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Event-Related Potential Studies of Cognitive and Social Neuroscience

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1. Introduction

In this chapter, we assess the role of Event-Related Potentials (ERP) in the field of cognitive neuroscience, particularly in the emergent area of social neuroscience. This is new ground that combines approaches from cognitive neuroscience and social psychology, highlighting the multilevel approach to emotional, social and cognitive phenomena, and representing one of the most promising fields of cognitive neuroscience (Adolphs, 2003, 2010; Blakemore, Winston and Frith, 2004; Cunningham and Zelazo, 2007; Decety and Sommerville, 2003; Frith and Frith, 2010; Insel, 2010; Lieberman and Eisenberger, 2009; Miller, 2006; Ochsner, 2004; Rilling and Sanfey, 2011; Sanfey, 2007; Singer and Lamm, 2009; Zaki and Ochsner, 2009).

The technique of ERPs is a precise tool regarding time resolution (on the order of milliseconds). ERPs are useful not only for their excellent temporal resolution but because recent advances (e.g., dense arrays, single trial analysis, source localization algorithms, connectivity and frequency measures, among others) provide multiples sources of brain activity in response to cognitive events.

First, a definition of ERPs and an explanation about the recordings and features of main components (P1, N1, N170, VPP, EPN, N2, P2, P3, N400, N400-like LPC, LPP, P600, ERN, fERN, CNV, RP; LRP, MP, RAP) are detailed (including a description of their generating sources when available). We then introduce some representative examples of cognitive and social neuroscience: contextual approaches to language, emotions and emotional body language; empathy; and decision-making cognition. All these areas are reviewed, highlighting their relevance for cognitive neuroscience and clinical research (neuropsychiatry and pathophysiology). Finally, important issues, such as sleep research, intracranial ERPs recordings, source location in dense arrays and co-recordings with fMRI, are discussed.

2. Event-Related Potentials (ERPs)

The technique of ERPs is a precise tool regarding time resolution (on the order of milliseconds) that incorporates the recording of ongoing electrophysiological activity using

electroencephalography (EEG). ERPs result from the synchronous activation of neural subpopulations that occur in response to events (sensory, motor or cognitive). ERPs are useful not only for their excellent temporal resolution but because recent advances (e.g., dense arrays, single-trial analysis, source localization algorithms, connectivity and frequency measures, among others) provide multiples sources of brain activity in response to cognitive events.

To measure the brain activity, the ERP quantifies electrical fields through the skull and scalp. This last procedure is named electroencephalography (EEG). ERPs are the ongoing electrophysiological activity resulting from the synchronous activation of several neural subpopulations that occur in response to sensory, motor or cognitive events (Hillyard and Picton, 1987). ERPs are the summed activity of excitatory postsynaptic potential (EPSP) and inhibitory postsynaptic potential (IPSP) activated in response to each new stimulus or subject response. The ERPs are less precise for the anatomical localization of the neural generators than the neuroimaging techniques. Nonetheless, this technique has an exceptional temporal resolution of milliseconds (Kutas and Federmeier, 2000). An ERP's spatial distribution on the scalp is not indicative of its brain-source generators (although some mathematical tools for source algorithm localization can enhance the spatial precision).

Electrodes are attached to diverse points on the scalp relative to bony landmarks. Using a standardized EEG-measurement technique to determine the correct spots, the entire head is measured. Normally, the participants are placed in front of a computer screen with electrodes fixed onto the scalp and connected to electric amplifiers and auditory headsets displaying a pattern of stimuli. One computer records and amplifies the electrical peaks elicited by each stimulus onset (or the participant response).

The EEG activity is time-locked to several presentations of similar events (stimuli or participants responses), and the averaging of these segmented EEG traced together is the usual procedure. The average decreases the influence of noisy activity (i.e., EEG not related to experimental events or background noise) while maintaining the event-related activity. Several signal processing steps, such as filtering (e.g., 0.5 to 30 hz), segmentation, artifact detection and correction, bad channel replacements, re-referencing, baseline correction and averaging, are usually required to obtain a suitable signal-to-noise ratio (see Figure 1). After these processing steps, positive or negative changes of voltage constitute ERPs that appear at specific latencies after the stimulus presentation. Most ERP components are referred to by a preceding letter (e.g., "N"), indicating polarity followed by the typical peak latency in milliseconds (e.g., the "N400" ERP component is described as a negative voltage deflection occurring approximately 400 ms after the stimulus onset). The timing of the brain processing is measured by the timing of these cortical responses.

The simplest ERP parameters are latency (how long after the event they appear), direction (positive or negative), amplitude (the strength of the voltage change) and topological distribution of the component on the surface of the head (frontal, parietal, occipital, etc.). The standard procedure to visualize and measure the ERP activity consists of quantifying the amplitude and latency (measured in microvolts and milliseconds, respectively) of the waveform associated with a specific stimulus or response. By means of this procedure, different stimuli or conditions can be contrasted in terms of amplitude or latency. It is usually stated that a given ERP "is modulated by," "is sensitive to" or "discriminates" a given condition when statistically significant differences are found in latency, amplitude or morphology, respectively, as a function of such condition manipulation.
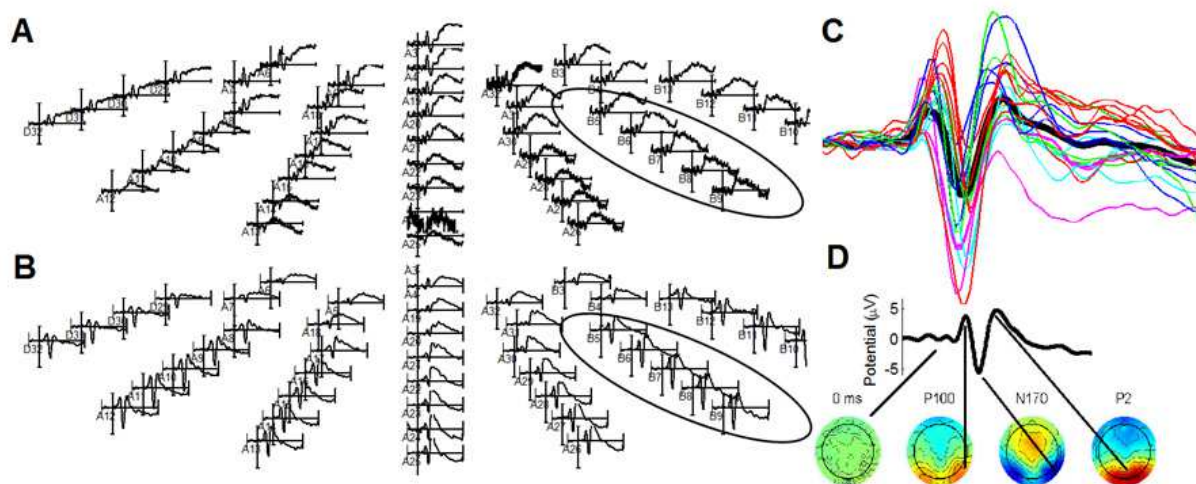
Fig. 1. ERP signal-to-noise ratio. A) ERPs at temporo-occipital scalp in response to face stimuli without preprocessing and (B) with preprocessing. Note how the N170 can be clearly observed after preprocessing over the right occipito-temporal sites (comparing both ellipses). C) N170 estimation over a representative electrode (T8) demonstrating the signal-to-noise ratio reduction in between the subject's average waveform (black line). D). Voltage map reconstruction by interpolation showing the scalp activity at 0, P100, N170, 200 and P2 after the presentation of face stimuli.

A continuous reconstruction of electrical activity on the scalp, normally based on spatial interpolation of the electrode sites, is termed a topographical map (or a voltage map or topomap). Each component usually has a relatively specific topographic distribution. The so-called long latency components (cognitive components or endogenous components) occur after 100 ms and are sensitive to changes in cognitive processing, as the meaning of the stimulus, or resources of processing required in the task performed (Hillyard, 2000). In the following section, we provide a succinct description of several components.

3. A selective description of main components

3.1 P100 and N100 (P1 and N1)
Eason et al. (1969) found that visual stimuli situated in visual fields with focused attention elicited components with larger amplitude (approximately 100 ms after stimulus onset, P1 and N1), compared with ignored or unnoticed stimuli. This amplitude enhancement is at its maximum in the temporal-occipital region, contralateral to the localization of the stimuli and is sensitive the specific localization of the stimuli in the visual field (Mangun et al., 1993). Comparable results were obtained in the auditory modality by a dichotic listening paradigm (Hillyard et al., 1973). This auditory early-attention effect reflects a response increase of the auditory primary cortex (Woldorff et al., 1993). The P1 and N1 components are also modulated by several factors in the attentional task, such as emotional saliency, relevance or familiarity.

3.2 P200 (or P2)
Is a positive deflection occurring approximately 200 ms after the onset of the stimulus? P200 has been interpreted as reflecting selective attention (Hackley, Woldorff and Hillyard, 1990) and visual-feature detection processes (Luck and Hillyard, 1994). Similarly, P2 has been

shown to be sensitive to orthographic/phonological tasks, semantic categorization tasks, reward-punishment discrimination and lexical decision tasks.

3.3 N200 (or N2)

Is a negative deflection resulting from a deviation in form or context of a prevailing stimulus? Normally, N2 is evoked 180 to 235 ms following the presentation of a specific visual or auditory stimulus. Additionally, the N2 is considered to be a family of different components, but its classic consideration can be elicited through an experimental oddball paradigm and is sensitive to perceptual features (Bentin et al., 1999). This component is also associated with conflict detection during the regulation of successful behavior (Nieuwenhuis, Yeung, Van Den Wildenberg and Ridderinkhof, 2003). The source of N2 modulation compromises the anterior cingulate cortex (ACC hereafter, a brain area susceptible to social monitoring of conflict) and other prefrontal cortex areas (Nieuwenhuis et al., 2003).

3.4 N170/Vertex Positive Potential (N170/VPP)

The N170/VPP complex is a negative peak around 170 ms in the temporal-occipital regions and simultaneously one central-frontal positivity (VPP), functionally equivalent (Joyce and Rossion, 2005). The source of N170 compromises the inferior temporal gyrus and the fusiform gyrus (two neural areas associated with specific face processing). Its amplitude is greater for human faces, compared with objects or other stimuli (Bentin, Allison, Puce, Perez and McCarthy, 1996; Jeffreys, 1989). During the face-processing task, N170 is sometimes followed by a P2, a N250 and an LPP component modulated by other variables. The N170 component has shown amplitude/latency modulation based on race cues (Ibanez et al., 2010c; Ito and Ulrand, 2005; Gonzales et al., 2008), emotional variables (Ashley, Vuilleunier and Swick, 2004) and contextual effects (Ibanez et al. 2011d).

3.5 Early Posterior Negativity (EPN)

The EPN is a middle-latency component that has been associated with different stages of valence information processing and affective discrimination (Schupp et al., 2004a, 2004b). Di Russo, Taddei, Apnile and Spinelli (2006) suggested that EPN would reflect early valence discrimination and response selection processes. Additionally, Schupp et al. (2004a) have stated that the processing indexed by the EPN is modulated by perceptual features that facilitate further evaluation of arousing stimuli. Different studies have found a modulation differing from the neutral for both emotional (pleasant, unpleasant) categories of pictures (e.g., Dufey et al., 2010; Cuthbert, Schupp, Bradley, Birbaumer and Lang (2000). Nevertheless, specific effects (task or stimuli-dependent) on EPN in relation to valence and the influence of arousal should be further assessed.

3.6 P300 (or P3)

This component has been described as engaging higher-order cognitive operations related to selective attention and resource allocation (Donchin and Coles, 1988). The P3 amplitude may serve as a covert measure of attention that arises independently of behavioral responding (Gray et al., 2004). The component has also been related to a post-decisional "cognitive closure" mechanism (Desmedt, 1980; Verleger, 1998); and to the access of information for consciousness (Picton, 1992). Its amplitude generally varies as a function of the temporal

distance between a target and a preceding outgoing stimulus (e.g., Cornejo et al., 2007). There are two sub-components (P3a and P3b). The P3a has a more frontal distribution and is observed after an unexpected event, regardless of the relevance of the stimulus. Usually, it is associated with automatic attentional modulation. The P3b is related to attention, working memory and superior cognitive functions and is observed at centro-parietal sites. This ERP is affected by several psychological processes, the most important of which are motivation and sustained attention.

3.7 Late Positive Components (LPP, PPC, P600)

The late positive potential (LPP) is considered to be a family of components (although initially was described by Sutton in 1965 as a unique, frontal bilateral positivity). This late component (300 to 700 ms) is sensitive to stimuli valence and to the previous emotional context (Cacioppo et al., 1994, Schupp et al., 2000). Its amplitude, according to several studies, increases in response to motivationally relevant stimuli (i.e., pleasant or unpleasant images; Cuthbert et al., 2000; Schupp et al., 2000; Schupp, Junghofer, Weike and Hamm, 2004). The amplitude, latency and topography of LPP are modulated by the semantic emotional valence of stimuli (Cunningham et al., 2007) and contextual information (Cornejo et al., 2009; Hurtado et al., 2009). The late positive complex (LPC) is a component similar to LPP and has been related to the process of re-analysis of the incongruent situation produced by inconsistent meaning (Ibanez et al., 2010a, 2011b; Sitnikova, Kuperberg and Holcomb, 2003). The P600 is considered to be an index for second pass-parsing processes of information processing, having much in common with working memory operations. It is associated with superior frontal, temporal and parietal regions, which are believed to contribute to some aspects of information processing during recognition memory.

3.8 N400 and N400-like

The N400 is a negative component that appears around 400 ms after the presentation of semantically unrelated information between two words or between a context and a word. Although this component was first studied in the linguistic field, recent studies have extended previous results to richer action sequences and pictorial stimuli (sometimes called N350 or N400-like), such as congruent-incongruent pictures or videos of gestures, actions and motor events (Aravena et al., 2010; Cornejo et al., 2009; Proverbio et al., 2010; Ibañez et al., 2010b, 2011; Guerra et al., 2009; Sitnikova et al., 2003). Although spatial resolution provided by ERP does not allow a precise localization of N400 neural generators, evidence from lesion studies, MEG and intracranial recordings converge to implicate temporal areas (left superior/middle temporal gyrus, the anterior-medial temporal lobe, the PHC and anterior fusiform gyrus) as the possible sources of N400 (Van Petten and Luka, 2006). This N400 points to a distributed and multimodal system that is simultaneously open to verbal and nonverbal meanings (Kutas and Federmeier, 2000).

3.9 Contingent Negative Variation (CNV)

CNV is an extended and prolonged negative potential recorded during simple, warned reaction time paradigms from central and parietal scalp fields. Its scalp distribution always begins bilaterally and symmetrically at the midline of the precentral-parietal regions, approximately 1.000 to 1.500 ms before response movement. CNV is a correlate of anticipation of the latter presentation of a stimulus target (Picton and Hillyard, 1988; Walter, Cooper, Aldridge, McCallum and Winter, 1964).

3.10 Error-Related Negativity (ERN) and Feedback Error-Related Negativity (fERN)

The ERN is a component observed 50 to 100 ms after a response characterized as being of high conflict in which a dominant response is inconsistent with respect to the correct response (Hohnsbein, Falkenstein and Hoormann, 1995 and others). The ERN is an index for the general sensitivity of the conflict monitoring system, which can be used to predict successful patterns of control (Yeung, Botvinick, and Cohen, 2004). Feedback error-related negativity (fERN) has been referred to as a negative deflection in the event-related potential (ERP), which distinguishes between wins/losses or correct/error trials in terms of expected and unexpected outcomes (e.g., San Martin et al., 2010). In correct (ERN) or win trials (fERN), similar components have been named Correct Related Negativity (CRN) and
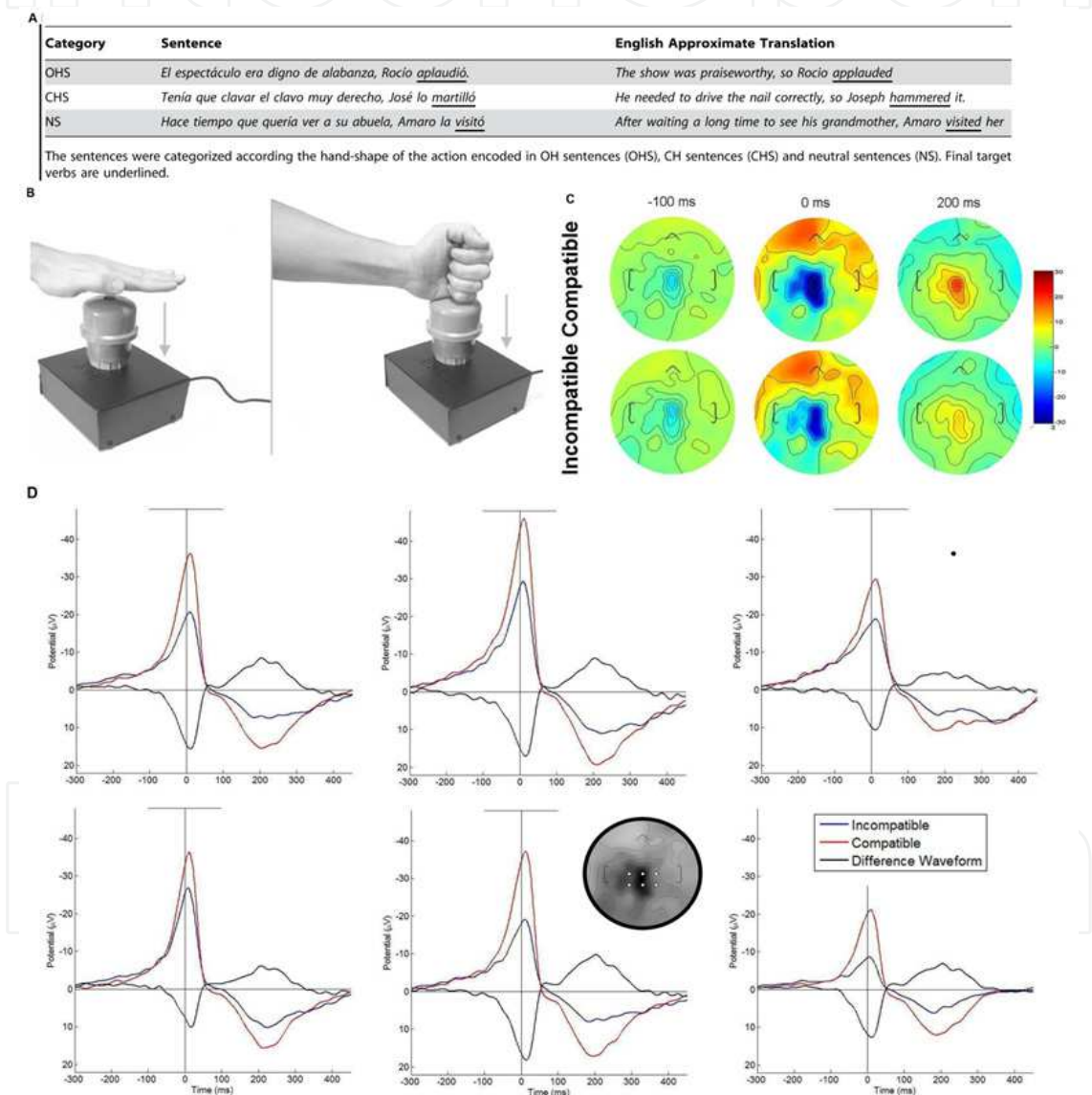

Fig. 2. Motor potential (MP and RAP) modulated by compatibility with semantic stimuli. A) Verbal stimuli used in an action-sentence compatibility paradigm. B) Participants' open- and close-hand responses. C) Scalp topography of the motor response at baseline, zero-time response and 200 ms after the response. D) Motor potential (MP and RAP) modulated by the compatibility between the participant motor responses (open or close) and the semantic stimuli (sentences containing open- or close-hand actions). Modified from Aravena et al., 2010.

feedback correct-related positivity (fCRP), respectively. According to an extended theory called the "reinforcement learning theory of ERN," both forms of ERN/fERN reflect the function of a generic, high-level error-processing system in humans (Holroyd and Coles, 2002). Both the ERN and fERN have a main source on the cingulate cortex, the anterior and the posterior division.

3.11 Motor components (RP, LRP, MP, RAP)

The movement-related cortical potentials (MRCP) associated with self-paced movements are considered to be a measure of motor cortex excitability and allow the exploration of cortical changes related to motor preparation and execution. The readiness potential (RP, or in its original German name, Bereitschaftspotential) precedes voluntary muscle movement and represents the cortical contribution to the pre-motor planning of volitional movement. The RP was first described in 1964 by Hans Helmut Kornhuber and Lüder Deecke. The lateralized readiness potential (LRP) is a particular form of RP in response to certain movements of one side (left or right) of the body. Being related to RP, another negativity measured over Cz beginning shortly before the response onset (-90 ms) has been named the motor potential (MP) or late motor-related potential (late MRP; Aravena et al., 2010). The MP is likely to represent pyramidal neuron activity in the primary cortex (M1) at motor execution. MP amplitude modulation has been associated with the rapidness and precision of movement and also with short-term training effects. Finally, another component with a peak over Cz after movement onset (200-300 ms) has been named the re-afferent potential (RAP). RAP is an index of movement-related sensory feedback to the primary sensory-motor cortex and is considered an indicator of attention (Aravena et al., 2010, see Figure 2).

4. Representative areas of social cognitive neuroscience

4.1 Contextual approaches to language

Context-dependence effects are pervasive in everyday cognition (Barutta et al., 2011; Cosmelli and Ibañez, 2008; Ibanez and Cosmelli, 2008; Ibanez et al., 2010a), especially in the case of language (Ledoux, Camblin, Swaab and Gordon, 2006; Rodriguez-Fornells, Cunillera, Mestres-Misse and de Diego-Balaguer, 2009). We listen and say words within other streams of words. We perceive the emotion of a face altogether with the emotional body language, the semantics, the prosody and other cues from the situation. Language use can be tracked by assessing the influence of context parameters (such as intonation, lexical choice, prosody, and paralinguistic clues) in a current communicative situation. ERPs studies of early (N170 and ELAN) and late components (N400, LPC, LPP) have provided important insights about the temporal brain dynamics of contextual effects in language. For instance, important issues, such as automaticity of contextual effects, multimodal blending of meanings, action-sentence coupling, language-like gesture processing, language and social information coupling, and early emotional word processing have been demonstrated within ERP research (Aravena et al., 2010; Cornejo et al., 2009; Hagoort, 2008; Ibanez et al., 2006, 2009, 2010b, 2010c, 2011b; 2011c, 2011d, 2011e, Van Petten and Luka, 2006). Contextual effects in language assessed with ERPs is a relevant topic in diverse areas of neuropsychiatric research, such as schizophrenia (Guerra et al., 2009; Ibanez et al., 2011c), Alzheimer's disease and mild cognitive impairment (Schwartz et al., 2003; Taylor and Olichney, 2007), focal basal ganglia lesions (Paulmann, Pell and Kotz, 2008) alcoholism (Roopesh et al., 2009) and aphasia (Wassenaar and Hagoort, 2005), among other conditions.

4.2 Emotion and emotional body language

Today, it is well known that complex social skills depend on basic emotional processing and inference (Grossmann, 2010). Moreover, facial emotional expressions can provide an automatic and rapid shortcut to alarm signals, mentalizing and inter-subjective communication. Important issues in emotion research, such as face emotional processing (Eimer and Holmes, 2007), emotion regulation (Hajcak, MacNamara and Olvet, 2010) and the intertwining of attention and emotion (Schupp, Flaisch, Stockburger & Junghofer, 2006) have a long tradition in ERP research.

Early, automatic and unaware processing of emotion in faces, words and pictures have been demonstrated within ERP research (Guex et al., 2011; Ibanez et al., 2010c, 2011d, In press, Submitted b, see Figure 3.A). Theoretical models of emotion perception (Vuilleumier and Pourtois, 2007) propose a parallel and interactive system indexing object recognition (e.g., triggered by the fusiform gyrus) and emotional discrimination (e.g., triggered by the amygdala). Emotional signs that can denote confidence or danger may occur before and parallel to the process of object codification. In other words, emotional significance can be processed before a stimulus is completely identified. At the same time, processing of complex social stimuli intermixed with emotional processing has been reported at late stages, indexed with the LPP and LPC (Dufey et al., 2010; Hurtado et al., 2009; Ibanez et al.,
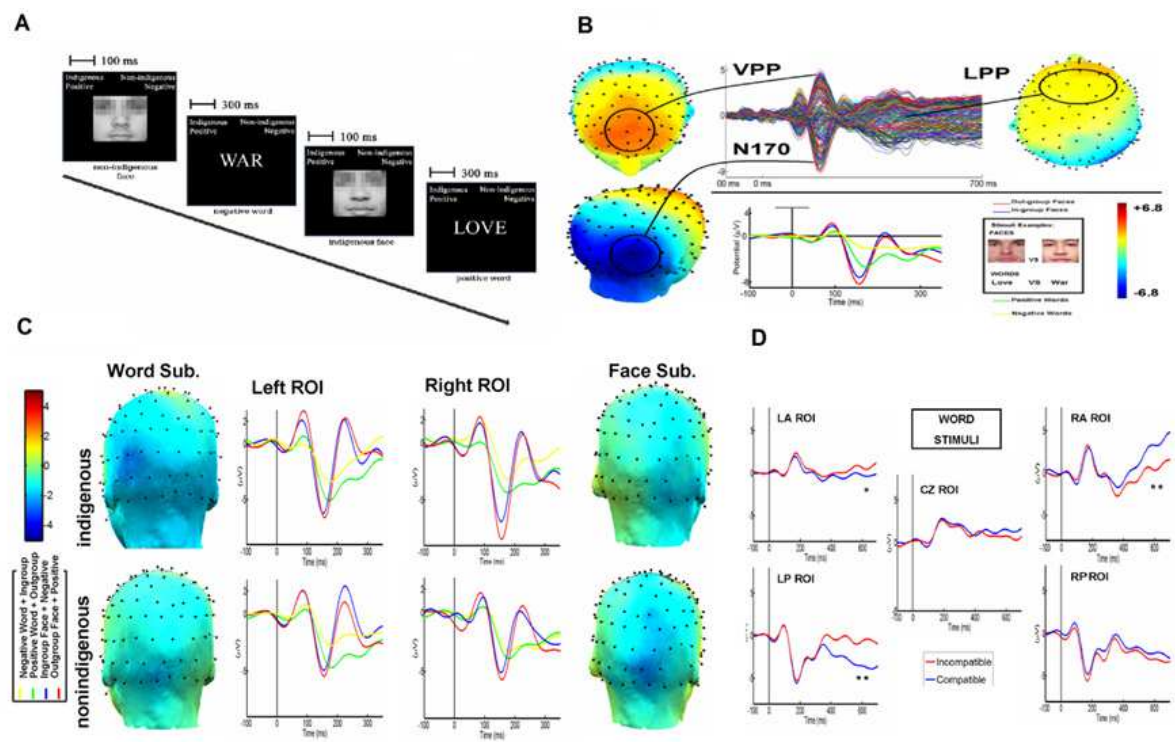

Fig. 3. Early and late emotional-cognitive processing. A) Implicit association test (IAT) schematic representation. Both ingroup and outgroup faces, along with words of positive and negative valence, are presented. The subject is required to classify each stimulus to the left or to the right according to labels displayed on top of the screen. B) Early (N170) and late (LPP) effects of IAT. C) N170 contextual modulation based on valence and membership stimuli. D) Late processing (LPP) of semantic stimuli compatibility. Modified from Hurtado et al. 2009 and Ibanez et al 2010c.

2009, 2010b, 2011b, see Figure 3.B). Emotional body language (EBL) is another emergent area in neuroscience research (de Gelder, 2006). Neuroimaging studies have shown that the EBL activates similar areas of emotional face processing, such as amygdala and fusiform gyrus. EBL signals are automatically perceived and influence emotional communication and decision making. ERP research has demonstrated that EMB (a) is automatic and processed early in the brain; (b) influences the emotional recognition of face processing; and (c) is processed in an integrated way with face processing (de Gelder et al., 2006; Meeren, van Heijnsbergen and de Gelder, 2005).

4.3 Empathy

A large number of studies using functional MRI, and more recently electrophysiology, have used the presentation of stimuli depicting people in pain (i.e., people suffering from physical injuries or expressing facial expressions of pain) to characterize the neural underpinnings of empathic processing (Botvinick et al., 2005; Jackson et al., 2006; Cheng et al., 2008a; Fan et al., 2008; Han et al., 2008; Akitsuki and Decety, 2009, Decety et al., 2010c). The results from these studies suggest that empathy for pain involves a somatosensory resonance mechanism between other and self that draws on the affective and sensory dimensions of pain processing (Jackson et al., 2006). This mechanism provides crucial and rapid information to help us understand the affective states of others and respond to them (Decety and Lamm, 2006).

ERP studies of empathy for pain showed an N1 differentiation (neutral pictures eliciting greater negative amplitudes) over the frontal area, as well as a late P3 over the centro-parietal region (pain pictures producing greater positive amplitudes; Fan et al., 2008; Han et al., 2008; Decety et al., 2010). These ERPs studies have shown early modulation by contextual reality of stimuli and late modulation based on cognitive regulatory and task demands (Fan and Han, 2008; Han et al., 2008; Decety et al., 2010c; Li and Han, 2010), as well as 'other-related' information, such as priming for treat signaling (Ibanez et al. 2011e). ERP studies have provided important insights regarding the context-dependent processing and differences in automatic-controlled processing on empathy for pain research.

4.4 Decision making and reward

The current neuroscience of decision making has assessed multiple processes engaged in this complex cognitive ability. Evidence from animals, healthy human volunteers and neuropsychiatric patients (e.g., Bechara and van Der Linden, 2005; Brand et al., 2006; Camerer et al. 2008; Gleichgerrcht et al. 2010; Kable and Glimcher, 2009; Glimcher and Rustichini, 2004; Rangel 2008; Rangel, Rushworth et al., 2007) highlights the role of frontostriatal and limbic loops in decision making. Despite some discrepancies between different models, three main systems are thought to be involved in frontostriatal and limbic loop: a stimulus-encoding system (orbitofrontal cortex), a reward-based action-selection and monitoring system (cingulate cortex) and an expected-reward system (basal ganglia and amygdala). We have shown (Gleichgerrcht et al., 2010) that these systems are crucial in the decision-making process in normal voluntaries, as well as in neuropsychiatric disorders, such as neurodegenerative diseases (Figure 4). The action-selection and monitoring system can be tracked directly with the P2, the ERN and the fERN, opening a new branch of research (Nieuwenhuis et al., 2004, 2005). Gambling and decision-making tasks can be assessed with ERPs (e.g., San martin et al., 2010). Behavioral measures of affective and risky

decision-making tasks would be not so sensitive as to assess subtle deficits in decision making in disorders such as adult attention deficit hyperactivity disorder and bipolar disorders. Conversely, ERP abnormal neural processing of valence and magnitude of rewards in a gambling task in those disorders may help to integrate reward, action-selection and monitoring systems, providing an excellent shortcut to goal-directed action (Ibanez et al., Submitted a). ERP research on gambling tasks provides both a clinical and a theoretical branch of research linking decision making, soft frontal diseases, monitoring-reward systems and psychiatry.

Fig. 4. A neuroanatomical model of decision making. Three main systems are thought to be involved in decision making: a stimulus-encoding system (orbitofrontal cortex shown in red), an action-selection system (anterior cingulate cortex shown in green) and an expected-reward system (basal ganglia and amygdala shown in blue). The anterior, medial and posterior cingulate cortex, together with basal ganglia (ellipse), seem to modulate the ERN and fERN in gambling and error-monitoring tasks. Modified from Gleichgerrcht et al., 2010.

5. Complementary issues

We have described several ERP components involved in studies of social and cognitive neuroscience. Now, in this section we review some methodological approaches of ERP research that complement and improve the advances in traditional ERP assessment: sleep research, intracranial recordings, source location analysis and co-recordings with fMRI.

5.1 Sleep research

The study of cognitive processing during sleep is a topic of great interest because ERPs allow the study of stimulation with passive paradigms (without conscious or behavioral response), opening multiple research possibilities during different sleep phases (Ibanez et al., 2008a). Different cognitive discriminations during sleep related to the learning, frequency, intensity, duration, saliency, novelty, proportion of appearance, meaning and even sentential integration of stimuli are topics of intense research (e.g., Ibanez et al., 2006). Methodological control of ERP sleep research, such the use of qualitative and quantitative measures of sleep stages (see Figure 5), the control of the so-called first night effect and the assessment of sleep disturbances are important factors for improving this research area (Ibanez et al., 2008b). Better control of experimental paradigms is relevant for the growth of the neuroscience of sleep.
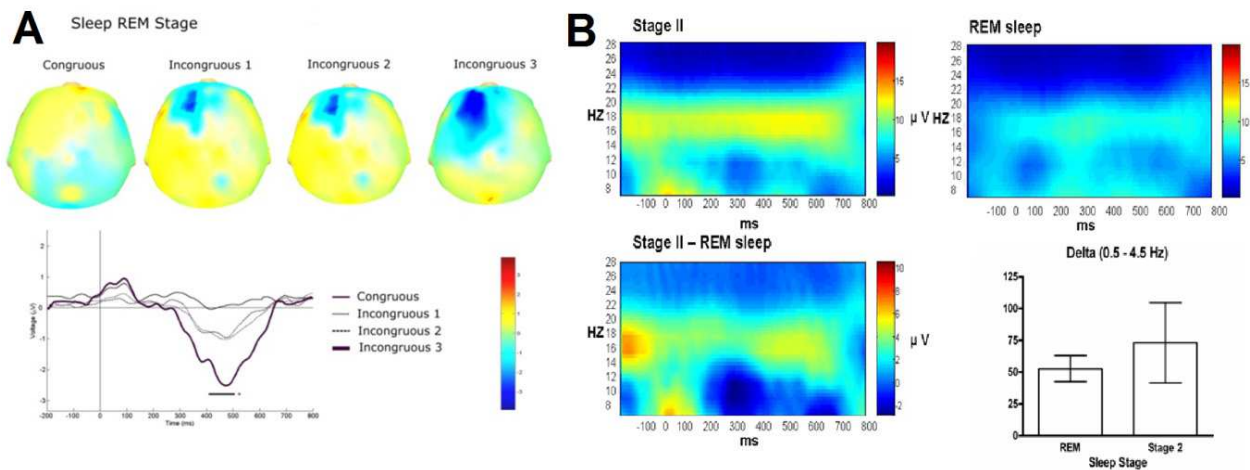

Fig. 5. Quantitative assessment of sleep stages during ERP recordings. A) The voltage maps and N400 waveform modulation of contextual semantic discrimination during REM sleep. B).Comparison of frequency bands between sleep stages (time-frequency charts for stage II sleep, REM sleep and stage II-minus-REM subtraction). Microvolt differences (mean and standard deviations) of delta band activity during stage II and REM (right bottom). Modified from Ibanez et al., 2006, 2008b.

5.2 Intracraneal recordings

The use of local field potentials (LFP) and electrocorticography (ECoG) in patients with surgically implanted electrodes (Figure 6) have provided a recent, new pathway to study the spatiotemporal brain dynamics of cognition. Intracraneal recordings help to diagnose and treat neurological conditions, such as epilepsy, Parkinson's disease and tumors. LFP and ECoG are measures of direct brain activity that have better (combined) temporo-spatial resolution than any other human neuroscience method. The ERP assessment, together with evoked oscillatory activity, has provided important insights on working memory, episodic memory, language, face processing, consciousness and spatial cognition (Jacobs and Kahana, 2010; Lachaux et al., 2003).
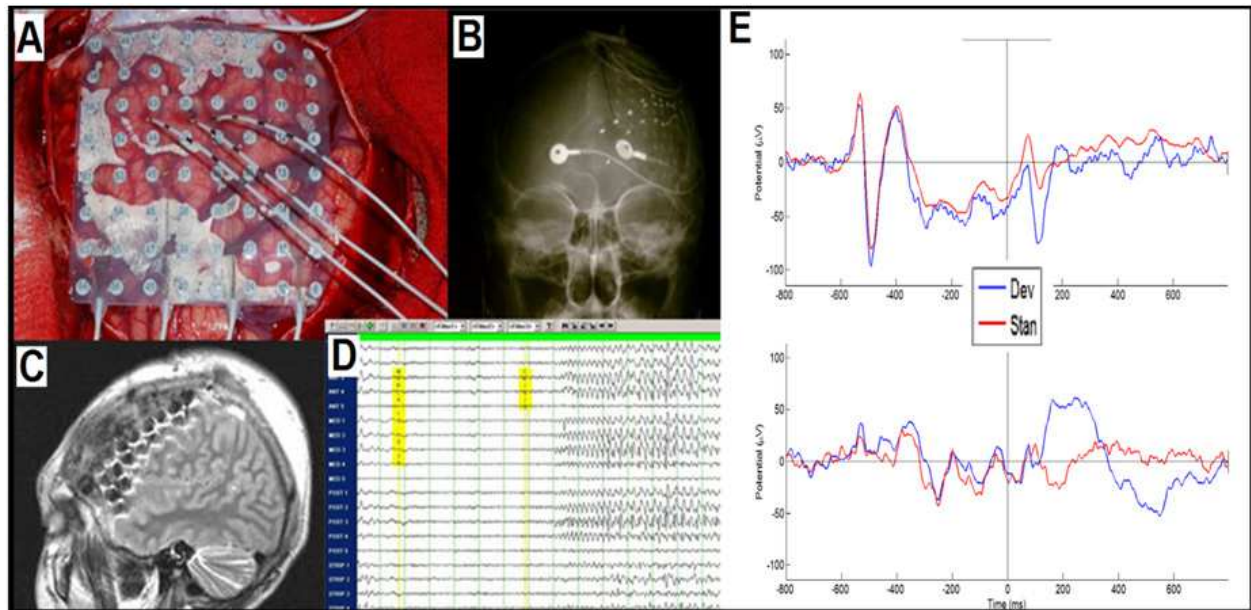
Fig. 6. Intracranial recordings. A) Grid of 63 electrodes for electrocorticography in a patient with refractory epilepsy. B) X-ray computed tomography (CT) and C) MRI showing the electrode grid and deep electrodes for local field potentials. D) Intracranial EEG. E) iERP recordings of deviant (DEV, Blue) and standard (STA, Red) stimuli during a global-local oddball task. Selected electrodes demonstrated an N2 and P3 modulation at the frontal (above) and parieto-temporal sites (below).

5.3 Source location in dense arrays

The current use of dense arrays of electrodes (from 64 to 256 channels) allows a better characterization of field potentials and improves the estimation of cortical brain sources, which generates the ERPs. The source estimation reduces the spatial imprecision of ERPs and links the temporal information with low-resolution anatomical measures. Important advances on parametric and non-parametric methods have been developed recently (Grech et al., 2008). Several engineering solutions of an inverse problem to find ERP sources using parametric and non-parametric approaches are available (e.g., LORETA, sLORETA, VARETA, S-MAP, ST-MAP, Backus-Gilbert, LAURA, SLF, SSLOFO and ALF; BESA, MUSIC and FINES). Methods of distributed sources (Figure 7), including biophysical and psychological constraints (e.g., LAURA), can produce more relevant results. Finally, principal-component analysis (PCA) and independent-component analysis (ICA) are now accessible for ERP source localization. The development of distributed EEG/MEG source analysis using statistical parametric mapping of MRI promises further advances in social-affective neuroscience (e.g., Junghofer, Peyk, Flaisch and Schupp, 2006).

5.4 FMRI-ERP simultaneous recordings

FMRI provides a fine spatial resolution but measures indirect brain signatures (hemodynamic response) and has poor temporal resolution. ERPs are a direct measure of cortical activity but have poor spatial resolution. Combining fMRI and ERPs provides a spatial and temporal fine-ground resolution of cognitive brain activity (Gore, Horovitz, Cannistraci and Skudlarski, 2006). Recently, removal algorithms of fMRI artifacts on ERPs
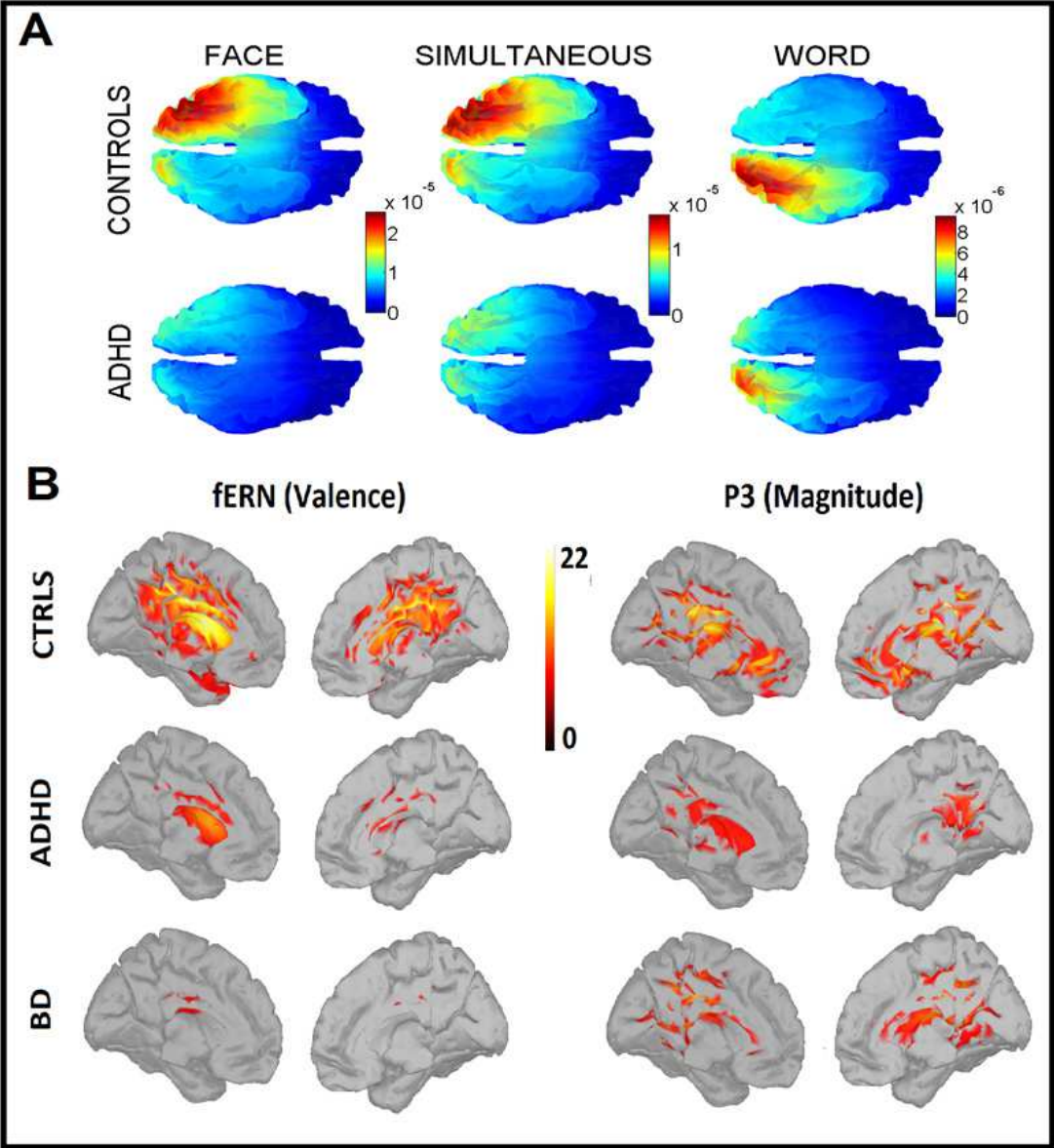
Fig. 7. ERP source estimation using distributed dipole modeling (N170 and fERN). A) N170 source imaging estimation of fusiform gyrus for faces, words and face-word simultaneous stimuli in controls (above) and patients (below) with ADHD. Average values of estimated, standardized current density power at maximum peaks of activation. B) Cortical current density mapping of valence and reward magnitude. The source estimation of distributed valence dipoles (fERN, left) and magnitude effects (P3, right) for controls, patients with ADHD and those with bipolar disorders (BD). Color-map values represent the t-values of comparisons between signal and noise. Modified from Ibanez et al., Accepted, Submitted a.

have been developed, facilitating the combined use of both methods. For instance, ERP/fMRI co-recording allows an enhanced study of origins and locations of ERP neural generators. For example, the spatial (face-processing brain areas) and temporal brain dynamics (N170) of face processing in the human brain have been reported with this methodology (Sadeh et al., 2008)

6. Conclusions

In this chapter, we highlighted the role of ERP research in the field of cognitive and social neuroscience. We introduced the ERP methodology and then a selective description of main components was developed. Subsequently, some representative fields of ERP research on the neural basis of language, emotion, empathy and decision-making cognition were presented. Finally, complementary methodological approaches (sleep research, intracranial recordings, source location in dense arrays and fMRI-ERP co-recordings) were introduced, highlighting the broad horizons of ERP research. By providing the fine, temporal brain dynamics of social and cognitive processes in normal, psychiatric and neurological participants, ERP research constitutes an important branch of human neuroscience.

7. Acknowledgments

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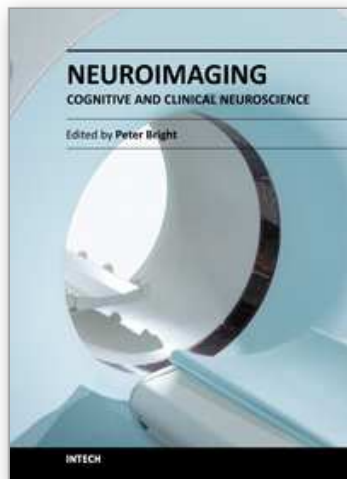
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Neuroimaging - Cognitive and Clinical Neuroscience

Edited by Prof. Peter Bright

The rate of technological progress is encouraging increasingly sophisticated lines of enquiry in cognitive neuroscience and shows no sign of slowing down in the foreseeable future. Nevertheless, it is unlikely that even the strongest advocates of the cognitive neuroscience approach would maintain that advances in cognitive theory have kept in step with methods-based developments. There are several candidate reasons for the failure of neuroimaging studies to convincingly resolve many of the most important theoretical debates in the literature. For example, a significant proportion of published functional magnetic resonance imaging (fMRI) studies are not well grounded in cognitive theory, and this represents a step away from the traditional approach in experimental psychology of methodically and systematically building on (or chipping away at) existing theoretical models using tried and tested methods. Unless the experimental study design is set up within a clearly defined theoretical framework, any inferences that are drawn are unlikely to be accepted as anything other than speculative. A second, more fundamental issue is whether neuroimaging data alone can address how cognitive functions operate (far more interesting to the cognitive scientist than establishing the neuroanatomical coordinates of a given function - the where question).

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