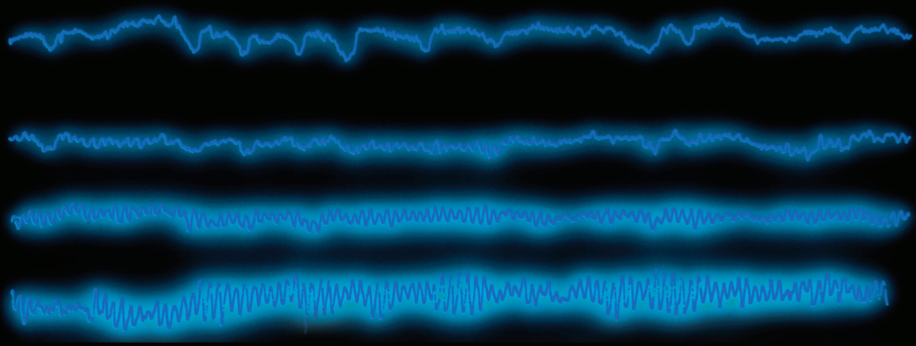
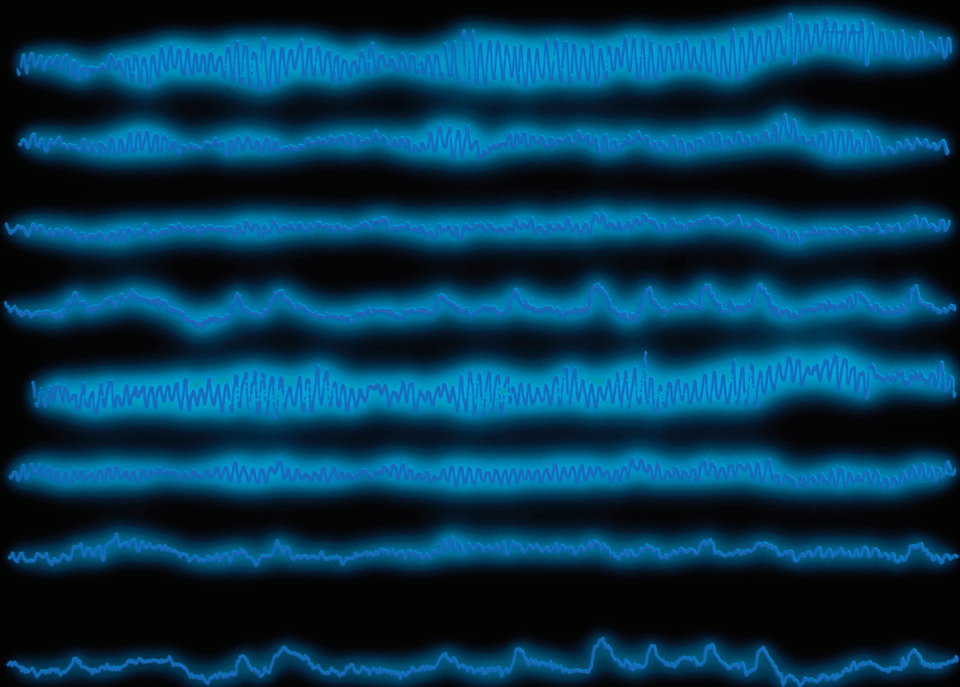


EEG METHODS FOR THE PSYCHOLOGICAL SCIENCES



CHERYL L DICKTER AND PAUL D KIEFFABER

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Editor: Michael Carmichael
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Indexer: Adam Pozner
Marketing manager: Alison Borg
Cover design: Wendy Scott
Typeset by: C&M Digitals (P) Ltd, Chennai, India
Printed in India at Replika Press Pvt Ltd

First published 2014

Library of Congress Control Number: 2013937182

British Library Cataloguing in Publication data

A catalogue record for this book is available from the British Library

ISBN 978-1-4462-4923-9
ISBN 978-1-4462-8300-4 (pbk)

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PREFACE

Neuroscience methods have become integrated with nearly all domains of psychological inquiry over the past several decades. Once thought to be an archaic technology likely to fade into the shadow of techniques like functional magnetic resonance imaging, electroencephalography (EEG) as a research tool in social and personality psychology has instead seen dramatic increases in application. This trend is likely due to both rapid advances in desktop computing, making possible highly sophisticated analysis of the information-rich EEG signals, and to the affordability and accessibility of EEG by comparison with other brain imaging technologies. Our foremost goal in authoring this book was to provide an introduction to the technology and techniques of EEG in the context of social neuroscience research that would appeal to both individuals wishing to broaden their research aims to include EEG measures and to individuals already using EEG, but wishing to develop a better understanding of the technology and methods. This book provides an introduction to the theory, technology, and techniques of EEG data analysis with a focus on providing practical skills required to engage this popular technology.

Beginning with a brief history of EEG and an important background in the neural basis and electric principles involved in recording EEG, readers will be introduced to many practical considerations of EEG recordings and guidelines for the configuration of an EEG laboratory including hardware and software considerations. This book will also provide readers with practical skills required to perform conventional analyses with EEG data in the context of contemporary social neuroscience research. Analyses covered include event-related potentials, spectral asymmetry, and time-frequency analysis. For each type of analysis, we provide a conceptual background, a review of the application of that method to contemporary research within the fields of social and personality psychology, and a guided analysis including step-by-step instruction for performing the analysis in EEGlab. Sample datasets are provided for each of the analyses on a companion website (www.sagepub.co.uk/dickter). Finally, we end with a review of several additional research areas within social and personality psychology to provide a demonstration of how EEG measures have been used to answer important research questions, and provide suggestions for future directions for using EEG methods to study additional social and personality psychological issues.

This book will likely be particularly appealing to new investigators setting up an EEG laboratory, especially those in the social and personality psychology fields. In addition, researchers who already use EEG techniques in their laboratory will find this book useful as an instruction manual to help new research assistants with background and instructional information. This book will also serve well as a textbook in a graduate or an upper-division undergraduate course in any area of behavioral neuroscience such as social neuroscience or cognitive neuroscience, as it provides a solid introduction to EEG and its techniques while also supplying datasets with step-by-step instructions in which students will be able to obtain practical experience with EEG data analysis using free, easily accessible software. Finally, this book is a good reference text for graduate students, post-doctoral students, and faculty studying social and personality psychology who currently employ EEG techniques.

1

INTRODUCTION TO SOCIAL NEUROSCIENCE

Social and personality psychologists have historically excelled as behavioral scientists, tackling difficult questions about the complexities of human social behavior. The tools of social and personality psychologists have traditionally been questionnaires, behavioral paradigms, and observational skills. Within the last two decades, however, research in social and personality psychology has become increasingly imbued with neuroscience methods. The field of social neuroscience has emerged as a popular subfield in its own right, including specialized societies, journals, conferences, and textbooks. Indeed, there has been an explosion of interest in the field over the past few decades as neuroscience methods have become increasingly available and accessible to social and personality psychologists trying to address questions about the biological underpinnings of human social behavior.

WHAT IS SOCIAL NEUROSCIENCE?

The term social neuroscience was first used by John Cacioppo and Gary Berntson in a 1992 publication in *American Psychologist*, in which they wrote about the place of social psychological research and theory in the 'decade of the brain'. In fact, because of this landmark publication and years of significant contributions to the literature, John Cacioppo and Gary Berntson are often regarded as the fathers of social neuroscience. Put simply, the term 'social neuroscience' refers to a field that is broadly defined by its aim of developing an understanding about how information relevant to our social interactions is processed by the brain. Social neuroscience is a highly interdisciplinary field, attracting anthropologists, economists, neuroscientists, philosophers, psychiatrists, psychologists, and sociologists, each of whom bring a unique perspective to bear on questions about human social information processing. At the heart of the field is a dedication to understanding how biological systems affect social processes and behavior. More specifically, the goal of the field is to understand the cellular, genetic, hormonal, and neural mechanisms that determine the nature of social behavior and the cognitive processes that are engaged in the course of social interaction.

HISTORY OF SOCIAL NEUROSCIENCE

Interest in understanding how the brain and social behavior are related began long before social or personality psychology were defined as fields. Indeed, Erasistratos, a Greek doctor in the 3rd century BC, in trying to find the cause of a boy's erratic heart rate, measured the boy's heart beat in the presence of his attractive stepmother. Erasistratos concluded that infatuation, not an illness, was causing the variability in heart rate. Many centuries later, individuals interested in identifying the strength of personality traits such as conscientiousness and skills such as language used phrenology diagrams to locate bumps on the skull that supposedly corresponded to such traits and skills. Although work by phrenologists like Franz Joseph Gall has long been discredited (though phrenology services were ruled to be subject to a 6% sales tax in Michigan as recently as December 2007), the idea behind phrenology was not a bad one. That is, although specific functions of the brain are not related to the location of bumps on the skull, the notion that they may be localized in the brain has been a major impetus for cognitive neuroscience research over the past few decades.

The most notable early observation of functional specialization in the brain comes from the story of Phineas Gage and his fateful accident in 1848. While working with explosives and an iron tamping bar to prepare a road for an impending railroad track, the blasting powder exploded, sending the 3-foot iron rod into the side of Gage's face and through his brain. Though the rod completely passed through Gage's brain, he survived the incident, but not without changes to his personality and social behavior. That Gage's social behavior became intolerable to those who knew him but that his other cognitive abilities such as speech remained intact provided important evidence to support the idea of functional specialization in the brain. A great deal of evidence for this kind of functional specialization has accumulated over the last several decades, but there is also a general consensus among neuroscientists that many different areas of the brain likely work together to make complex behavior and mental processes possible.

As mentioned above, psychologists have been successful in using behavioral and self-report measures to assess social phenomena. At the same time, researchers have been aware of the drawbacks of relying on such methods to investigate certain social processes that cannot be assessed by behavioral measures, and have tried a variety of methods to evaluate these underlying processes. For example, researchers studying racial prejudice against Blacks in the United States in the mid-20th century began to worry that White participants in their studies were not answering questions honestly regarding their attitudes about Blacks. That is, they worried that self-report methods were susceptible to self-presentation biases that arose from an increase in egalitarian racial attitudes and a general stigma against those with racist beliefs. To examine more subtle measures of racial bias, Rankin and Campbell (1955) conspicuously measured galvanic skin response – a measure of anxiety – and found that White participants had greater skin conductance when interacting with a Black compared to a White experimenter. To more directly examine the effects of social desirability in the measurement of racial attitudes, Sigall and Page (1971) used a bogus pipeline procedure in which participants who were told that the electrodes on their arms were connected to a (fake) lie detector machine admitted to more racially biased attitudes than participants who simply provided their racial attitudes. The findings from this line of research suggest that relying on self-reported measures of racial prejudice, which have demonstrated steady declines in negative racial attitudes over the past 70 years (e.g., Devine & Elliot, 1995), may not accurately portray the true state of affairs in Whites' racial attitudes. For psychologists interested in studying phenomena such as prejudice, a neuroscience measure that permits the characterization of processes that are unknown to participants or considered undesirable may therefore be appealing. The field of racial prejudice is just one area in which researchers may desire to assess phenomena that are subject to social biases; we will describe several other areas of research throughout this book that have and can benefit from the use of neuroscience measures.

The development of new and exciting measurement techniques has played a role in the use of physiological measures throughout the years. One of the first tools developed to measure a physiological event was the capillary electrometer, which was developed in the 1870s and used mercury to measure electrical activity with electrodes. It was used by Waller in 1887 to record the electrical activity of the human heart. Social psychologists today use heart rate to study threat and challenge responses (e.g., Blascovich & Tomaka, 1996). Human electroencephalography (EEG) was popularized in 1929 by Berger to measure electrical activity in the brain using electrodes at the front and the back of the head. Through the years, social and personality psychologists have used developing physiological techniques to better understand social processes such as using electrodes placed on the face to measure muscle movements in the face to study emotional processes (e.g., Cacioppo & Petty, 1981). Modern social psychologists use EEG to examine a host of social processes, such as person perception (see Chapter 5), emotional responses (see Chapter 6), and empathy (see Chapter 7).

In the 1970s and 1980s, the development of new brain imaging methods like computerized axial tomography (CAT) and positron emission tomography (PET) permitted some of the first structural and functional imaging of the brain with good spatial resolution in three dimensions. Only as recently as the early 1990s was functional magnetic resonance imaging (fMRI) introduced to the neuroscience community. Since its introduction, fMRI has been the most popular method for brain imaging due to the fact that it is relatively non-invasive. The explosion of research using fMRI over the past several decades has contributed significantly to the rapid development of our understanding about the localization of function in the brain and has arguably helped shape consensus regarding the critical role of neuroscience in social and personality psychology.

This consensus has been expressed, in part, by the promotion of neuroscience techniques. For example, both the *Journal of Personality and Social Psychology* – one of the leading journals in the field of personality and social psychology – and *Neuropsychologia* included special sections on social neuroscience in 2003. The journal *NeuroImage* followed suit in the next year. In March of 2006 the first journal dedicated to the field, *Social Neuroscience*, was launched, followed quickly by *Social Cognitive and Affective Neuroscience* in June of the same year. In 2010 *Social Cognition* emphasized publications describing how social psychological theory has been advanced by findings in neuroscience, including articles by a number of pioneers in the field of social neuroscience, including David Amodio, Bruce Bartholow, John Cacioppo, William Cunningham, Tiffany Ito, and Jeffrey Sherman. Today social neuroscience research permeates all of the leading journals in the fields of social and personality psychology as well as many general psychological journals.

WHY ADD NEUROSCIENCE METHODS TO SOCIAL AND PERSONALITY PSYCHOLOGY?

Two common fallacies regarding social neuroscience research are (1) that the aim of social neuroscience is to localize (i.e., 'map') psychological processes regarding social and personality variables to specific areas in the brain and (2) that investigators using neuroscience methods are simply rehashing earlier research using behavioral and self-report methods. Although each of these research approaches has its time and place, applying neuroscience techniques to social and personality research questions can add much more to the field than these limited directions.

One way that the use of neuroscience methods can aid in studying substantive questions related to social and personality psychology is by providing unobtrusive measures of an individual's response to a stimulus that he/she may be unable or unwilling to report (for a review, see Guglielmi, 1999). Although researchers have begun using implicit measures such as reaction time paradigms to examine less explicit attitudes or biases, these measures also have their drawbacks. For example, although often discussed as reflecting cognitive processes, reaction time data actually reflect the outcome of a cognitive operation rather than the operation itself. That is, reaction time data confound concept activation with response output processes (Ito, Thompson, & Cacioppo, 2004), and thus cannot indicate the level at which the cognitive process occurs. It is often desirable and perhaps necessary to expand existing behavioral research on a topic to a methodology that allows the examination of multiple components of the cognitive process. Neuroscience measures can provide a multifaceted picture of the neural activity associated with a given cognitive process.

Another benefit that neuroscience measures can offer social and personality psychologists is the identification of the time-course of specific cognitive processing that occurs as a result of social events. That is, the use of neuroscience methods such as EEG allows for the precise measurement of rapid changes in neural activity related to observable stimuli, making it possible to assess the timing of task-relevant cognitive operations and to separate component processes in the stream of information processing (Stern, Ray, & Quigley, 2001). Measures that are temporally accurate are important in studying many phenomena that social and personality psychologists are interested in studying. For example, researchers have used event-related potentials to investigate when the processing of facial expressions occurs. EEG studies demonstrated that faces depicting emotions affect neural processing between 120 and 180 ms following exposure to human faces (see Eimer & Holmes, 2007). These findings have helped inform models of emotional processing and elucidate the time-course of this processing.

Utilizing neuroscience methods can also allow for an examination of the effects of social events and stimuli on neural processing, making it possible to understand how social phenomena affect the brain. Eisenberger, Lieberman, and Williams (2003), for example, used fMRI data to demonstrate that the processing of social pain caused by social rejection is processed in similar brain regions that are activated during the experience of physical pain. Using EEG measures, Crowley, Wu, McCarty, David, Bailey, and Mayes (2009) also demonstrated that the perceived distress experienced by participants following social rejection was correlated with neural responses in the late positive potential after this event. Studies such as these can help provide insight into the neural basis of social cognitive perceptual processes, and help inform theory in social and personality psychology. Some of the major research areas that have been explored with the use of neuroscience methods are described in more detail in later chapters of this book.

There are several imaging technologies that social and personality psychologists use to investigate the neural processes involved in social behavior. The strengths and weaknesses of each measure (e.g., fMRI, PET, EEG) are well documented and thus will not be reviewed extensively here. Social and personality psychologists trying to decide which method is best for them should weigh the benefits and drawbacks of each method for their particular research question in deciding which technology to use. Generally speaking, when trying to identify where in the brain neural activity is occurring resulting from a specific behavior or trait, imaging technologies such as fMRI are better than EEG because with EEG measurement, the minuscule bioelectric voltages produced by post-synaptic potentials are both attenuated and dispersed by the obstacles through which they pass, making it difficult to pinpoint from where they originate. On the other hand, if your goal is to examine the time-course of an unfolding cognitive event or behavior, using EEG would be the better option because of its ability to measure voltage dynamics over time. For example, it is common to record EEG at a rate of 1000 samples/second, permitting a unique characterization of the scalp-recorded voltages every millisecond. This distinguishes EEG from other imaging methods like PET and fMRI that provide temporal resolution on the order of seconds. Importantly, this means that EEG can be effectively used to characterize sensory, perceptual, and cognitive processes as they unfold. Another, more practical advantage of EEG over other imaging methods is the cost. While technologies such as PET and fMRI require millions of dollars in equipment and personnel, an EEG laboratory can be established for well under $50,000 and is generally associated with very low maintenance and operational costs. Because the focus of this book is on EEG, below we briefly review the history and the basic principles of this methodology.

ORIGINS OF ELECTROENCEPHALOGRAPHY

It was just over a century ago that biologists discovered the bioelectric nature of nerve impulses. In 1870, Gustav Fritsch and Eduard Hitzig published a landmark paper entitled 'On the Electrical Excitability of the Cerebrum' (Fritsch & Hitzig, 1870), demonstrating that electrical stimulation of the cerebral cortex could produce limb movements contralateral to the hemisphere of stimulation. In addition to being the first clear experimental demonstration of the involvement of the cerebral cortex in motor function, their research provided the first evidence that the cortex was electrically excitable. Shortly thereafter, Richard Caton (1875) described the first observations of electrical impulses recorded directly from the surface of the cerebral cortex in living, animal subjects. A review of some of these early experiments can be found in Brazier (1963).

In 1929, a German psychiatrist named Hans Berger published his work demonstrating the first recordings of the human electroencephalogram (EEG), opening the door to a new era of neuroscience. At a time when the field was consumed by questions about morphology and cerebral localization, Berger's research prompted a shift to questions about the dynamics of neural activity as reflected in the electrical patterns of the brain. In addition to coining the term 'electroencephalogram', Berger is best known for his observation of rhythmic oscillations in the range of 10–30 Hz, which he likened to the 'rhythm A' component of oscillations that had been previously described in recordings of peripheral action currents in the elbow joint (Hoffman & Strughold, 1927). Berger was also the first to demonstrate that this oscillatory activity, later known as the 'Berger rhythm' or Alpha band (8–13 Hz), was related to the mental state of the individual. For example, he described the so-called alpha blockade or suppression of alpha rhythms that occurs when an individual opens his/her eyes.

As remarkable as the impact of Berger's early research is the primitive nature of the technology with which it was carried out. At the time, electrophysiological activity, including EEG, was recorded by photographing the deflections of the light beam of a galvanometer. Recording these deflections at regular intervals provided a means by which to reconstruct an EEG trace. Galvanometers were soon replaced by cathode-ray oscilloscopes, which displayed voltage as a function of time such that a single photographic record now contained a brief but continuous series of voltages. In the 1940s, two technological leaps for EEG were the development of 'pen writers', which made possible the recording of an immediate and permanent record of the continuous voltage dynamics without the need for photography, and the differential amplifier – a technology still in use today.

Developing alongside these technological advances was recognition of EEG's vast potential as a non-invasive measure of brain activity that could be used to address questions about the nature of sensory, cognitive, and motor functions. For example, Pauline Davis (Davis, 1939) provided one of the first demonstrations of a sensory-evoked potential in the scalp-recorded EEG, presenting participants with acoustic tones while recording from a single EEG channel. Davis observed what she referred to as an 'on-effect', a polyphasic wave immediately subsequent to the onset of an acoustic stimulus. Davis' early research also revealed that 'on-effects' could be observed prior to the onset of the acoustic stimuli after a number of repetitions in a predictable sequence of stimuli. These 'anticipatory' effects may thus constitute one of the first examples of an evoked-potential measure of endogenous cognitive brain activity.

EEG Basics

EEG is a measure of electrical potentials thought to be produced by post-synaptic potentials in the brain. EEG is recorded from sensors (electrodes) placed on the scalp. There are many ways that EEG recordings can be used to address research questions in psychology. One of the most common methods is known as the event-related potential (ERP) technique. The essence of the ERP technique (explained in more detail in Chapter 5) is that brief segments of ongoing brain activity (i.e., EEG) are measured repeatedly immediately following the presentation of some experimentally relevant stimuli (e.g., images, tones, etc.). Because the EEG segments are all taken with respect to the onset of a stimulus, averaging the segments together yields a measure of the EEG voltages that are consistently related to the sensory, perceptual, and decision-making processes that followed the stimulus. Although sometimes used interchangeably, the terms EEG and ERP are used to denote ongoing and event-related brain activity respectively. While the ERP technique is generally concerned with the amplitude of voltages at a specific point in time, other approaches to EEG analysis, including quantitative EEG (qEEG) and event-related oscillation (ERO) techniques, aim to characterize the voltage dynamics over time. The term qEEG is often used to describe the measurement of oscillatory activity in ongoing EEG and, similar to ERP, ERO describes measures of the average oscillatory activity time-locked to experimentally relevant events. EEG and its derivatives (e.g., ERPs, qEEG, and EROs) have been used to address questions in many research contexts relevant to social and personality psychology, several of which will be covered in subsequent chapters of this book.

CONCLUSION

As you can see, social and personality psychologists stand to gain many benefits from utilizing neuroscience measures in their research. Although there are several different neuroscience measures, each with its own strengths and weaknesses, the focus of this book is to describe the use of EEG data in investigating research questions that are typical of social and personality research.

REFERENCES

Berger, H. (1929). Über das Elektrenkephalogramm des Menschen. *European Archives of Psychiatry and Clinical Neuroscience*, *87*(1), 527–570. doi:10.1007/BF01797193.

Blascovich, J., & Tomaka, J. (1996). The biopsychosocial model of arousal regulation. *Advances in Experimental Social Psychology*, *28*, 1–51.

Brazier, M. A. B. (1963). The history of the electrical activity of the brain as a method for localizing sensory function. *Medical History*, *7*(3), 199–211.

Cacioppo, J. T., & Petty, R. E. (1981). Electromyograms as measures of extent and affectivity of information processing. *American Psychologist*, *36*(5), 441–456.

Caton, R. (1875). The electric currents of the brain. *British Medical Journal*, *2*(1), 278.

Crowley, M. J., Wu, J., McCarty, E. R., David, D. H., Bailey, C. A., & Mayes, L. C. (2009). Exclusion and micro-rejection: Event-related potential response predicts mitigated distress. *NeuroReport*, *20*(17), 1518–1522.

Davis, P. A. (1939). Effects of acoustic stimuli on the waking human brain. *Journal of Neurophysiology*, *2*(6), 494 –499.

Devine, P. G., & Elliot, A. J. (1995). Are racial stereotypes really fading? The Princeton trilogy revisited. *Personality and Social Psychology Bulletin*, *21*, 1139–1150.

Eimer, M., & Holmes, A. (2007). Event-related brain potential correlates of emotional face processing. *Neuropsychologia*, *45*(1), 15–31.

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, *302*(5643), 290–292.

Fritsch, G. T., & Hitzig, E. (1870). On the electrical excitability of the cerebrum (1870). In G. von Bonin, *Some papers on the cerebral cortex* (pp. 73–96). Springfield, IL: Charles C. Thomas.

Guglielmi, R. S. (1999). Psychophysiological assessment of prejudice: Past research, current status, and future directions. *Personality and Social Psychology Review*, *3*(2), 123–157.

Hoffman, P., & Strughold, H. (1927). Ein Beitrag zur Frage der Oszillationsfrequenz der willkurlichen Innervation. *Zsch. Biol.*, *85*, 599–603.

Ito, T. A., Thompson, E., & Cacioppo, J. T. (2004). Tracking the timecourse of social perception: The effects of racial cues on event-related brain potentials. *Personality and Social Psychology Bulletin*, *30*(10), 1267–1280.

Rankin, R. E., & Campbell, D. T. (1955). Galvanic skin response to Negro and white experimenters. *Journal of Abnormal and Social Psychology*, *51*(1), 30–33.

Sigall, H., & Page, R. (1971). Current stereotypes: A little fading, a little faking. *Journal of Personality and Social Psychology*, *18*(2), 247.

Stern, R. M., Ray, W. J., & Quigley, K. S. (2001). *Psychophysiological recording*. Oxford: Oxford University Press.

2

FROM CORTEX TO COMPUTER: THE PRINCIPLES OF RECORDING EEG

THE NEURAL BASIS OF EEG

Electrical Potentials in the Brain

When scalp-recorded EEG was first described, there was considerable skepticism in the scientific community regarding its validity. Many simply refused to believe that the small electrical potentials generated by neural activity could be recorded at such great (relatively speaking) distances and through barriers such as the meningeal layers, skull, and scalp. Today the physics and physiology that give rise to scalp-recorded EEG are more widely accepted and better understood.

The first step toward understanding the neural origins of EEG is to clarify the difference between electrical current and electrical potential. Electrical current is the *flow* of electric charge, meaning that current (typically measured in amperes) is a measure of the amount of charge moving across a surface in a given time. Electrical currents can be generated in a number of ways. For example, the electrical current that powered your coffeemaker this morning can be attributed to the flow of electrons in the conductive wiring of your home. The electrical currents used by your brain as you read this book, however, are caused by the movement of charged atoms and molecules called ions.

Electrical potential is a form of potential energy and can be thought of as the potential for current to flow. Electrical potential is usually measured in volts (V) and is directly related to the *difference* in charge between two points. One example of how electrical potentials are generated in the brain is the resting membrane potential of neurons. The resting membrane potential is a direct result of the unequal concentration of ions between the inside and outside of the cell, resulting in a difference in charge across those two points. For example, the combination of high concentrations of sodium (Na^+) and chloride (CL^-) ions outside the cell and high concentrations of potassium (K^+) and other anions (negatively charged particles) inside leads to a net difference of charge across the cell membrane measuring approximately 75 millivolts (mV) or 0.075 V. While the resting membrane potential of neurons serves as a good