An Introduction to the Event-Related Potential Technique

Steven J. Luck

The MIT Press

From The MIT Press
MITCogNet

MIT Press books may be purchased at special quantity discounts for business or sales promotional use. For information, please email special_sales@mitpress.mit.edu or write to Special Sales Department, The MIT Press, 55 Hayward Street, Cambridge, MA 02142.

This book was set in Melior and Helvetica on 3B2 by Asco Typesetters, Hong Kong.
Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Luck, Stephen J.
An introduction to the event-related potential technique / Stephen J. Luck.
p. cm. — (Cognitive neuroscience)
Includes bibliographical references and index.
ISBN 0-262-12277-4 (alk. paper) — ISBN 0-262-62196-7 (pbk. : alk. paper)
1. Evoked potentials (Electrophysiology) I. Title. II. Series.
QP376.5.L83 2005
616.8′047547—dc22 2005042810

10 9 8 7 6 5 4 3 2 1

Notes

Chapter 1

1. The concept of noise is fundamental to any data recording technique, but this term is unfamiliar to many beginners. The term noise simply refers to any source of variation in the data that is unrelated to thing you are trying to record (which is termed the signal). Keep in mind that one researcher's noise may be another researcher's signal. For example, electrical activity generated by the heart (the EKG) may sometimes contaminate ERP recordings, and ERP researchers treat it as noise. To a cardiologist, however, the EKG is a signal, not noise. Noise may be random and unpredictable or it may be nonrandom and predictable. As long as it causes the recorded data to differ from the signal, however, it's still noise.
2. This assumes that the recording electrode is at a sufficient distance from the activated cortex, which will always be true in scalp recordings.
3. To be more precise, the high resistance of the skull causes a small amount of volume-conducted electrical current to flow perpendicular to the skull, and this perpendicular electrical activity is accompanied by a small magnetic field. In this manner, the high resistance of the skull may indirectly cause a small amount of distortion in magnetic fields. However, this is a relatively minor effect compared to the distortion of the electrical activity.
4. You may wonder why all this research has not led to a consensus about the psychological or neurophysiological processes reflected by the P3 wave. I suspect there are two main contributing factors. One factor is that the P3 wave is present, at least to some extent, in almost every condition of almost every experiment. Because the P3 wave is so ubiquitous, it's hard to narrow down the general cognitive domain associated with it. A second factor is that it's difficult to isolate the P3 wave from other overlapping ERP components. It seems very likely that many different positive-going ERP components are active over the broad time range and scalp distribution of the P3 wave, each reflecting a different cognitive process. Because we don't have a good means of isolating these different P3 subcomponents, it's very hard to associate this amalgam of P3 activity with a specific psychological process.

Chapter 2

1. An abbreviated version of this chapter has been published previously (Luck, 2005).
2. This definition has a bit of wiggle room in the definition of a neuroanatomical module. You could use Brodmann's areas to define the modules, but you could also use the finer

divisions of modern neuroanatomy (Felleman & Van Essen, 1991) or coarser divisions such as the dorsal stream or the ventral stream.

3. The results in the figure are summarized in a bar graph, and ERP waveforms are not shown. Because it is difficult to measure the latent components from the observed ERP waveforms, it is important to show the ERP waveforms and not just provide measurements of component amplitudes and latencies (see the first section of chapter 6 for more details). However, at the time of this experiment, computers were quite primitive, and computing something as straightforward as the average waveform across subjects was not terribly common. The original journal article describing this experiment did not contain any grand averages, and instead showed examples of the waveforms from a few subjects. The individual-subject waveforms were just too ugly to show here.

Chapter 4

1. Technically speaking, covariance is used rather than correlation, which means that the matching EEG segment must be large as well as being similar in shape to the template.
2. The data shown in this figure were actually computed using a somewhat different technique, which used *wavelet* transforms instead of Fourier transforms. However, the general principle is the same.
3. This framework was originally developed by Jon Hansen at UCSD. He also developed several of the specific artifact rejection algorithms described later in this chapter.
4. Although a chinrest seems like it ought to reduce muscle tension, my lab has found that they actually increase muscle noise. But it may be possible to set up a chinrest in a way that reduces rather than increases muscle noise.

Chapter 5

1. In this context, power is simply amplitude squared.
2. The discussion of filtering presented here applies to transient waveforms from virtually any source, including event-related magnetic fields. However, these principles are relevant primarily for the transient responses that are elicited by discrete stimuli and not to the steady-state responses that are elicited by fast, repetitive streams of stimuli presented at a constant rate.
3. Plots of phase are often difficult to understand, and the Fourier transforms shown in this chapter will show the amplitude information without the corresponding phase information.
4. The process is actually somewhat more complex than this due to the fact that both the ERP waveform and the impulse response function are finite in duration and digitally sampled.
5. A 12.5-Hz half-amplitude cutoff is much lower than the cutoff frequencies typically employed for attenuating high frequency noise. However, filter-induced distortions are more apparent in this context with lower cutoffs, and a 12.5 Hz cutoff was therefore chosen to make these distortions clearer.
6. Artifact rejection is a nonlinear process, and filtering before artifact rejection and averaging will not yield the same result as filtering after artifact rejection and averaging

(although the result will be very similar if the specific filter used doesn't influence the artifact rejection process very much).

Chapter 6

1. Occasionally, the waveform will not have a local peak within the measurement time range that exceeds the average of the three to five points on either side. This occurs when the waveform gradually increases or decreases monotonically through the entire measurement window. In this case, you can just use the simple peak amplitude or the amplitude at the midpoint of the latency range. These aren't perfect solutions, but they're better than always using the simple peak amplitude.
2. The Greenhouse-Geisser adjustment tends to be overly conservative, especially at moderate to high levels of non-sphericity. Many statistical packages also include the Hyun-Feldt adjustment, which is probably somewhat more reasonable and may be useful when low statistical power is a problem.

Chapter 7

1. A physicist with no knowledge of BESA or ERPs was also tested, but his localizations were both unrepresentative and far from correct, so I will not include his results in the discussion here.
2. If two dipoles are assumed to be mirror-symmetrical, only seven parameters are required to represent the two dipoles, rather than the twelve that would be otherwise required. That is, six parameters are used to represent one of the two dipoles, as usual, but the other dipole requires only one additional parameter, representing its magnitude (which is the only parameter that may differ from the other dipole). Moreover, because magnitude is treated differently from the other parameters in BESA, the assumption of mirror symmetry essentially removes all of the major parameters from one of the two dipoles. Thus, this ten-dipole simulation is equivalent to an unconstrained seven-dipole simulation.

Chapter 8

1. Because of the integration time of the retina, reducing the duration of a stimulus from 100 ms to some shorter duration leads to the perception of a dimmer stimulus rather than a shorter stimulus (this is *Bloch's law*). In addition, stimuli of approximately 100 ms or less do not elicit separate onset and offset ERP responses, but longer stimuli do. Consequently, I would recommend a duration of 100 ms for experiments with brief stimuli, and I would recommend a duration that exceeds the interesting portion of the ERP waveform for experiments with long stimuli. This way you will not have offset responses in the middle of your waveform.