the earlier, time window ($t = -2.77, p = .014$). The opposite trend was found for posterior sensors ($t = 2.12, p = .051$).

McCarthy and Wood (1985) demonstrated that condition × topography interactions can be significant even if the same neural generator is active in different conditions, because the ANOVA is based on the additivity assumption—whereas real electrophysiological effects are not additive. For example, if the generator doubles its activity in a Condition 2 instead of a Condition 1, the amplitude recorded by spatially close electrodes or sensors increases more than does that recorded by remote electrodes or sensors, possibly leading to an interaction effect that might be erroneously interpreted as evidence for different generators in different conditions. McCarthy and Wood suggested several techniques for correction of such artificial interactions. Importantly, however, in the above example the amplitudes would increase at all sensors. This

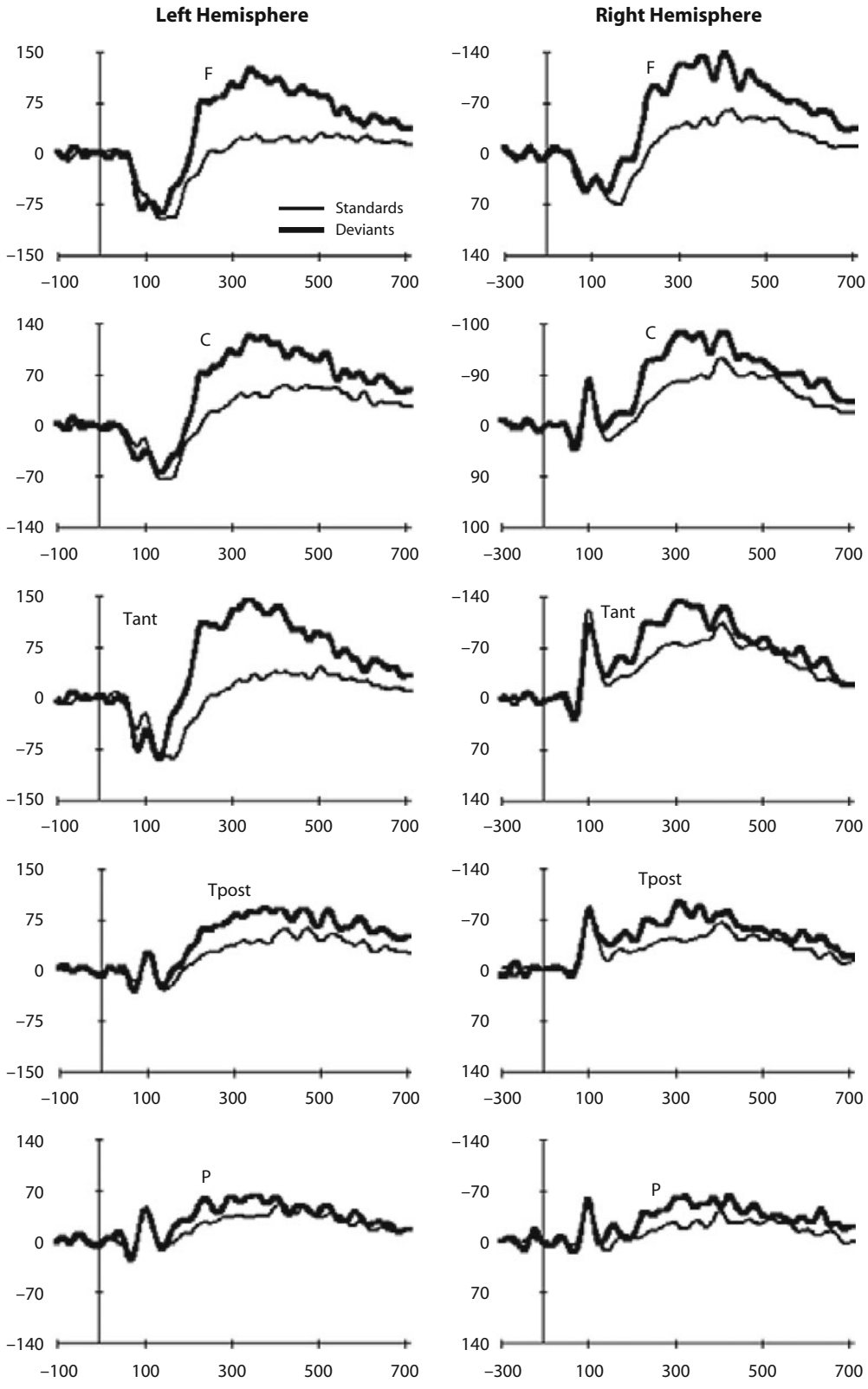

Figure 2. Time course of MEG responses to standards (joyful screams, thin line) and deviants (sad screams, bold line) is exemplified at five symmetrical recording points over each hemisphere, which correspond approximately to the following 10–20 positions (from top to bottom): F3 and F4; C3 and C4; T3 and T4; T5 and T6; P3 and P4. Amplitude in femtotesla (fT), time in milliseconds. Note the opposite polarity of the amplitude scales for the left and right hemispheres.

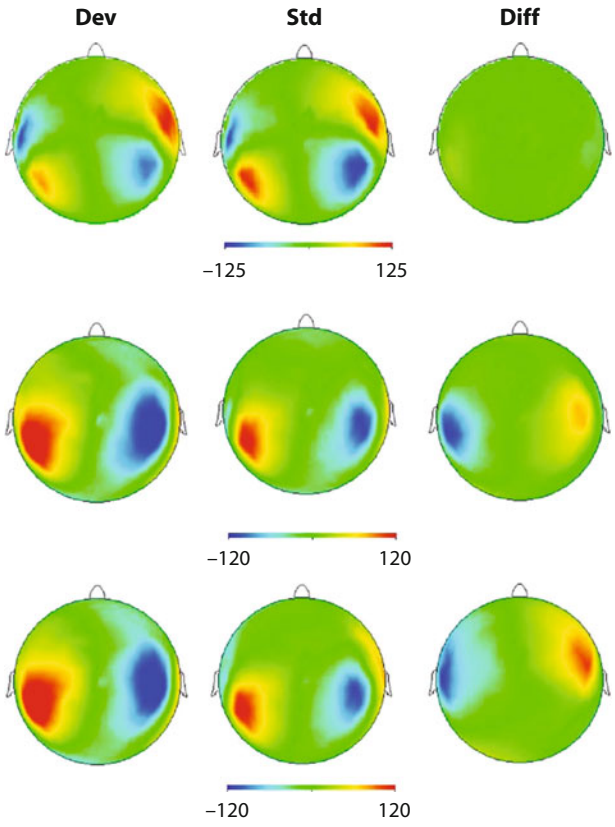

Figure 3. Surface distribution of magnetic fields for the time windows 80–140 msec (N1, top row), 200–250 msec (N300, middle row), and 300–500 msec (slow activity, bottom row). Dev, deviant stimuli; Std, standard stimuli; Diff, difference deviant minus standard. The color scale in fT.

is an "ordered" interaction, in which all levels of the factor A (i.e., all sensor sites) change in the same direction, albeit in different degrees. The present data give an opposite case of an "unordered interaction," because the difference between standards and deviants in the earlier time window increases in the posterior direction, whereas in the later time window it increases in the anterior direction. In this situation, a nonadditivity correction is not necessary (e.g., Scheffé, 1959).

Patients

Significant differences between emotionally positive and negative stimuli were found in 6 of the 27 patients with severe brain damage. The corresponding significance values were $F(1,298) = 21.56, p < .001$; $F(1,290) = 9.91$, $p = .001$; $F(1,295) = 4.36$, $p = .019$; $F(1,297) = 3.32$, $p = .035$; $F(1,298) = 3.35$, $p = .034$; and $F(1,298) = 3.11$, $p = .04$, one-tailed. When the group was split into those with ($n = 15$) and without ($n = 12$) a well-expressed damage to the RTL, the frequency of significant results was higher in the latter group than in the former [42% vs. 7%; $\chi^2(1) = 4.7$, $p < .05$]. Figure 4 shows the data of the 3 patients whose history is described in the Method section above.

When ERPs were grouped regardless of their emotional tone, 108 individual comparisons were performed. A significant effect was found in 5 of them; this does not significantly differ from chance.

We also tried to group the patients according to factors other than the RTL lesion, but no classification yielded a significant result. Thus, no difference in significant responses to prosody was found between patients with the PVS versus MCS diagnosis ($\chi^2 = 0.39$, n.s.), between patients with traumatic rather than nontraumatic brain injury ($\chi^2 = 0.20$, n.s.), or between those with disease duration <10 months versus >10 months ($\chi^2 = 0.02$, n.s.).

In both completely locked-in patients (J.B. [ALS] and A.O. [GBS]), ERPs significantly differentiated between sad and joyful exclamations [$F(1,298) = 5.37$, $p = .011$, and $F = 6.73$, $p = .005$, for J.B. and A.O., respectively]. A similar result was obtained with the severely paralyzed ALS patient, J.W. [$F(1,298) = 7.16$, $p = .004$]. The waveforms of these patients are presented in Figure 5.

DISCUSSION

Prosodic Responses in Patients and Controls

The data demonstrate the reliability of the phenomenon previously described by Bostanov and Kotchoubey (2004): In an emotional oddball condition in which a single sad exclamation is presented with four equiprobable joyful exclamations, the sad deviant elicits a broadly distributed negativity starting (in healthy subjects) about 150 msec poststimulus. The effect is clearly seen in both EEG and MEG. The significant effect, similar in latency and morphology, was also obtained in 6 out of 27 patients diagnosed with definite or probable PVS, as well as in all 3 patients with severe motor paralysis.

In the paralyzed patients, the intactness of speech comprehension (including prosody) might be expected, given that their diseases primarily affect the motor cortex and spinal cord (ALS) or the peripheral nervous system (GBS). However, numerous cognitive deficits have been described in ALS patients at both behavioral (Abe et al., 1997; Abrahams et al., 2000; Ludolph et al., 1992) and electrophysiological (Hanagasi et al., 2002; Paulus et al., 2002; Vieregge, Wauschkuhn, Heberlein, Hagenah, & Verleger, 1999) levels—apart from their well-known motor deficits. These studies investigated patients at intermediate stages of the disease. It remains ultimately unknown what extent those dysfunctions may attain in the last stages of ALS (Kotchoubey, Lang, Winter, & Birbaumer, 2003; Lakerveld, Kotchoubey, & Kübler, 2008; Strong, Grace, Orange, & Leeper, 1996). As regards Patient A.O., she had been completely locked in for more than 3 years, which also might result in secondary deficits in cognitive functions. Nevertheless, significant differential responses to emotional deviants were recorded in each of the 3 patients.

In the patients with severe brain damage, a significant response was obtained in 22%, a high proportion given these patients' behavioral nonresponsiveness and their di-

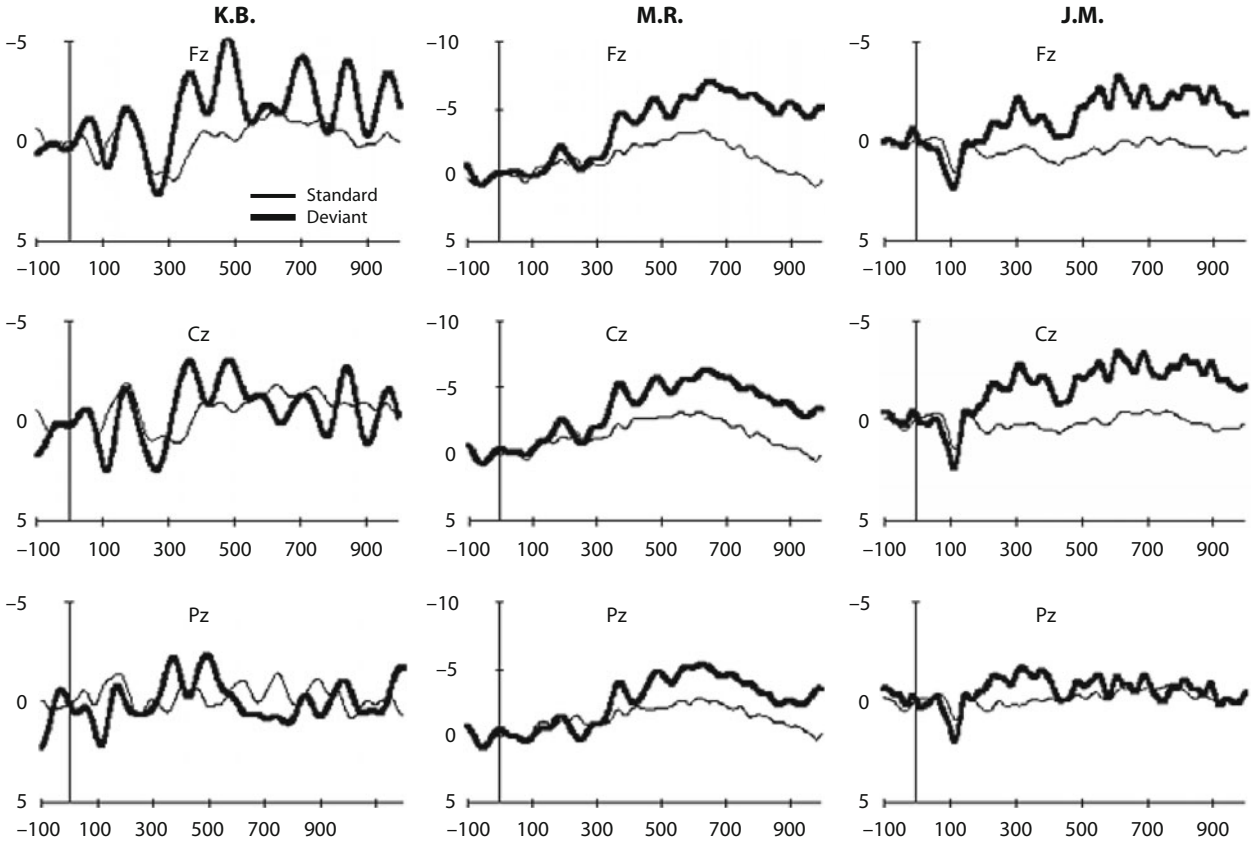

Figure 4. ERPs of two patients diagnosed as being in a persistent vegetative state (K.B. and J.M.) and patient M.R., who was in a minimally conscious state. Negativity is up. Only midline recording sites are shown. Amplitude is in μV (different scales for different patients, according to their individual EEG size); time is in milliseconds. The difference between standards (thin line) and deviants (bold line) was significant in each of these patients. Note that although the patients' waveforms are not identical to the averaged waveform of control subjects presented in Figure 1, they also exhibit the two critical components: the N300 and the late slow negativity to deviant stimuli. The former is delayed compared with control subjects, which may be why the two merged, as with patient M.R.

agnosis, the most severe that exists in neurology (Jennett, 2002). Of course, these data should be interpreted with caution. A positive finding demonstrates that the brain is able to discriminate affective screams, but not that the patient consciously experiences the emotional content of the screams. There is MEG evidence that the brain of human newborns in quiet sleep can differentially respond to the affective features that the human voice can be recognized by (Sambeth, Ruohio, Alku, Fellman, & Huotilainen, 2008). Monkeys respond very adequately to emotional screams of their conspecifics. This does not imply that we can now make wide-ranging inferences about subjective emotional experience in newborns and monkeys.

Also, the lack of a significant response does not prove an inability to recognize prosody. As discussed at length elsewhere (Kotchoubey et al., 2005; Neumann & Kotchoubey, 2004), all neuroscience assessment techniques are prone to false negatives—that is, to miss a response despite a preserved underlying function (see also Owen et al., 2006). However, the high percentage of positive findings indicates that the proposed oddball paradigm with brief emotional exclamations can be used in a clinical setting for the assessment of the perception of emotional prosody.

Topography

The topographic distribution of the response to deviant affectively negative stimuli, obtained by means of a 151-channel MEG, does not indicate a distinct cerebral generator. Dipole modeling did not result in a clearly localizable source of the N300; rather, the projected dipole was localized in the depth of the head, which is highly improbable, given the biophysical features of the MEG signal. This probably results from a large number of broadly distributed, perhaps overlapping sources. It cannot be ruled out that a better result might be obtained using another imaging technique (e.g., fMRI) more suitable for an analysis of the activity in deeper brain structures and whose data, in contrast to MEG data, would not depend on the orientation of the electromagnetic forces.

Figure 3 shows a contrast between the N1 component, with its clearly bilateral temporal sources on the one hand and the broad distribution of the following negativities on the other. The distribution of the N1 magnetic fields is virtually identical to that found in other studies (e.g., Lütkenhöner & Steinsträter, 1998; Pantev et al., 1995). The N1m component does not vary as a function of stimulus condition.

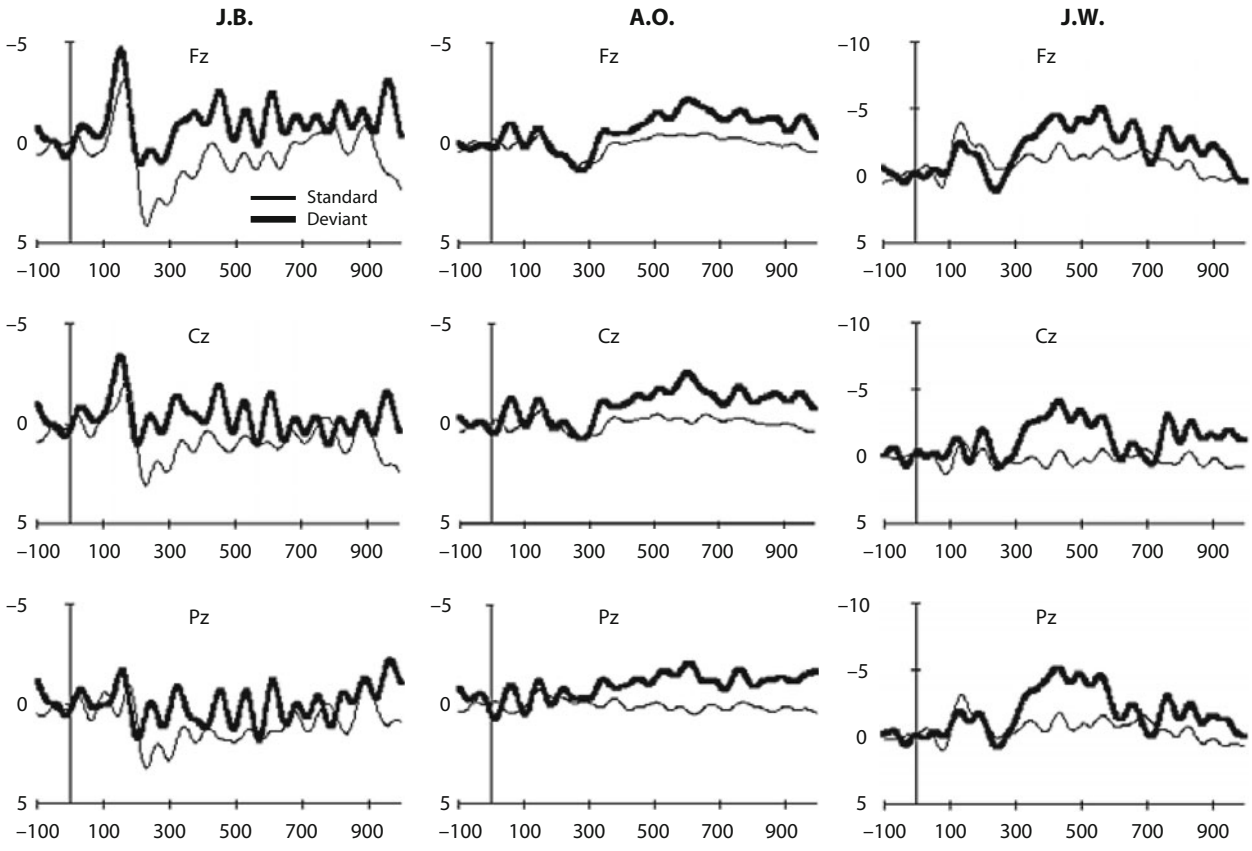

Figure 5. The same as Figure 4, except for severely paralyzed patients J.B., A.O., and J.W.

Although the application of the MEG did not result in the expected spatial localization of the N300, it was nonetheless useful in two important respects. First, it appears that this component is not a member of the MMN family. The MMNm has frequently been investigated in our group (e.g., Kaiser & Lutzenberger, 2001; Kaiser, Lutzenberger, & Birbaumer, 2000; Kaiser, Lutzenberger, Preissl, Ackermann, & Birbaumer, 2000), as well as by many other scholars (e.g., Mathiak, Hertrich, Lutzenberger, & Ackermann, 1999; Shtyrov et al., 1998; Thönnessen et al., 2008; Tiitinen, May, Reinikainen, & Näätänen, 1994). Even though the results of these studies are not identical (which is not surprising, taking into account the huge variability among MMN paradigms), they converge on a well-defined dipole localized at, or in the vicinity of, the temporal planes (Mathiak et al., 2002; Näätänen & Winkler, 1999).

Since most typical MMN studies use several hundred deviants, one might ask whether increasing the number of deviants would result in more typical MMN topography. This supposition, however, is implausible, since many clinical studies (e.g., Kawakubo et al., 2007; Korpilahti et al., 2007; Thönnessen et al., 2008, "traditional condition") and nonclinical studies (e.g., Pulvermüller et al., 2008; Röttger, Schröger, Grube, Grimm, & Rübsamen, 2007; Ruusuvirta, Huotilainen, & Näätänen, 2007), including MEG studies (e.g., Lipski & Mathiak, 2007; Mathiak et al., 1999), use about 100 deviants or even fewer (e.g., Mueller, Brehmer, von Oertzen, Li, & Lindenberger, 2008; Schröger & Wolff, 1997; Srinivasan & Baijal, 2007), which does not prevent important findings. Kane, Curry, Butler, and Cummins (1993) and Kane et al. (1996), using only 32 deviants in coma patients, were the first to discover the high positive predictive value of the MMN regarding the outcome of acute coma, a finding later supported by numerous large studies (see a meta-analysis by Daltrozzo, Wioland, Mutschler, & Kotchoubey, 2007). The same was found in chronic disorders of consciousness using 70 deviants (Kotchoubey et al., 2005). Although a small number of deviants (mostly enforced by the necessity of short-time clinical investigations) decreases the signal–noise ratio, it does not result in a radical change of wave topography. Thus the distributions of magnetic fields shown, for example, by Kaiser, Lutzenberger, Preissl, et al. (2000, Figure 4), Mathiak et al. (1999, Figure 2), and Thönnessen et al. (2008, Figure 1) are strikingly similar, notwithstanding different MMN procedures and different numbers of trials, whereas our Figure 3 is clearly at odds with all of them.

Second, although visual inspection of the EEG data indicated a difference in scalp distribution between the N300 and the subsequent slow negative deflection, the expected condition × topography interaction was far from significant. In contrast, the MEG data allowed us

to disentangle the two components, although both distinguished between emotionally positive standards and emotionally negative deviants. Whereas the N300 had a more posterior distribution, the subsequent slow component was frontocentral. Taking into account the remaining uncertainty about the generators of these components, it would be incautious to claim that those generators were different. Even the same generators might produce dipoles of a different orientation, thereby resulting in a different topography. Nevertheless, a significant change of dipole orientation, like a significant change in dipole structure, also indicates a change in processing; we may therefore assume that deviants in this experiment elicited at least two different, albeit overlapping, processes.

Comparison With Other Negativities

Given the lack of evidence of similarity between the N300 and the MMN, two other ERP components may be suggested as possible analogues of the response to prosodic mismatch: the N400 to semantic mismatch and the "phonological mismatch negativity" (PMN; Connolly, Phillips, Stewart, & Brake, 1992; Connolly, Service, D'Arcy, Kujala, & Alho, 2001). As regards the PMN, it has a latency close to the present N300 and has been proposed to reflect an obligatory mechanism of phonological processing (e.g., Newman & Connolly, 2004). However, the origin of the PMN is clearly related to left-hemispheric speech areas. Two EEG studies using current source density analysis (Connolly et al., 2001) and BESA (D'Arcy, Connolly, Service, Hawco, & Houlihan, 2004) indicated left-hemispheric sources, probably in Broca's area and the inferior parietal lobe. Using MEG, Kujala, Alho, Servece, Ilmoniemi, and Connolly (2004) obtained a distinct response in the left (and in a minority of subjects, also in the right) temporal lobe, localized anterior to the earlier N1 component and the later N400.

As regards the N400, imaging and lesion studies indicate its critical dependence on the temporal, inferior frontal and inferior parietal regions on the left side (for reviews of this and of the difference between lesion and imaging data, see Van Petten & Luka, 2006). However, these sources are not unequivocally manifested in electrophysiological data obtained with the MEG or high-density EEG. Whereas some experiments resulted in well-defined dipoles in the left frontal and temporal lobes (Halgren et al., 2002; Karniski, Vanderploeg, & Lease, 1993; Mäkelä, Mäkinen, Nikkilä, Ilmoniemi, & Tiitinen, 2001), others yielded more symmetrical (Helenius et al., 2002), sometimes very broad scalp distributions (Brandeis, Lehmann, Michel, & Mingrone, 1995; Curran, Tucker, Kutas, & Posner, 1993; Haan, Streb, Bien, & Rösler, 2000; Johnson & Hamm, 2000; Mäkelä et al., 2001; Nobre & McCarthy, 1994; Rösler, Streb, & Haan, 2001). One group even obtained a right temporal generator of the semantic N400 (Nakagome et al., 2001). An MEG study of an N400 related to linguistic prosody resulted in a broad distribution without the expected right-side asymmetry (Hayashi et al., 2001). Furthermore, it was shown that N400 topography strongly depends on subtle features of stimulation (Mäkelä et al., 2001; Münte et al., 2001), and that the contributions of adjacent regions can have the opposite sign; that is, activity in response to congruent rather than incongruent words (Rossell, Price, & Nobre, 2003) can increase in one region and decrease in the other. This makes it difficult to formulate strong predictions concerning the putative type of the N400 obtained in response to affective prosody violations.

To explore the issue on similarity versus difference between the "prosodic N300" and other negativities, further experiments are necessary in which several kinds of linguistic mismatch (phonological, prosodic, semantic) will be applied on the same material in a within-subjects design. As mentioned above, the interplay between prosody and semantics in generating an N400 to nonprimed words has already been shown with respect to both linguistic (e.g., Kerkhofs et al., 2007; Magne et al., 2005) and affective (e.g., Paulmann & Kotz, 2008a, 2008b; Schirmer et al., 2002) prosody. Those paradigms could be modified in an attempt to elicit and compare both N400 and N300.

Neurophysiology of Affective Prosody

Earlier neuropsychological and imaging data, as well as dichotic listening experiments, have indicated a role of the right hemisphere—particularly the right superior temporal cortex—in the analysis of speech prosody (Buchanan et al., 2000; Grimshaw, Kwasny, Covell, & Johnson, 2003; Perry et al., 2001; Ross et al., 1998). On the other hand, evidence is accumulating that the network underlying the recognition of affects from prosody involves other brain areas in addition to the RTL regions such as BA 22, including the dorsolateral and orbital frontal cortex, the frontal pole, the right insula, and the operculum (e.g., Adolphs et al., 2002; Breitenstein, Daum, & Ackermann, 1998; Kotz et al., 2003; Plante, Holland, & Schmithorst, 2006; Wildgruber et al., 2005). Data of Hornak, Rolls, and Wade (1996) and Hornak et al. (2003) demonstrated that frontal lesions at any side can considerably impair recognition of affective prosody. Also, the symmetrical left superior temporal gyrus can be active during prosodic perception, although this activity is usually smaller than in the right hemisphere (e.g., Ethofer, Anders, Wiethoff, et al., 2006; Humphries, Love, Swinney, & Hickok, 2005). In summary, the data diverge considerably on the question of whether the pattern of brain activity is strongly right-lateralized (e.g., Mitchell, Elliott, Barry, Cruttenden, & Woodruff, 2003; Wildgruber et al., 2005) or virtually symmetrical (e.g., Kotz et al., 2003). Among the factors possibly leading to different findings in different imaging studies are task requirements (e.g., paying attention to prosody or not); the amount and importance of semantic information delivered by the same stimuli that bear emotional information (e.g., words, pseudowords, exclamations); specific emotions, such as fear, that lead to particular activation patterns; basic physical stimulus features such as F0, intensity, and (in fMRI experiments) duration;[2] and finally, the nonspecific arousal elicited by stimuli (e.g., Mitchell et al., 2003; Sander et al., 2005; Schirmer et al., 2005; Wambacq et al., 2004; Wildgruber et al., 2005). A recent study even showed that the additional activation of the right middle superior temporal gyrus over its left tempo-

ral counterpart in response to prosodic emotional stimuli disappears, if simple acoustical features and arousal are controlled (Wiethoff et al., 2008).

Despite these complicating factors, the extant data permit a suggestion that any component immediately related to the recognition of emotional prosody would reflect the activity of the right temporal cortex. Accordingly, the responses of PVS patients to emotional prosody were found to depend critically on the involvement of the RTL in the lesion. Nonetheless, the scalp distribution of magnetic fields did not show any particular activity of the RTL. In contrast to Bostanov and Kotchoubey (2004), this fact cannot be attributed to the insufficient spatial resolution of the EEG; thus, the N300 may be thought of as reflecting not the recognition of prosody per se, but rather, the following detection of a prosodic mismatch between the given stimulus and its affective context.

Recently, two neurophysiological models of processing of affective prosody have been proposed. One of them (Ethofer, Anders, Erb, et al., 2006), as a result of mathematical modeling on the basis of the authors' own data, suggests that the right temporal cortex[3] serves as the input area for prosodic information, which is then conveyed to both frontal lobes for further processing. The other theory, based largely on a review of the literature (Schirmer & Kotz, 2006), also assumes that, after an initial stage of basic spectrotemporal analysis in the primary and secondary auditory cortex, vocal emotional information is processed in the right hemisphere (superior temporal gyrus and sulcus) and then in frontal cortex for evaluative judgment concerning possible affective and semantic implications of emotional contents.

The present data are very much in line with both models. An initial analysis of basic auditory information is manifested in the temporal N1. After this, the emotional tone of a vocal stimulus (probably regardless of its semantic content or the lack thereof) is recognized on the basis of voice quality. As our patients' data show, this process requires the activity of right temporal regions. Like other (physical, conceptual) features of stimuli, prosodic features are continuously projected (anticipated) by the brain, and if the actual affective message is congruent with the anticipated one, it is "understood" at the emotional level of comprehension, and the process is closed. If it is incongruent, further cortical resources are mobilized to search for information necessary for the reestablishment of congruence. From this point of view, the present centroparietal N300 reflects this mobilization of resources for affective integration, just as the N400 reflects resource allocation for the following semantic integration (Holcomb, 1993; Silva-Pereyra et al., 1999). The next step, whose functional meaning is not completely clear (this might be the anticipation of future stimuli, or "higher-order evaluative processes"—Schirmer & Kotz, 2006, p. 29), is related to the activity of the frontal cortex and manifested in the frontal slow wave that followed the more posterior N300. This activity was absent in a priming experiment in which stimuli were presented as pairs ("name of an emotion—scream") rather than a stream of screams in the oddball experiments (Bostanov & Kotchoubey, 2004).

Whereas Ethofer, Anders, Erb, et al.'s (2006) model does not specify the temporal parameters of the processing, Schirmer and Kotz (2006) first suggested that about 300 msec are necessary for an analysis of affective prosody. Later on, however, Paulmann and Kotz (2008a) found ERP signs of affective prosodic processing even before 200 msec. The latter view is more in accordance with the present data, because the N300 onset can be as early as about 150 msec and in no case later than 200 msec. Even though the hypothesized processes can overlap, the affective tone of the stimulus should at least partially be recognized by this time point. If this is true, emotional prosody can possibly be recognized within some 100–150 msec after the onset of an affective exclamation.

AUTHOR NOTE

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NOTES

1. Some MCS patients had been examined before the exact criteria of MCS were published (Giacino et al., 2002) and were that time regarded as "probable PVS" or "inconsistently unconscious."

2. Duration is largely irrelevant in many EEG and MEG experiments in which the critical responses are recorded long before the offset of the stimuli.

3. The authors obtained the largest activation in the *middle* right temporal gyrus, in contrast to the *superior* right temporal gyrus found most active in many other studies. This incongruence cannot be discussed here.

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