INTRODUCTION

The event-related potentials (ERPs) of the brain are wave forms reflecting brain voltage fluctuations in time. These wave forms consist of a series of positive and negative voltage deflections relative to some base line activity prior to the onset of the event. Under different conditions, changes may be observed in the morphology of the wave forms (e.g., the presence or absence of certain peaks), the latency, duration, or amplitude (size) of one or more of the peaks, or their distribution over the scalp. ERPs are useful measures for studying mind and brain functions because they are continuous, multidimensional signals. Specifically, ERPs give a direct estimate of what a significant part of the brain is doing just before, during, and after an event of interest, even if this is prolonged. ERPs can indicate not only that two conditions are different, but also whether, for example, there is a quantitative change in the timing and/or intensity of a process or a qualitative change as reflected by a different morphology or scalp distribution of the wave forms. For all these reasons, ERPs are well established as powerful tools for studying physiological and cognitive functions of the brain.

ERPs AND COGNITIVE THEORY

The so-called cognitive revolution (Baars, 1986) that has permeated research on the mind in psychology and the neurosciences has led to widespread recognition that cognition and the knowledge that derives from it, rather than being an accumulation of sensory experiences, is a constructive process that requires the verification of hypotheses influenced by previous knowledge, past experience, and current aims, as well as emotional and motivational states. Cognitive theory led not only to the rejection of the mind–brain dualism (Mecacci and Zani, 1982; Finger, 1994), but also to firm establishment of the notion that the nature of the mind is determined to a large extent by the neurofunctional architecture of the brain. An important corollary of this concept is the idea that in order to understand the mind it is essential to study and understand the brain (Gazzaniga, 1984, 1995; Posner and DiGirolamo, 2000).

Understanding the mind and brain does not in any way mean understanding conscious processes—quite the contrary, because to a large extent it means investigating nonconscious neural processes. This fact suggested to researchers of the stature
of Le Doux (1996) that the unconscious is real, and the renown Gazzaniga (1998) stated that “many experiments highlight how the brain acts earlier than we realize.” This occurs at different hierarchical levels within the complex entity of the mind–brain, ranging from intra- and intercellular ion exchanges at the microcellular level to the flow of information, at the macrosystem level, along the different functional circuits underlying the very function of the brain and the mind. On the other hand, at a macrosystem level, unconscious function is manifested throughout almost all spheres of the mind, starting from the basic operations of analyzing physical characteristics of stimuli by our sensory system, to recording past events or making decisions.

We do not believe that this is surprising if we consider results of modern research on the brain; contemporary studies demonstrate the existence of processes of unconscious or subliminal knowledge and perception that influence a manifested behavior, or the capacity of the brain to “filter” or suppress the processing of stimuli (this argument is dealt with more fully in Section III of this volume, on processes of attention). This capacity to filter, studied by Freud, who used the term “repression” to describe it, allows us to be conscious of specific thoughts and perceptions, but not others, apparently under free will and by choice.

In consideration of the relevance of this substantial unconscious component of the mind and, indeed above all, the emotions, it can only be concluded that a heuristically valid cognitive theory of the mind is one that considers the mind’s rational and cognitive aspects, which are maintained by the activity of the neocortex, inseparable from the emotive and irrational aspects, expressed by the amygdala and the limbic anterior cingulate cortex (Bush et al., 2000; see also Chapter 8, this volume). This conclusion is also supported by the close relationship existing between thought processes and emotional processes, suggested by authoritative researchers of the brain such as Le Doux (1996) and Damasio (1994). According to this logic, the brain is seen as a so-called living system. A system, despite being the sum of various parts, each with its specific function, acts as a whole in which each function inevitably influences the other.

Furthermore, it must be remembered that whatever conception of the mind is adopted, it is not heuristically correct to consider this latter as an immutable entity. In fact, the mind must be considered in dynamic terms, that is, as undergoing continuous variations on the basis of evolutive processes and experience (Berlucchi and Aglioti, 1997). It is essential to remember that the functional processes that distinguish the mind vary as a function of the ontogenetic development of the individual—depending, as a consequence, on the diversified maturation of cerebral structure—and as a function of the individual’s learning processes and specific experience gained for the stage of development reached (Nelson and Luciana, 2001; see also Chapter 9, this volume).

Cognitive electrophysiology is a very well-established field of science (Heinze et al., 1994; Kutas and Dale, 1997). The new technologies used to pursue the investigation of mind and brain, with the theoretical backing of the cognitive sciences, have developed at a dizzying speed over the recent “decade of the brain.” As a research tool, cognitive electrophysiology may provide relevant contributions to both cognitive and brain sciences, putting together new knowledge about humans as integrated sociobiological individuals. This ambitious task implies an integration of neurofunctional concepts and basic or more complex cognitive concepts, such as those proposed in cognitive sciences (Wilson and Keil, 1999). Unlike most electrophysiological research, mired down by data collection and “correlation statements,” to the detriment of theorization,
the main assumption of cognitively oriented electrophysiological research is that cognition is implemented in the brain through physiological changes. An implicit corollary of this assumption is that electrophysiological measures, i.e., ERP components, may be taken as manifestations, and not simply as correlates, of these intervening processes of the flow of information processing (McCarthy and Donchin, 1979).

Indeed, arguments may be, and indeed often are, raised against this theoretical view in the name of “physiological objectivity.” However, we are aware that these statements arise from questionable adherence, in many cases without any awareness, to operational meaning theory. The procedure of giving meaning to concepts inductively on the basis of measures provides an outmoded brand of operationism that may have functioned well for theoretically developed sciences, such as physics, proceeding in the framework of the Popperian view of scientific progress, but which has been only detrimental to atheoretical electrophysiological research. Indeed, the difficulties often met in defining any intrinsic and immutable property of a physiological response, changing as a function of the conditions of its occurrence, make the latter loosely defined in conceptual terms. This failure to find a specific response definition is a problematic criterion for delineating a psychological process for the correlational approach.

To cope with the spatiotemporal overlap in scalp-recorded manifestations of underlying cerebral processes, and with the problems in determining their physiological generators, cognitive electrophysiologists identify ERP components, i.e., the cerebral responses, as the portions of a recorded wave form that can be independently changed by experimental variables—task condition, state, subject strategy, etc. ERP components are not viewed as “structural markers” per se, but as “psychological tools,” as is any other psychological measure, e.g., reaction times. The relationships between these “tools” and cognitive processing are deduced by means of an “assumed” criterion that locates these physiological responses in accordance with hypothesized constraints about their position and function within ongoing activity. These constraints are mediated by well-defined theories of human cognition and information processing (Donchin, 1982, 1984a).

In seeking to clarify these procedural steps, let us take a concept such as learning, viewed from the psychological or behavioral level, and let us try to show how this concept may fruitfully drive electrophysiological experiments. Both at the levels of cognition and brain neurofunction three different, major principles of learning have been coherently identified: (1) knowing what is out in the world, to be used in later recognition and recall (2) knowing what goes with, or follows, what, and (3) knowing how to respond or what to do, given the drive and the situation. The interweaving of these three kinds of knowledge is manifested as complex voluntary action and skilled performance. In many respects these principles underlie the acquisition and deployment of procedures that manipulate the knowledge structures (Bransford et al., 1999). A very relevant topic relative to these procedures is the distinction between so-called controlled and automatic procedures. Skill learning is thought to be characterized by a slow transition from dominance by controlled processes to dominance by automatic processes. However, this transition has been shown to take place only for tasks for which consistent—i.e., repetitive and predictable—information is available. Taking this theoretical framework as a starting point for psychophysiological research on learning, it may be predicted that any spatiotemporal changes in ERP components (amplitude and latency) that may occur with learning should only be observed in tasks providing such consistent information (Kramer and Strayer, 1992).
In the past decades, evidence strongly supporting this prediction has been accumulated in ERP literature relative to all the best known components, especially the contingent negative variation (CNV) and the so-called late positive complex (LPC), i.e., N2, P300, and slow wave (see, Proulx and Picton, 1980; Kramer et al., 1986). Thanks to its inconsistent features, the “oddball” task is a simple but flexible experimental task that has helped to provide evidence, either as such or in the context of a probe-based dual-task paradigm, for the limited capacity of controlled processes and the spatiotemporal stability of ERP components.

**ERPs AND THE BRAIN**

Traditionally, for more than 100 years cognitive and neurophysiological processes in humans have been studied by psychophysical and behavioral methods. Modern neurosciences offer several hemodynamic, anatomofunctional, and electrophysiological methods to further investigations of the mind and brain. Nevertheless, only noninvasive whole-system procedures can be used to examine humans (see Appendix A, this volume, for a synopsis of molecular and systemic research methods). Because neurophysiological processing takes place in fractions of a second, one of the most feasible tools is to record brain electrofunctional activity (see, e.g., Heinze et al., 1994; Rugg and Coles, 1995). The advantages of electrophysiological signals, or ERPs, lie in their very high time resolution—in the order of milliseconds—and their reliable sensitivity in detecting functional changes of brain activity. The high temporal resolution and noninvasiveness of this method privilege its use over brain imaging techniques such as computed tomography (CT), positron emission tomography (PET), or functional magnetic resonance imaging (fMRI), as well as over the behavioral measures most used in traditional neuropsychological studies. Thanks to these advantages, event-related brain potentials may reveal steps in sensory–cognitive information processing occurring very rapidly within the brain. Furthermore, unlike behavioral and neuroimaging techniques, ERPs may reveal details of functional organization, and timing of the activation, of regional areas of anatomically distributed functional systems of the brain involved in cognitive skills as well as in executive capacities.

Volume conduction and lack of three-dimensional reality do, however, mean that these brain signals are of more limited use than neuroimaging techniques for examining where in the brain processes take place. Nevertheless, localization processes carried out using these signals may be made more sound through source-modeling algorithms.

There is no doubt that modern neuroimaging techniques have dramatically increased our knowledge of the brain and the mind (Posner and Raichle, 1994; Rugg, 1998; Cabeza and Kingstone, 2001). As with ERPs, studies carried out with these techniques focus on an individual’s brain when it is involved in carrying out a particular mental task: memorizing a list of words, distinguishing some objects from others that are similar but not the same, directing attention toward objects presented in a particular part of the visual field, etc. The theory underlying all these studies is that the areas of the brain that are found to be most active during the tasks are those that are crucial for the various types of mental activity.

However, simple mapping of the sites of mental processes can indicate only where in the brain a given functional activation takes place but, at present, can in no way explain the mechanisms of the mind. How do we recognize objects and faces, how do we recall the memory of experiences and things, how do we direct our attention to objects and the surrounding space, etc.? These complex and extraordinary
mental mechanisms still remain uncharted territory.

No spatial or temporal resolution, however good, can localize something of which we have only superficial knowledge. In fact, in order to be able to “localize” a given cognitive state or mental process (for example, “remembering something”) in the brain we must know clearly what the state or process is and what the functional subprocesses are that invariably lead to one cognitive state and not another. If we do not know what these subprocesses are, or whether they vary in different conditions, we cannot reliably localize them in the brain.

It is not at all difficult to find examples in the literature to illustrate what we mean. The reader is referred to Chapter 7 in this volume for an impressive review showing how different the cerebral localizations of activity can be during episodic mnemonic analysis of figurative and linguistic information, according to the different type/state of analysis carried out by subjects (e.g., familiarity, encoding effort, recognition). Furthermore, there is no lack of examples of different localizations in different studies by different scientists for a similar form of mental activity, such as spatial attention. For example, Mangun and colleagues repeatedly reported activation of the fusiform gyrus with PET imaging, and of this same gyrus together with the medial occipital gyrus, when imaged with fMRI, during attention to a relevant space location (see the exhaustive review by Mangun in Chapter 10), whereas Corbetta and colleagues (see Corbetta, 1998) reported a localized activity in the parietal lobe, a region of the cortex classically associated with the control of spatial attention, in addition to the more dorsolateral occipital regions. It is not inconceivable that to cope with differences in the spatial tasks across these studies, different cognitive processes, and thus, different regions of the volunteers’ brains, must have been activated during what was reported by the authors as apparently the same mental activity.

The difficulty in differentiating cognition from brain localization is not, however, unique to neuroimaging and electrophysiological studies. Unfortunately, it is also difficult in most traditional clinical neuropsychological research. Consider, for instance, research on hemineglect or cortical blindness, or any other clinical syndrome. Although robust, direct post-mortem and neuroimaging evidence is available for the anatomical localization of brain lesions from which these syndromes derive, only controversial theories can be advanced to explain which processes are lacking, compared to normal cognition, in these patients’ cognitive processing and thus to explain their symptomatology. Examples of opposing theories can be found in Köhler and Moscovitch’s (1997) outstanding review on unconscious visual processing.

To complicate the picture further, localization research is often pushed to an extreme, frequently without being soundly based on the theory of the mind or the functional architecture of the brain. There are now many authoritative investigators speaking out against this approach to research, and it will probably emerge as more of a hindrance than a help for understanding the mind and brain. For example, according to Frith and Friston (1997), most neuroimaging studies concentrate exclusively on subtraction techniques and on functional segregation to associate a given area with a given function. However, according to Frith and Friston, in order to build an accurate map of the mind, it is crucial to understand the functional interconnectivity of the centers and pathways of the brain by investigating the correlations between these different anatomo-functional entities.

This problem is felt, shared, and creatively developed in the excellent review by Cabeza and Nyberg in Chapter 3. Not by chance did they give their chapter the
title “Seeing the Forest through the Trees: The Cross-Function Approach to Imaging Cognition”; they identify “the trees” as the single cognitive functions on which many imaging studies focus their concern, with loss of sight the whole—“the forest”—represented by the fact that, on the one hand, many brain areas are involved in many cognitive functions, and, on the other, that cognition is not actually subdivided into distinct modular cognitive processes, as artificially proposed in cognitive science textbooks for explanatory purposes.

Fuster (2000) is of the same opinion, and authoritatively reports that “common sense, psychophysics, and experimental psychology provide ample evidence that all cognitive functions are interdependent. …Also interdependent must be, of course, their neural foundations.” And, cautioning the reader about some of the problems with the neuromodular principle of cognition, Fuster advances the concept of a “distributed cortical network” according to which performance in cognitive tasks, or, more specifically, tasks of executive control functions, is not solely mediated via localized areas of the brain, but by many regional brain areas that are dispersed throughout the brain, although being strictly linked to each other, and activated in a divergent and convergent way at different times. Again in Fuster’s (2000) words, “practically any cortical neuron or neuronal assembly, or module, can be part of many networks. A network can serve several cognitive functions, which consists of neuronal interactions within and between cortical networks.” The close resemblance between this carefully worded and articulate definition and the nowadays forgotten “functional system” theory of brain neurofunctional architecture, first advanced by the great Russian neuropsychologist Alexander Lurija (Lurija, 1962, 1976), will, we believe, have hardly escaped anyone.

In the light of these considerations, we believe that it is correct to think that the moment has returned for researchers to dedicate more of their forces to studying the mechanisms inherent to human cognition in order to reach a fuller understanding not merely of the brain, of which in a broad sense we know quite a lot, but rather the mind, that is, its higher and more arcane product, of which we are still profoundly ignorant.

For decades, aware of the limited capacity of ERPs to localize intracerebral processes of cognition, cognitive electrophysiologists have continued their research in the firm belief that the brain’s electromagnetic signals spread over the scalp during electrofunctional activation are precious for understanding the ways with which the brain changes with experience and knowledge. Furthermore, they have shared the belief that the nature and mechanisms of the neural processes of cognitive and emotional reorganization are objectively and reliably codified by the different components of the ERPs and event-related fields (ERFs) (Donchin, 1979, 1984b; Hillyard and Picton, 1979; Zani, 1988; Hillyard, 1993; Näätänen and Ilmoniemi, 1994; Rugg and Coles, 1995; Kutas and Dale, 1997).

It was in this conceptual “framework” that the idea was advanced that ERPs could make an important contribution to our understanding of the cerebral mechanisms of knowledge (Kutas and Hillyard, 1984; Heinze et al., 1994). And it is following this idea that the ERPs, rather than being considered a now obsolete method in comparison with the currently available techniques, are still used as a direct, quantifiable measure of processes of knowledge, both conscious and unconscious, and as such are still used to produce and validate models of the mind rather than to provide generic “correlates” of poorly defined psychological constructs. This will become extremely clear in the prestigious articles written by renowned researchers collected together in this book.
In conclusion, it seems that using ERPs, in combination with other available techniques, as quantifiable measures of cognitive and affective processes of the brain, the cognitive electrophysiologist can help test existing theories on the human mind and also can propose newer and more heuristic ones. In order to be efficient in this task of identifying mental processes arising from the brain, it is essential to work in the context of well-founded theories and with sophisticated methodology capable of distinguishing between these theories.

**THIS BOOK—OVERVIEW**

The chapters of this book—prepared by a panel of international neuroscientists and electrophysiologists—provide state-of-the-art reviews of the latest developments in the study of the relationships between mind and brain as investigated by event-related potentials and event-related fields. Some indications are explored of how these signals may be combined with the high spatial resolution of the hemodynamic signals of the brain, such as those acquired through positron emission tomography and functional magnetic resonance imaging, in order to come closer to the goal of localizing cognition within the brain.

The book is systematically organized into thematic sections. The three chapters in the first section cover the theoretical and methodological framework of investigating the human mind through the recording of electrical, magnetic, and hemodynamic signals of the brain. In Chapter 1 we have raised the point that the study of cognition can benefit enormously from the use of brain electrical and magnetic activity. Efforts are being made to demonstrate that these benefits will derive mostly from theoretically oriented electrophysiological research in the framework of cognitive sciences and neurosciences. Chapter 2 focuses on the morphology of visual, auditory, and somatosensory wave forms of electric potentials and magnetic fields of the brain, and also on the functional significance of these electrophysiological indices in relation to the basic and higher domains of cognition. Furthermore, the intracranial electro ionic origins of these scalp-recorded physiological measures are described, with indications for solving the “direct” and “inverse” problems of localizing their electromagnetic dipoles within the brain.

Chapter 3 (Cabeza and Nyberg) offers an original theoretical cross-function framework for guiding hemodynamic functional imaging of brain and cognition. This framework provides the foremost constraints to functional interpretations, particularly when assuming the so-called sharing view, that is, the view that the same brain region is recruited by different cognitive functions. In the authors’ words, these constraints “help us overcome function-chauvinism and see the ‘big picture.’ In other words, cross-function comparisons allow us to see the forest [what many functional studies have in common] through the trees [the single cognitive domains investigated by single studies].”

The second section (Chapters 4–9) systematically covers electromagnetic research on a representative sample of the neural domains of human cognition. Chapter 4 (Skrandies) illustrates how the recording of brain electrical activity in combination with knowledge on the human visual system may be employed to study visual information processing in healthy volunteers as well as in patients with selective visual deficiencies. Data are presented on different experimental questions related to human visual perception, including contrast and stereoscopic vision as well as perceptual learning.

Chapter 5 (Aine and Stephen) deals with magnetoencephalography (MEG) mapping of the ventral and dorsal streams in human visual cortex. MEG cues, proving that isoluminant, central field stimuli
preferentially excite the ventral stream structures and, alternatively, that peripheral stimuli alternating at high rates preferentially activate the dorsal stream, are systematically addressed. Furthermore, the focus is on present progress in our understanding of brain cortical areas involved in higher visual processing, such as recognition memory, as investigated by means of MEG, and the future direction of MEG research in this field is discussed.

Chapter 6 (Federmeier, Kluender, and Kutas) reviews ERP studies on language. Rather than simply presenting a collection of various processes, throughout the chapter the authors illustrate the viewpoint that the goals of electrophysiological investigations of language, as well as the goals of research exploring language processing with other tools, are to fashion an understanding of how the various processes involved in language comprehension and production are coordinated to yield the message-level apprehension we attain from reading or listening to speech. As stated in Chapter 6, “linguists, psycholinguists, and neurolinguists alike strive to understand how the brain ‘sees’ language—because, in turn, language is such an important facet of how humans ‘see’ their world.”

Chapter 7 (Wilding and Sharpe) is devoted to memory processes that constitute another very important domain of human cognition. Indeed, memory has been a subject of fascination to psychologists and other brain scientists for over a century. Recently, the study of the role of different brain areas in memory has received a boost from new techniques and changing pretheoretical orientations. The authors offer an original review of the bulk of electrophysiological studies on retrieval and encoding processes underlying episodic memory. Commendably, they do not simply share knowledge from ongoing research, but identify some acute outstanding problems in this field of investigation, indicating its likely future developments.

Chapter 8 (Luu and Tucker) is intended to close the misleading gap that exists in the “cognitive” approach to brain function and architecture between a pure cognitive functional processing of the brain and its emotional counterpart, which is of such importance in producing thinking and behavior, both in normal and emotionally disordered people. With such a goal, the authors deal specifically with mental processes involved in emotion, motivation, and reward, reviewing studies in this field from a modern neuroscience-based viewpoint.

Chapter 9 (Mitchell and Neville) addresses “neuroplasticity,” a dominant research theme in neuroscience at present. Neuroplasticity usually refers to some change in the nervous system as a function of age and/or experience. This contribution reviews studies on the effects of age and experience on the development of neurocognitive systems. A broad survey and synthesis are provided of essential data on normal brain and cognitive development, as well as on development after early deafness, blindness, or following delays in language acquisition. The authors provide insights into and ideas on the complexity and diversity of contemporary brain neuroplasticity research in humans.

The three chapters gathered in the third section are concerned with visual attention. Chapter 10 (Mangun) and Chapter 11 (Di Russo, Teder-Sälejärvi, and Hillyard) mostly address neural mechanisms of spatial attention. Chapter 10 reviews findings indicating how human spatial attention involves top-down processes that influence the gain of sensory transmission early in the visual cortex. Chapter 11 deals with steady-state cortical processing of the brain that reveals slow-rising changes in cortical reactivity to the outer world. First, the authors provide an overview of this processing mode in the visual modality. Then they present a review of experimental findings of modulations of this processing mode with selective attending of spatial
and, to a lesser extent, nonspatial features (color, shape, etc.) of visual information, in line with the previous chapter. Unlike Chapters 10 and 11, Chapter 12 (Proverbio and Zani) concentrates on feature-based and object-based selection mechanisms of the brain as investigated with ERPs. An overview is provided of studies showing the close interconnections across the anterior and posterior attention systems. In addition, a review is made of studies reporting the differential activation of the “Where” and “What” systems of the visual brain in conditions in which stimulus attributes have to be separately and/or conjointly attended. Efforts are made to demonstrate the task-related relative segregation and complex interactions of the aforementioned systems during the separate or conjoint processing of stimulus attributes.

The final two chapters comprising the fourth section are concerned with clinical and applied perspectives of ERP research. Chapter 13 (Verleger) provides an exhaustive overview of ERP studies on neuropsychological syndromes. The detailed description given of these syndromes is subdivided into three main categories. The result is a unique, up-to-date, and wide-ranging discussion of these disorders that draws on biology, genetics, neuropsychology, clinical presentation, and treatment. Chapter 14 (Näätänen, Brattico, and Tervaniemi) introduces the mismatch negativity (MMN), a component of auditory ERPs reflecting the brain’s automatic response to any discriminable change in auditory stimulation. Because the MMN can be measured even in the absence of attention and without any task requirements, it is particularly suitable for investigating several clinical populations as well as infants. Moreover, the MMN provides a unique index of the subject’s accuracy in the processing of speech and musical sounds. It can be used, for example, to unravel the neural determinants of language skills and musical expertise.

In addition to the specialist review chapters, a fifth section of this book collects together a number of appendixes containing the primers of the theoretical and methodological matters—including some simple-level mathematical material—treated in the specialist chapters. These appendixes are intended for the benefit of nonexperts (such as psychology and medical students), as well as experts in other neighboring fields. These appendixes have been included in order to clarify, in simple but detailed terms, the basics of molecular and systemic methods of investigating the nervous system (Appendix A), as well as neuropsychological clinical practice (Appendix B). They also provide the fundamentals of electromagnetic recording and data analysis and laboratory setup (Appendices C and D), and topographic and dipole mapping methods (Appendix E). Last but not least, the invasiveness and the spatial and temporal resolution of electromagnetic techniques, as compared to other techniques, are given (Appendix F).

References


