NeuroReport 10, 1741–1746 (1999)

Emotional impairment after right orbitofrontal lesion in a patient without cognitive deficits

Alessandro Angrilli,[CA]
Daniela Palomba, Anna Cantagallo,[1]
Alessandra Maietti[1] and
Luciano Stegagno

Dipartimento di Psicologia Generale, University of Padova, Via Venezia 8, 35131 Padova; [1]Unità Operativa di Medicina Riabilitativa, Ospedale di Ferrara, Via Boschetto 20, 44100 Ferrara, Italy

[CA]Corresponding Author

THE present study describes a patient, M.L., with right orbitofrontal lesion, who showed no impairment on main neuropsychological tests, including those measuring frontal functions. Nevertheless, he had deeply affected emotional responses. In line with Damasio's work, the patient had lower skin conductance during the projection of a standardized set of emotional slides. Furthermore, he showed altered facial expressions to unpleasant emotions, displaying low corrugator supercilii electromyographical activity associated with reduced recall of unpleasant stimuli. During a task focusing on imagery of emotional situations, M.L.'s heart rate and skin conductance responses were affected during both pleasant and unpleasant conditions. Facial expressions to unpleasant imagery scripts were also impaired. Thus, the orbitofrontal cortex proved to play a critical role in retrieval of psychophysiological emotional patterns, particularly to unpleasant material. These results provide the first evidence that orbitofrontal lesions are associated with emotional impairment at several psychophysiological levels. *NeuroReport* 10:1741–1746 © 1999 Lippincott Williams & Wilkins.

Key words: Corrugator muscle; Emotion; Facial expression; Heart rate; Imagery; Memory; Orbitofrontal cortex; Skin conductance

Introduction

Most literature shows that prefrontal lesions induce both cognitive and emotional deficits (for review see [1]). The cognitive deficits associated with frontal lobe lesions are well known, and many neuropsychological tests have been developed and standardized to measure the specific functions supported by this anatomical structure. More recently, there has been an increasing interest in emotional deficits originating from frontal cortex damage [2–4]. These deficits are clearly evident after a few minutes of interaction with patients, yet they are more difficult to measure in a laboratory setting. The behavioral and emotional alterations are so pervasive that they also affect most everyday activities and social functioning. In fact, patients are often completely impaired in finding and keeping a job, and generally in social skills and decision planning [5]. Despite this evidence, it is commonly argued that the lack of such capabilities is a consequence of the cognitive deficits typically observed in frontal lobe syndromes. Unfortunately, given the large extent of most brain lesions, many patients show both the classical frontal lobe deficits and emotional impairment, and patients with dissociation between the two functions are rare.

The literature contains few descriptions of patients affected by severe impairment of emotions and social skills, yet showing no neuropsychological deficits even on tests checking frontal lobe functions [6]. There is agreement on the fact that patients with pure emotional deficits have more limited lesions, at the level of the orbitofrontal cortex, which spare the dorsolateral areas. Data on few neuropsychologically intact patients may provide evidence that cognitive and emotional deficits are dissociated.

Damasio [5,7,8] first advanced a coherent hypothesis based on the evidence of a lack of autonomic response to emotional stimulation in patients with ventromedial frontal damage. According to the hypothesis, autonomic activation provides the covert information (implicit knowledge) related to past emotional experiences, which is necessary to find a solution (decision) in complex everyday situations. The theory of the 'somatic marker' is supported by several behavioral and neuropsychological data [9], but it mainly relies on the observation of reduced skin conductance emotional responses in patients with prefrontal damage. It is conceivable that emotional impairment also involves other psychophysiological measures, such as facial expressions of emotional experience and heart rate responses to emotional imagery. In addition, the lack of autonomic activation affects both memory for affective stimuli and emotional imagery because the emotional physiological patterns stored as implicit affective memory in the limbic system, cannot be reactivated if limbic–frontal structures, or their connections, are damaged. We hypothesize that, given the importance of orbitofrontal cortex in integrating information coming from both cortical areas involved in higher cognitive functions and from the limbic system, lesions of this area impair patients' ability to activate the appropriate physiological responses on both passive (slide viewing) and active (imagery) emotional tasks.

In the present study, we investigated the emotional psychophysiological responses in a rare, neuropsychologically well preserved, patient with a right prefrontal orbitofrontal lesion.

Materials and Method

M.L. is a 35-year-old male who had a car accident in May 1991. He is a medical doctor (19 years' education). Following the accident he had a severe open traumatic brain injury involving the right prefrontal cortex. MRI performed in 1994 (Fig. 1a,b) and PET in 1995 showed the lesion at the level of the right orbitofrontal cortex (a large portion of Brodmann areas 8, 9, 32 and the anterior part of area 24) involving most of the ventromedial frontal cortex (areas 10, 11 and 12). Damage involved the right portion of the anterior cingulate, but spared most of the right dorsolateral frontal cortex (areas 44, 45 and 46) and the genu of the corpus callosum. The anterior commissures were intact.

M.L. was administered first a battery of neuropsychological tests assessing both general cognitive ability and frontal lobe functioning. Next, in a psychophysiological session, his responses to emotional material were compared with those obtained from 16 age-matched healthy male controls. Stimuli were 18 coloured photographic slides selected from a set of pictures (IAPS, International Affective Picture System), standardized on an international sample of subjects [10]. The IAPS set has also been tested in several psychophysiological paradigms [11–13]. The slides were divided into three groups according to male normative ratings of emotional valence and arousal on a 9-point scale. Groups included pleasant pictures (positive condition: valence > 6; arousal > 6) representing happy people, naked women, sport scenes; neutral pictures (neutral condition: valence between 4 and 5.5; arousal < 5), household objects and city views; unpleasant pictures (negative condition: valence < 3.5; arousal > 6) of aimed guns, war scenes and blood/injuries. Each slide was projected for 6 s, and the interstimulus interval varied randomly between 10 and 15 s. Picture presentation was randomized across conditions.

Physiological recordings included heart rate, derived from the ECG by a lead II configuration. According to the literature [14,15] the most reliable index of facial expressions induced by unpleasant emotions is the integrated EMG of the corrugator supercilii: two active electrodes, 7 mm in diameter, were placed above the left eyebrow, close to the nasion, at a distance of 1 cm from each other. Skin conductance was recorded by means of a constant voltage transducer from two electrodes placed on the index and middle fingers of the non-dominant hand.

Subjects participated in two psychophysiological sessions: the first session consisted of the projection of the emotional slides. The second session consisted of an emotional imagery task: six trials, divided into positive, neutral and negative contents, were pre-

A B

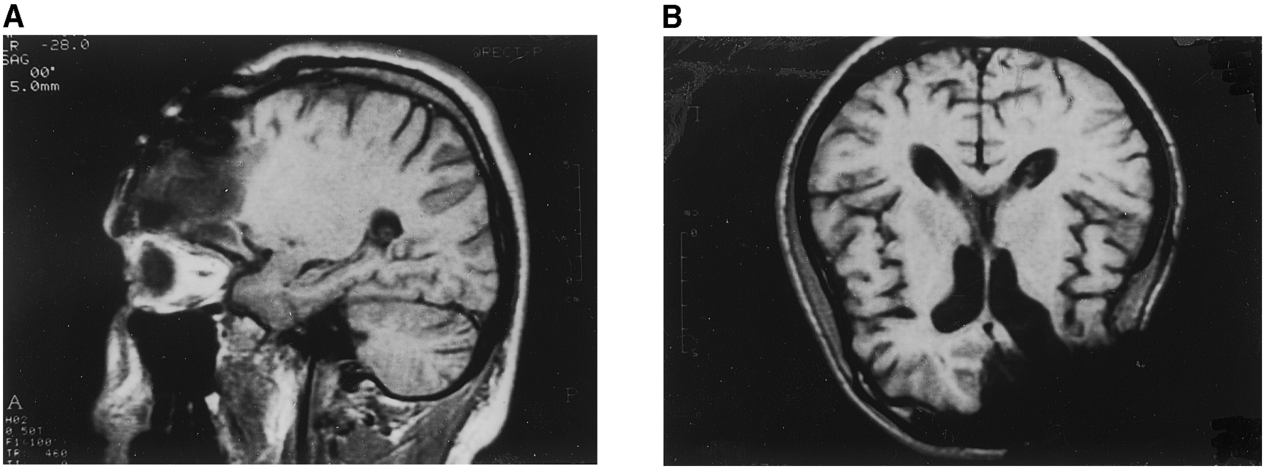

FIG. 1. MRI scans of M.L.'s brain. Sagittal (**a**) and horizontal (**b**) sections show extent of lesion, involving right orbitofrontal cortex.

sented in randomized order. In each trial a slide with written instructions was projected for 12 s. Subjects were asked to read carefully, and when a second slide with the instruction 'Image' appeared, they had to imagine the emotional condition described for 12 s. After the slide projection, subjects had to list the slides they recalled.

Physiological data were recorded and analysed according to Angrilli [16]. Two seconds of the preceding baseline were subtracted from the mean values measured during slide projection (6 s) or imagery trials (12 s).

Statistical analysis of the control group was computed on the mean of all trials grouped under the same emotional condition. A one-way ANOVA with three levels (positive, neutral, negative) was calculated for each variable. Patient data were compared to group data by analysing the relative patterns amongst the three emotional conditions.

Results

Neuropsychological assessment of M.L. Neuropsychological assessment revealed no deficits in the general section: intelligence (WAIS IQ = 106; Raven's Progressive Matrices, age IQ = 103), visual discrimination (Scrawl Visual Discrimination test) selective attention (TEA battery), short- and long-term memory (Verbal and Corsi spans, Story Memory, Verbal Learning Supraspan), constructional apraxia (Freehand Copying of Drawings; Copying Drawings with Landmarks), language (Sentence Building test; Token test), all showed normal scores (for a more detailed description refer to [17]).

Executive functions and frontal lobe tests included: Stroop test as a measure of attention (word reading = 39 s, cut-off > 50 s; color naming = 68 s, cut-off ⩾ 80 s; color–word naming = 116 s, cut-off ⩾ 180 s); Reversal Learning test (M.L.'s score = 24, cut-off ⩽ 18.25) and Hayling test (score = 37 s, cut-off ⩾ 38 s) as measures of responses to rules; Wisconsin Card Sorting test (score = 20% perseverative errors, cut-off ⩾ 50%) and Weigl's Sorting test (score = 9.5, cut-off < 4.25) to measure sorting and shifting capabilities; Tower of London (score = 11, cut-off < 9) and Elithorn's Perceptual Maze test (score = 18.25, cut-off ⩽ 13.25) to measure planning; Semantically Cued Word Generation test (score = 12.25, cut-off ⩽ 7) and Generative Associative Naming (score = 7.5, cut-off ⩽ 3.75) as indexes of simple strategy generation; Behavioral Assessment of Dysexecutive Syndrome (total score = 18, cut-off ⩽ 11.95), a six-test battery developed to detect the everyday problems arising from frontal lobe dysexecutive syndrome. M.L. had normal scores on all these tests, which are typically impaired in patients with lesions of dorsolateral prefrontal cortex.

Psychophysiological assessment: During the projection of emotional slides, control subjects (Fig. 2a) showed greater skin conductance to both positive and negative conditions than to neutral conditions ($F_2 = 7.27$, $p < 0.005$; Newman–Keuls *post-hoc* $p < 0.005$ between neutral and positive slides, $p < 0.0008$ between neutral and negative conditions). The pleasant and unpleasant imagery conditions also induced greater skin conductances than did the neutral condition (Fig. 2b).

M.L. showed an altered pattern to the emotional material. The patient was able to produce skin conductance responses to unconditioned stimuli, such as deep breathing or a loud noise but, although he showed a few normal skin conductance responses (the largest response recorded had 0.2 μMho amplitude, i.e. normal range) before and during the experiment, he had responses > 0.04 μMhos to only

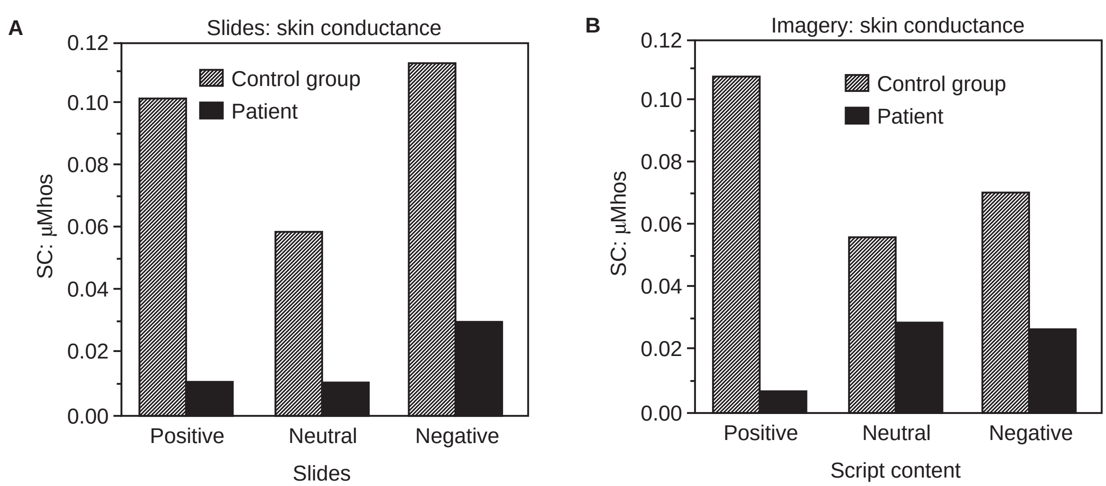

FIG. 2. Skin conductance responses recorded during viewing of emotional slides (**A**) and during session on emotional imagery (**B**). Comparison between control group and patient M.L. Units in μMho changes from baseline.

one positive and one negative slide, and to one imagery practice trial. Furthermore, notwithstanding his claims (collected from a post-experimental interview) that he had no difficulty in imaging the requested situations, he did show poor skin conductance responses during all imagery conditions (Fig. 2b). Therefore, he did not display the typical greater responses to arousing emotional (positive and negative) conditions compared with the neutral condition.

The corrugator supercilii muscle, a sensitive index of unpleasant emotions, showed a linear increase with increasing unpleasantness of slide contents (Fig. 3a; $F_2 = 8.59$, $p < 0.0004$). Normal subjects exhibited less muscular tension to pleasant than to neutral slidess (Newman–Keuls *post-hoc*: $p < 0.05$) and greater tension to the unpleasant slides than to the neutral ones ($p < 0.05$). During the imagery trial (Fig. 3b) the corrugator of controls discriminated emotional conditions ($F_2 = 9.62$, $p < 0.0002$), particularly between positive and negative conditions ($p < 0.002$).

M.L. showed different patterns on both tasks. During slide viewing, he had greater corrugator activity to neutral slides, and the lowest activity was observed to unpleasant stimuli (Fig. 3a). Also during the imagery task, whereas normal subjects had greater muscular tension to unpleasant conditions, M.L. had reduced EMG values (Fig. 3b).

Heart rate typically increases during imagery of both pleasant and unpleasant situations (Fig. 4, control group) with respect to a neutral condition ($F_2 = 3.85$, $p < 0.02$). M.L. exhibited a reversed pattern, with increased heart rate to the neutral compared with the two emotional conditions.

As commonly observed, in the control group recall of emotional stimuli (Fig. 5) showed an

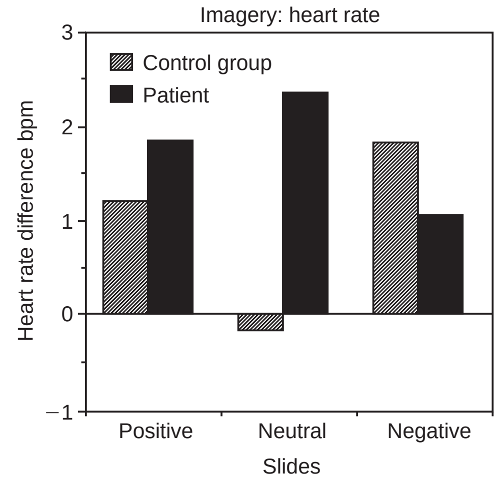

FIG. 4. Heart rate responses recorded during emotional imagery session. Units are beats per minute (b.p.m.) changes from baseline.

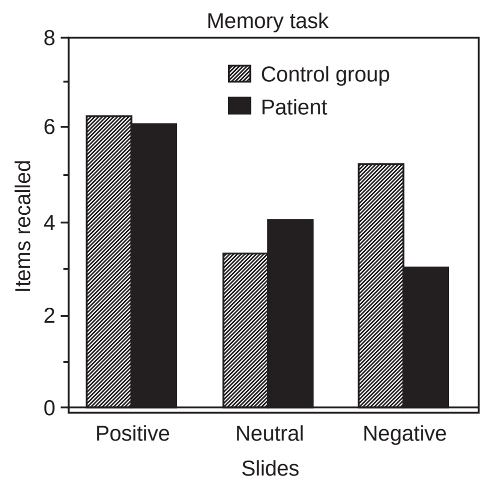

FIG. 5. Memory performance after slide viewing session. Units in number of slides recalled.

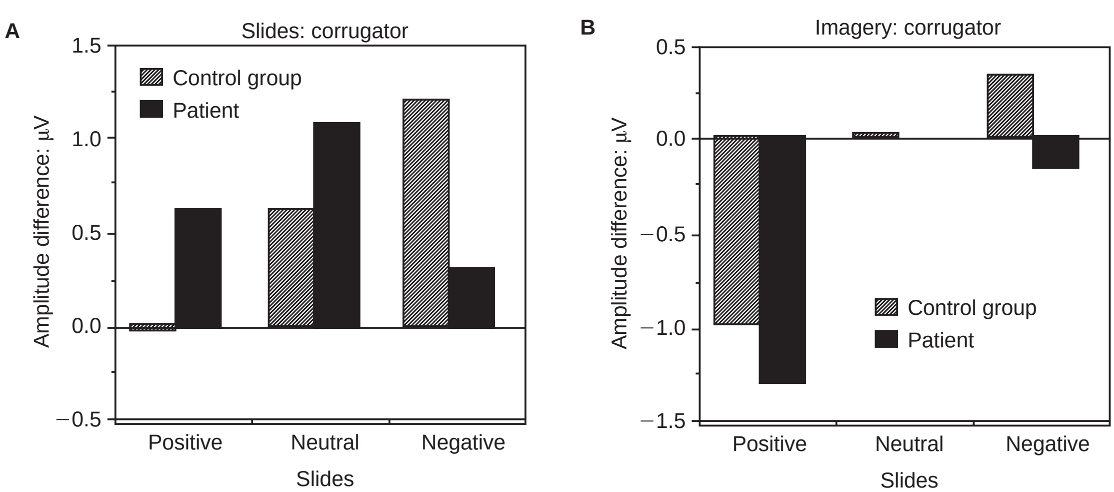

FIG. 3. Response of corrugator muscle, an index of unpleasant emotions, during slide viewing (**A**) and emotional imagery session (**B**). Muscular activity measured by integrated electromyography. Units in μV changes from baseline.

advantage for both pleasant and unpleasant material with respect to neutral ($F_2 = 11.57$, $p < 0.0001$). *Post-hoc* analysis indicated that control subjects recalled about two and three more unpleasant and pleasant items respectively, compared with the neutral condition. M.L., however, recalled fewer unpleasant ($n = 3$) than neutral ($n = 4$) and pleasant ($n = 6$) slides. This result was substantially replicated in a further session, 2 months later, aimed at repeating recall of emotional material: the patient retrieved fewer unpleasant ($n = 3$) than neutral ($n = 5$) and pleasant ($n = 6$) slides.

Discussion

The results of the present experiment confirm previous investigations in which a lower autonomic response to emotional stimulation, as assessed by skin conductance, was found in patients with lesions of the orbitofrontal cortex [7,8]. In particular, M.L., like Damasio's EVR [6], had no deficits on main neuropsychological tests [17], and displayed a lack of skin conductance response to almost all emotional stimuli. It could be argued that his lower skin conductance responses were related to a complete lack of any skin conductance activity also involving non-emotional stimuli. However, M.L. showed normal responses to two emotional slides but also to some unconditioned stimuli administered prior to the experimental sessions. In addition to previous results, M.L.'s skin conductance was also affected under active emotional production, as shown by his imagery results.

Electrodermal activity is an index of sympathetic nervous system activation [18]. Heart rate, however, depends on both the sympathetic and parasympathetic branches of the ANS. According to the literature, heart rate is a reliable index of emotional activation during imagery [19,20]: in both pleasant and unpleasant imagery conditions, heart rate increases with respect to neutral imagery. In fact, our control group showed results in agreement with literature data. Instead, M.L. showed a generalized heart rate increase, with the highest values in the neutral situation (Fig. 4). His atypical heart rate acceleration to the neutral slides suggests that the autonomic activation induced by the arousing slides was not emotion-dependent. This led us to hypothesize that M.L. has a deficit in retrieving past emotional experience and, consequently, the physiological activation appropriate to the emotional context. This result is in line with the 'somatic marker' hypothesis [9] and, more generally, with the view that the orbitofrontal cortex plays a role in integrating past emotional physiological patterns, stored in the limbic system (amygdala and hippocampus) and current information kept in working memory (prefrontal cortex). The integration of information from the two systems is essential for strategic planning and decision-making [5,9].

Spontaneous facial expressions induced by emotions was also impaired in M.L. The corrugator muscle is a reliable index of unpleasant emotions [14,15], and M.L., unlike control subjects, did not increase corrugator tension either to unpleasant stimuli or to unpleasant imagery scripts.

The memory task, performed after the slide projection session, further supports the interpretation of imagery results. Indeed, M.L. showed lower recall of unpleasant stimuli than did controls (Fig. 5). Healthy subjects typically recall emotional arousing stimuli, both pleasant and unpleasant, better than neutral stimuli [13]. For M.L., electrodermal responses were impaired to both positive and negative stimuli, whereas the memory task showed impairment of responses to unpleasant stimuli only.

An interesting interpretation of this dissociation is that there is an imbalance in processing positive and negative emotions: perhaps only negative emotions require an increase in arousal (as indexed by skin conductance), which helps their storage in explicit memory, while explicit recall of positive emotions may depend less on physiological activation. This hypothesis is in agreement with observations in the literature of the consistent inability of patients with orbitofrontal lesions to learn from punishment or personal loss. There are no clear data about the responses of these patients to appetitive rewards. However, in line with our interpretation, Damasio's data [5,7] point to selective representation of immediate rewards, and therefore to positive emotional items, in patients' working memory, and a lack of representation for punishments.

As a further result of our work, M.L.'s emotional impairment was associated with a lesion in the right orbitofrontal cortex. It is known from the literature that the right hemisphere, in particular the right prefrontal cortex, is crucial for processing unpleasant conditions [21] and for facial expressions of negative emotions [22]. In addition, lesions confined to the right amygdala, a key nucleus for unpleasant emotions which is closely connected to the orbitofrontal cortex [23], have been shown to decrease overall arousal and to impair emotional responses to aversive stimuli in humans [24]. Therefore, M.L.'s lower recall of negative slides, together with his impaired physiological responses, may be related to a more comprehensive deficit of elaboration for unpleasant compared with pleasant emotions. This deficit may be more closely associated with lesions of right frontal-limbic structures.

Conclusions

The present study aimed at extending our knowledge of the emotional impairment which characterizes orbitofrontal brain lesions. M.L. was a particularly interesting patient because of his intact neuropsychological condition. Investigation of his psychophysiological responses to both active and passive emotional conditions revealed a deficit with several psychophysiological components. In particular, his inability to show the typical physiological patterns evoked by emotional imagery points to a key deficit in the representation and activation of emotions. In line with most of the literature on frontal lobes, we found the right orbitofrontal cortex to be critical for emotional processing.

Summarizing the results of the present study, lesions of the orbitofrontal cortex affect emotion processing by involving more psychophysiological and cognitive functions: sympathetic, parasympathetic autonomic nervous systems, facial expressions of emotions as well as emotional imagery and memory.

References

1. Stuss DT and Benson DF. *Psychol Bull* **95**, 3–28 (1984).
2. Grafman J, Vance SC, Weingartner H *et al. Brain* **109**, 1127–1148 (1986).
3. Hornak J, Rolls ET and Wade D. *Neuropsychologia* **34**, 247–261 (1996).
4. Powell KB and Miklowitz DJ. *Clin Psychol Rev* **14**, 525–546 (1994).
5. Bechara A, Damasio H, Tranel D *et al. Science* **275**, 1293–1295 (1997).
6. Saver JL and Damasio AR. *Neuropsychologia* **29**, 1241–1249 (1991).
7. Damasio AR, Tranel D and Damasio H. *Behav Brain Res* **41**, 81–94 (1990).
8. Tranel D and Damasio H. *Psychophysiology* **31**, 427–438 (1994).
9. Damasio AR. *Descartes' Error: Emotion, Reason and the Human Brain*. New York: Grosset Putnam, 1994.
10. Center for the Study of Emotion and Attention—CSEA-NIMH. *The International Affective Picture System (IAPS; Photographic Slides)*. Gainesville, FL: University of Florida, 1995.
11. Lang PJ, Greenwald MK, Bradley MM *et al. Psychophysiology* **30**, 261–273 (1993).
12. Mini A, Palomba D, Angrilli A *et al. Percept Motor Skills* **83**, 143–152 (1996).
13. Palomba D, Angrilli A and Mini A. *Int J Psychophysiol* **27**, 55–67 (1997).
14. Brown SL and Schwartz GE. *Biol Psychol* **11**, 49–62 (1980).
115. Schwartz GE, Brown SL and Ahern L. *Psychophysiology* **17**, 75–82 (1980).
16. Angrilli A. *Behav Res Methods Instr Comp* **27**, 367–374 (1995).
17. Cantagallo A and Maietti A. *Eur J Neurol* **4**, 4 (1997).
18. Lidberg L and Wallin G. *Psychophysiol* **18**, 268–270 (1981).
19. Fiorito ER and Simons RF. *Psychophysiology* **31**, 513–521 (1994).
20. Lang PJ, Kozak MJ, Miller GA *et al. Psychophysiology* **17**, 179–192 (1980).
21. Davidson RJ, Ekman P, Saron CD *et al. Int J Person Social Psychol* **58**, 330–341 (1990).
22. Sackeim HA, Greenberg MS, Weiman AL *et al. Arch Neurol* **39**, 210–218 (1982).
23. Aggleton JP. *Trend Neurosci* **16**, 328–333 (1993).
24. Angrilli A, Mauri A, Palomba D *et al. Brain* **119**, 1991–2000 (1996).

Received 23 March 1999; accepted 13 April 1999