

An Introduction to the Event-Related Potential Technique

Steven J. Luck



The MIT Press

From The MIT Press



MITCogNet

© 2005 Massachusetts Institute of Technology

All rights reserved. No part of this book may be reproduced in any form by any electronic or mechanical means (including photocopying, recording, or information storage and retrieval) without permission in writing from the publisher.

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

References

- Adrian, E. D., & Matthews, B. H. C. (1934). The Berger rhythm: Potential changes from the occipital lobes in man. *Brain*, 57, 355–385.
- Aine, C., Huang, M., Stephen, J., & Christner, R. (2000). Multistart algorithms for MEG empirical data analysis reliably characterize locations and time courses of multiple sources. *Neuroimage*, 12, 159–172.
- Alcaini, M., Giard, M. H., Thevenet, M., & Pernier, J. (1994). Two separate frontal components in the N1 wave of the human auditory evoked response. *Psychophysiology*, 31, 611–615.
- American Encephalographic Society. (1994). Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, 11, 111–113.
- Baillet, S., Mosher, J. C., Leahy, R. M., & Shattuck, D. W. (1999). BrainStorm: A matlab toolbox for the processing of MEG and EEG signals. *Neuroimage*, 9, 246.
- Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*, 8, 551–565.
- Bentin, S., & Carmel, D. (2002). Accounts for the N170 face-effect: A reply to Rossion, Curran, & Gauthier. *Cognition*, 85, 197–202.
- Berg, P., & Scherg, M. (1991a). Dipole modelling of eye activity and its application to the removal of eye artefacts from the EEG and MEG. *Clinical Physics & Physiological Measurement*, 12 Suppl A, 49–54.
- Berg, P., & Scherg, M. (1991b). Dipole models of eye movements and blinks. *Electroencephalography & Clinical Neurophysiology*, 79, 36–44.
- Berg, P., & Scherg, M. (1994). A multiple source approach to the correction of eye artifacts. *Electroencephalography & Clinical Neurophysiology*, 90, 229–241.
- Berger, H. (1929). Ueber das Elektrenkephalogramm des Menschen. *Archives fur Psychiatrie Nervenkrankheiten*, 87, 527–570.
- Bertrand, O., Perrin, F., & Pernier, J. (1991). Evidence for a tonotopic organization of the auditory cortex with auditory evoked potentials. *Acta Otolaryngologica*, 491, 116–123.
- Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, 10, 433–436.
- Brainard, D. H., Pelli, D. G., & Robson, T. (2002). Display characterization. In J. Hornak (Ed.), *Encyclopedia of Imagine Science and Technology* (pp. 172–188). New York: Wiley.
- Brandeis, D., Naylor, H., Halliday, R., Callaway, E., & Yano, L. (1992). Scopolamine effects on visual information processing, attention, and event-related potential map latencies. *Psychophysiology*, 29, 315–336.
- Broadbent, D. E. (1958). *Perception and Communication*. New York: Pergamon.
- Carmel, D., & Bentin, S. (2002). Domain specificity versus expertise: Factors influencing distinct processing of faces. *Cognition*, 83, 1–29.

- Chelazzi, L., Duncan, J., Miller, E. K., & Desimone, R. (1998). Responses of neurons in inferior temporal cortex during memory-guided visual search. *Journal of Neurophysiology*, 80, 2918–2940.
- Chelazzi, L., Miller, E. K., Duncan, J., & Desimone, R. (1993). A neural basis for visual search in inferior temporal cortex. *Nature*, 363, 345–347.
- Chelazzi, L., Miller, E. K., Duncan, J., & Desimone, R. (2001). Responses of neurons in macaque area V4 during memory-guided visual search. *Cerebral Cortex*, 11, 761–772.
- Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 109–127.
- Clark, V. P., Fan, S., & Hillyard, S. A. (1995). Identification of early visually evoked potential generators by retinotopic and topographic analyses. *Human Brain Mapping*, 2, 170–187.
- Cohen, D., & Cuffin, B. N. (1991). EEG versus MEG localization accuracy: Theory and experiment. *Brain Topography*, 4, 95–103.
- Coles, M. G. H. (1989). Modern mind-brain reading: Psychophysiology, physiology and cognition. *Psychophysiology*, 26, 251–269.
- Coles, M. G. H., Gratton, G., Kramer, A. F., & Miller, G. A. (1986). Principles of signal acquisition and analysis. In M. G. H. Coles, E. Donchin & S. W. Porges (Eds.), *Psychophysiology: Systems, Processes, and Applications* (pp. 183–221). New York: Guilford Press.
- Coles, M. G. H., & Rugg, M. D. (1995). Event-related potentials: An introduction. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of Mind* (pp. 1–26). New York: Oxford University Press.
- Coles, M. G. H., Smid, H., Scheffers, M. K., & Otten, L. J. (1995). Mental chronometry and the study of human information processing. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of Mind: Event-Related Brain Potentials and Cognition* (pp. 86–131). Oxford: Oxford University Press.
- Courchesne, E., Hillyard, S. A., & Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, 39, 131–142.
- Cuffin, B. N., Cohen, D., Yunokuchi, K., Maniewski, R., Purcell, C., Cosgrove, G. R., Ives, J., Kennedy, J., & Schomer, D. (1991). Test of EEG localization accuracy using implanted sources in the human brain. *Annals of Neurology*, 29, 132–138.
- Dale, A. M., & Sereno, M. I. (1993). Improved localization of cortical activity by combining EEG and MEG with MRI cortical surface reconstruction: A linear approach. *Journal of Cognitive Neuroscience*, 5, 162–176.
- Davis, H., Davis, P. A., Loomis, A. L., Harvey, E. N., & Hobart, G. (1939). Electrical reactions of the human brain to auditory stimulation during sleep. *Journal of Neurophysiology*, 2, 500–514.
- Davis, P. A. (1939). Effects of acoustic stimuli on the waking human brain. *Journal of Neurophysiology*, 2, 494–499.
- de Jong, R., Coles, M. G., Logan, G. D., & Gratton, G. (1990). In search of the point of no return: The control of response processes. *Journal of Experimental Psychology: Human Perception & Performance*, 16, 164–182.
- Dehaene, S., Naccache, L., Le Clec, H. G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P. F., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature*, 395, 597–600.

- Dehaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science*, 5, 303–305.
- Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134, 9–21.
- Desmedt, J. E., Chalklin, V., & Tomberg, C. (1990). Emulation of somatosensory evoked potential (SEP) components with the 3-shell head model and the problem of “ghost potential fields” when using an average reference in brain mapping. *Electroencephalography & Clinical Neurophysiology*, 77, 243–258.
- Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review*, 70, 80–90.
- Di Russo, F., Martinez, A., Sereno, M. I., Pitzalis, S., & Hillyard, S. A. (2002). Cortical sources of the early components of the visual evoked potential. *Human Brain Mapping*, 15, 95–111.
- Di Russo, F., Teder-Sälejärvi, W. A., & Hillyard, S. A. (2003). Steady-state VEP and attentional visual processing. In A. Zani & A. M. Proverbio (Eds.), *The Cognitive Electrophysiology of Mind and Brain* (pp. 259–274). San Diego: Academic Press.
- Dien, J. (1998). Issues in the application of the average reference: Review, critiques, and recommendations. *Behavior Research Methods, Instruments, & Computers*, 30, 34–43.
- Donchin, E. (1981). Surprise! . . . Surprise? *Psychophysiology*, 18, 493–513.
- Donchin, E. (1979). Event-related brain potentials: A tool in the study of human information processing. In H. Begleiter (Ed.), *Evoked Brain Potentials and Behavior* (Vol. 2, pp. 13–88). New York: Plenum Press.
- Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral Brain Science*, 11, 357–374.
- Donchin, E., & Heffley, E. F., III. (1978). Multivariate analysis of event-related potential data: A tutorial review. In D. Otto (Ed.), *Multidisciplinary Perspectives in Event-Related Brain Potential Research* (pp. 555–572). Washington, D.C.: U.S. Government Printing Office.
- Duncan-Johnson, C., & Donchin, E. (1979). The time constant in P300 recording. *Psychophysiology*, 16, 53–55.
- Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology*, 14, 456–467.
- Duncan-Johnson, C. C., & Kopell, B. S. (1981). The Stroop effect: Brain potentials localize the source of interference. *Science*, 214, 938–940.
- Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, 99, 225–234.
- Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception and Psychophysics*, 25, 249–263.
- Falkenstein, M., Hohnsbein, J., Joormann, J., & Blanke, L. (1990). Effects of errors in choice reaction tasks on the ERP under focused and divided attention. In C. H. M. Brunia, A. W. K. Gaillard & A. Kok (Eds.), *Psychophysiological Brain Research* (pp. 192–195). Amsterdam: Elsevier.
- Felleman, D. J., & Van Essen, D. C. (1991). Distributed hierarchical processing in the primate cerebral cortex. *Cerebral Cortex*, 1, 1–47.

- Ferree, T. C., Luu, P., Russell, G. S., & Tucker, D. M. (2001). Scalp electrode impedance, infection risk, and EEG data quality. *Clinical Neurophysiology*, 112, 536–544.
- Gaillard, A. W. K. (1988). Problems and paradigms in ERP research. *Biological Psychology*, 26, 91–109.
- Galambos, R., & Sheatz, G. C. (1962). An electroencephalographic study of classical conditioning. *American Journal of Physiology*, 203, 173–184.
- Ganis, G., Kutas, M., & Sereno, M. I. (1996). The search for “common sense”: An electrophysiological study of the comprehension of words and pictures in reading. *Journal of Cognitive Neuroscience*, 8, 89–106.
- Garner, W. R., Hake, H. W., & Eriksen, C. W. (1956). Operationism and the concept of perception. *Psychology Review*, 63, 149–159.
- Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error-detection and compensation. *Psychological Science*, 4, 385–390.
- Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science*, 295, 2279–2282.
- George, J. S., Aine, C. J., Mosher, J. C., Schmidt, D. M., Ranken, D. M., Schlitt, H. A., Wood, C. C., Lewine, J. D., Sanders, J. A., & Belliveau, J. W. (1995). Mapping function in the human brain with magnetoencephalography, anatomical magnetic resonance imaging, and functional magnetic resonance imaging. *Journal of Clinical Neurophysiology*, 12, 406–431.
- George, N., Evans, J., Fiori, N., Davidoff, J., & Renault, B. (1996). Brain events related to normal and moderately scrambled faces. *Cognitive Brain Research*, 4, 65–76.
- Gevens, A., Le, J., Leong, H., McEvoy, L. K., & Smith, M. E. (1999). Deblurring. *Journal of Clinical Neurophysiology*, 16, 204–213.
- Gibbs, F. A., Davis, H., & Lennox, W. G. (1935). The electro-encephalogram in epilepsy and in conditions of impaired consciousness. *Archives of Neurology and Psychiatry*, 34, 1133–1148.
- Girelli, M., & Luck, S. J. (1997). Are the same attentional mechanisms used to detect visual search targets defined by color, orientation, and motion? *Journal of Cognitive Neuroscience*, 9, 238–253.
- Glaser, E. M., & Ruchkin, D. S. (1976). *Principles of Neurobiological Signal Analysis*. New York: Academic Press.
- Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifacts. *Electroencephalography and Clinical Neurophysiology*, 55, 468–484.
- Gratton, G., Coles, M. G. H., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and post-stimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance*, 14, 331–344.
- Gray, C. M., König, P., Engel, A. K., & Singer, W. (1989). Oscillatory responses in cat visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. *Nature*, 338, 334–337.
- Hagoort, P., Brown, C. M., & Swaab, T. Y. (1996). Lexical-semantic event-related potential effects in patients with left hemisphere lesions and aphasia, and patients with right hemisphere lesions without aphasia. *Brain*, 119, 627–649.
- Hämäläinen, M. S., Hari, R., Ilmoniemi, R. J., Knuutila, J., & Lounasmaa, O. V. (1993). Magnetoencephalography—theory, instrumentation, and applications to noninvasive studies of the working human brain. *Review of Modern Physics*, 65, 413–497.

- Hämäläinen, M. S., & Ilmoniemi, R. J. (1984). Interpreting measured magnetic fields of the brain: Estimates of current distributions. In *Technical Report TTK-F-A599*. Espoo: Helsinki University of Technology.
- Handy, T. C., Sotaniemi, M., & Mangun, G. R. (2001). Perceptual load and visuocortical processing: Event-related potentials reveal sensory-level selection. *Psychological Science*, 12, 213–218.
- Hansen, J. C., & Hillyard, S. A. (1980). Endogenous brain potentials associated with selective auditory attention. *Electroencephalography and Clinical Neurophysiology*, 49, 277–290.
- Heinze, H. J., Mangun, G. R., Burchert, W., Hinrichs, H., Scholz, M., Münte, T. F., Gös, A., Scherg, M., Johannes, S., Hundeshagen, H., Gazzaniga, M. S., & Hillyard, S. A. (1994). Combined spatial and temporal imaging of brain activity during visual selective attention in humans. *Nature*, 372, 543–546.
- Helmholtz, H. (1853). Ueber einige Gesetze der Vertheilung elektrischer Ströme in körperlichen Leitern mit Anwendung auf die thierisch-elektrischen Versuche. *Annalen der Physik und Chemie*, 89, 211–233, 354–377.
- Hillyard, S. A., & Galambos, R. (1970). Eye movement artifact in the CNV. *Electroencephalography and Clinical Neurophysiology*, 28, 173–182.
- Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science*, 182, 177–179.
- Hillyard, S. A., & Picton, T. W. (1987). Electrophysiology of cognition. In F. Plum (Ed.), *Handbook of Physiology: Section 1. The Nervous System: Volume 5. Higher Functions of the Brain, Part 2* (pp. 519–584). Bethesda, MD: Waverly Press.
- Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: Electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society: Biological Sciences*, 353, 1257–1270.
- Holcomb, P. J., & McPherson, W. B. (1994). Event-related brain potentials reflect semantic priming in an object decision task. *Brain and Cognition*, 24, 259–276.
- Holroyd, C. B., Nieuwenhuis, S., Yeung, N., Nystrom, L., Mars, R. B., Coles, M. G. H., & Cohen, J. D. (2004). Dorsal anterior cingulate cortex shows fMRI response to internal and external error signals. *Nature Neuroscience*, 7, 497–498.
- Hopf, J.-M., Luck, S. J., Girelli, M., Hagner, T., Mangun, G. R., Scheich, H., & Heinze, H.-J. (2000). Neural sources of focused attention in visual search. *Cerebral Cortex*, 10, 1233–1241.
- Hopf, J.-M., Vogel, E. K., Woodman, G. F., Heinze, H.-J., & Luck, S. J. (2002). Localizing visual discrimination processes in time and space. *Journal of Neurophysiology*, 88, 2088–2095.
- Hopfinger, J. B., Luck, S. J., & Hillyard, S. A. (2004). Selective attention: Electrophysiological and neuromagnetic studies. In M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences, Volume 3* (pp. 561–574). Cambridge, MA: MIT Press.
- Hopfinger, J. B., & Mangun, G. R. (1998). Reflective attention modulates processing of visual stimuli in human extrastriate cortex. *Psychological Science*, 9, 441–447.
- Huang, M., Aine, C. J., Supek, S., Best, E., Ranken, D., & Flynn, E. R. (1998). Multi-start downhill simplex method for spatio-temporal source localization in magnetoencephalography. *Electroencephalography & Clinical Neurophysiology*, 108, 32–44.
- Ikui, A. (2002). A review of objective measures of gustatory function. *Acta Otolaryngologica Supplement*, 546, 60–68.

- Ilmoniemi, R. J. (1995). Estimating brain source distributions: Comments on LORETA. *ISBET Newsletter*, 6, 12–14.
- Isreal, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. *Psychophysiology*, 17, 259–273.
- Ito, S., Stuphorn, V., Brown, J. W., & Schall, J. D. (2003). Performance monitoring by the anterior cingulate cortex during saccade countermanding. *Science*, 302, 120–122.
- Jasper, H. H. (1958). The ten-twenty electrode system of the International Federation. *Electroencephalography & Clinical Neurophysiology*, 10, 371–375.
- Jasper, H. H., & Carmichael, L. (1935). Electrical potentials from the intact human brain. *Science*, 81, 51–53.
- Jeffreys, D. A. (1989). A face-responsive potential recorded from the human scalp. *Experimental Brain Research*, 78, 193–202.
- Jeffreys, D. A., & Axford, J. G. (1972). Source locations of pattern-specific components of human visual evoked potentials. I: Components of striate cortical origin. *Experimental Brain Research*, 16, 1–21.
- Jennings, J. R., & Wood, C. C. (1976). The e-adjustment procedure for repeated-measures analyses of variance. *Psychophysiology*, 13, 277–278.
- Johnson, R., Jr. (1984). P300: A model of the variables controlling its amplitude. *Annals of the New York Academy of Sciences*, 425, 223–229.
- Johnson, R., Jr. (1986). A triarchic model of P300 amplitude. *Psychophysiology*, 23, 367–384.
- Joyce, C. A., Gorodnitsky, I. F., King, J. W., & Kutas, M. (2002). Tracking eye fixations with electroocular and electroencephalographic recordings. *Psychophysiology*, 39, 607–618.
- Joyce, C. A., Gorodnitsky, I. F., & Kutas, M. (2004). Automatic removal of eye movement and blink artifacts from EEG data using blind component separation. *Psychophysiology*, 41, 313–325.
- Jung, T. P., Makeig, S., Humphries, C., Lee, T. W., McKeown, M. J., Iragui, V., & Sejnowski, T. J. (2000). Removing electroencephalographic artifacts by blind source separation. *Psychophysiology*, 37, 163–178.
- Jung, T. P., Makeig, S., Westerfield, M., Townsend, J., Courchesne, E., & Sejnowski, T. J. (2000). Removal of eye activity artifacts from visual event-related potentials in normal and clinical subjects. *Clinical Neurophysiology*, 111, 1745–1758.
- Keppel, G. (1982). *Design and Analysis*. Englewood Cliffs, NJ: Prentice-Hall.
- Klem, G. H., Luders, H. O., Jasper, H. H., & Elger, C. (1999). The ten-twenty electrode system of the International Federation. *Electroencephalography & Clinical Neurophysiology, Supplement* 52, 3–6.
- Koles, Z. J. (1998). Trends in EEG source localization. *Electroencephalography & Clinical Neurophysiology*, 106, 127–137.
- Kornhuber, H. H., & Deecke, L. (1965). Hirnpotentialänderungen bei Willkurbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente potentials. *Pflügers Archives*, 284, 1–17.
- Kramer, A. F. (1985). The interpretation of the component structure of event-related brain potentials: An analysis of expert judgments. *Psychophysiology*, 22, 334–344.
- Kutas, M. (1997). Views on how the electrical activity that the brain generates reflects the functions of different language structures. *Psychophysiology*, 34, 383–398.

- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, 207, 203–205.
- Kutas, M., Hillyard, S. A., & Gazzaniga, M. S. (1988). Processing of semantic anomaly by right and left hemispheres of commissurotomy patients. *Brain*, 111, 553–576.
- Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. *Science*, 197, 792–795.
- Leahy, R. M., Mosher, J. C., Spencer, M. E., Huang, M. X., & Lewine, J. D. (1998). A study of dipole localization accuracy for MEG and EEG using a human skull phantom. *Electroencephalography & Clinical Neurophysiology*, 107, 159–173.
- Leuthold, H., & Sommer, W. (1998). Postperceptual effects and P300 latency. *Psychophysiology*, 35, 34–46.
- Lindsley, D. B. (1969). Average evoked potentials—achievements, failures and prospects. In E. Donchin & D. B. Lindsley (Eds.), *Average Evoked Potentials: Methods, Results and Evaluations* (pp. 1–43). Washington, D.C.: U.S. Government Printing Office.
- Lins, O. G., Picton, T. W., Berg, P., & Scherg, M. (1993a). Ocular artifacts in EEG and event-related potentials I: Scalp topography. *Brain Topography*, 6, 51–63.
- Lins, O. G., Picton, T. W., Berg, P., & Scherg, M. (1993b). Ocular artifacts in recording EEGs and event-related potentials. II: Source dipoles and source components. *Brain Topography*, 6, 65–78.
- Liu, A. K., Belliveau, J. W., & Dale, A. M. (1998). Spatiotemporal imaging of human brain activity using functional MRI constrained magnetoencephalography data: Monte Carlo simulations. *Proceedings of the National Academy of Sciences of the United States of America*, 95, 8945–8950.
- Loveless, N. E., & Sanford, A. J. (1975). The impact of warning signal intensity on reaction time and components of the contingent negative variation. *Biological Psychology*, 2, 217–226.
- Luck, S. J. (1998a). Neurophysiology of selective attention. In H. Pashler (Ed.), *Attention* (pp. 257–295). East Sussex: Psychology Press.
- Luck, S. J. (1998b). Sources of dual-task interference: Evidence from human electrophysiology. *Psychological Science*, 9, 223–227.
- Luck, S. J. (1999). Direct and indirect integration of event-related potentials, functional magnetic resonance images, and single-unit recordings. *Human Brain Mapping*, 8, 15–120.
- Luck, S. J. (2005). Ten simple rules for designing ERP experiments. In T. C. Handy (Ed.), *Event-Related Potentials: A Methods Handbook* (pp. 17–32). Cambridge, MA: MIT Press.
- Luck, S. J., Fan, S., & Hillyard, S. A. (1993). Attention-related modulation of sensory-evoked brain activity in a visual search task. *Journal of Cognitive Neuroscience*, 5, 188–195.
- Luck, S. J., & Girelli, M. (1998). Electrophysiological approaches to the study of selective attention in the human brain. In R. Parasuraman (Ed.), *The Attentive Brain* (pp. 71–94). Cambridge, MA: MIT Press.
- Luck, S. J., Girelli, M., McDermott, M. T., & Ford, M. A. (1997). Bridging the gap between monkey neurophysiology and human perception: An ambiguity resolution theory of visual selective attention. *Cognitive Psychology*, 33, 64–87.
- Luck, S. J., & Hillyard, S. A. (1990). Electrophysiological evidence for parallel and serial processing during visual search. *Perception & Psychophysics*, 48, 603–617.
- Luck, S. J., & Hillyard, S. A. (1994a). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, 31, 291–308.

- Luck, S. J., & Hillyard, S. A. (1994b). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 1000–1014.
- Luck, S. J., & Hillyard, S. A. (1995). The role of attention in feature detection and conjunction discrimination: An electrophysiological analysis. *International Journal of Neuroscience*, 80, 281–297.
- Luck, S. J., Hillyard, S. A., Mouloua, M., Woldorff, M. G., Clark, V. P., & Hawkins, H. L. (1994). Effects of spatial cuing on luminance detectability: Psychophysical and electrophysiological evidence for early selection. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 887–904.
- Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature*, 382, 616–618.
- Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences*, 4, 432–440.
- Macmillan, N. A. (1999). Editorial. *Perception & Psychophysics*, 61, 1–2.
- Magliero, A., Bashore, T. R., Coles, M. G. H., & Donchin, E. (1984). On the dependence of P300 latency on stimulus evaluation processes. *Psychophysiology*, 21, 171–186.
- Makeig, S. (1993). Auditory event-related dynamics of the EEG spectrum and effects of exposure to tones. *Electroencephalography and Clinical Neurophysiology*, 86, 283–293.
- Makeig, S., Jung, T. P., Bell, A. J., Ghahremani, D., & Sejnowski, T. J. (1997). Blind separation of auditory event-related brain responses into independent components. *Proceedings of the National Academy of Science*, 94, 10979–10984.
- Mangun, G. R. (1995). Neural mechanisms of visual selective attention. *Psychophysiology*, 32, 4–18.
- McCarthy, G., & Donchin, E. (1981). A metric for thought: A comparison of P300 latency and reaction time. *Science*, 211, 77–80.
- McCarthy, G., Nobre, A. C., Bentin, S., & Spencer, D. D. (1995). Language-related field potentials in the anterior-medial temporal lobe: I. Intracranial distribution and neural generators. *Journal of Neuroscience*, 15, 1080–1089.
- McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, 62, 203–208.
- McClelland, J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review*, 86, 287–330.
- Miller, J., & Hackley, S. A. (1992). Electrophysiological evidence for temporal overlap among contingent mental processes. *Journal of Experimental Psychology: General*, 121, 195–209.
- Miller, J., Patterson, T., & Ulrich, R. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology*, 35, 99–115.
- Miller, J., Riehle, A., & Requin, J. (1992). Effects of preliminary perceptual output on neuronal activity of the primary motor cortex. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 1121–1138.
- Miltner, W., Braun, C., Johnson, R., Jr., Simpson, G. V., & Ruchkin, D. S. (1994). A test of brain electrical source analysis (BESA): A simulation study. *Electroencephalography & Clinical Neurophysiology*, 91, 295–310.
- Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, 229, 782–784.

- Mosher, J. C., Baillet, S., & Leahy, R. M. (1999). EEG source localization and imaging using multiple signal classification approaches. *Journal of Clinical Neurophysiology*, 16, 225–238.
- Mosher, J. C., & Leahy, R. M. (1999). Source localization using recursively applied and projected (RAP) MUSIC. *IEEE Transactions on Signal Processing*, 47, 332–340.
- Mosher, J. C., Lewis, P. S., & Leahy, R. M. (1992). Multiple dipole modeling and localization from spatio-temporal MEG data. *IEEE Transactions on Biomedical Engineering*, 39, 541–557.
- Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology*, 24, 375–425.
- Näätänen, R., & Picton, T. W. (1986). N2 and automatic versus controlled processes. In W. C. McCallum, R. Zappoli & F. Denoth (Eds.), *Cerebral Psychophysiology: Studies in Event-Related Potentials* (pp. 169–186). Amsterdam: Elsevier.
- Nagamine, T., Toro, C., Balish, M., Deuschl, G., Wang, B., Sato, S., Shibasaki, H., & Hallett, M. (1994). Cortical magnetic and electrical fields associated with voluntary finger movements. *Brain Topography*, 6, 175–183.
- Norman, D. A. (1968). Toward a theory of memory and attention. *Psychological Review*, 75, 522–536.
- Nunez, P. L. (1981). *Electric Fields of the Brain*. New York: Oxford University Press.
- Osman, A., Bashore, T. R., Coles, M., Donchin, E., & Meyer, D. (1992). On the transmission of partial information: Inferences from movement-related brain potentials. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 217–232.
- Osman, A., & Moore, C. M. (1993). The locus of dual-task interference: Psychological refractory effects on movement-related brain potentials. *Journal of Experimental Psychology: Human Perception and Performance*, 19, 1292–1312.
- Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory & Language*, 31, 785–806.
- Osterhout, L., & Holcomb, P. J. (1995). Event-related potentials and language comprehension. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of Mind* (pp. 171–215). New York: Oxford University Press.
- Paller, K. A. (1990). Recall and stem-completion priming have different electrophysiological correlates and are modified differentially by directed forgetting. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 16, 1021–1032.
- Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): Technical details. *Methods & Findings in Experimental & Clinical Pharmacology*, 24 Suppl D, 5–12.
- Pascual-Marqui, R. D., Esslen, M., Kochi, K., & Lehmann, D. (2002). Functional imaging with low-resolution brain electromagnetic tomography (LORETA): A review. *Methods & Findings in Experimental & Clinical Pharmacology*, 24 Suppl C, 91–95.
- Pascual-Marqui, R. D., Michel, C. M., & Lehmann, D. (1994). Low resolution electromagnetic tomography: A new method for localizing electrical activity in the brain. *International Journal of Psychophysiology*, 18, 49–65.
- Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, 10, 437–442.

- Pernier, J., Perrin, F., & Bertrand, O. (1988). Scalp current density fields: Concept and properties. *Electroencephalography and Clinical Neurophysiology*, 69, 385–389.
- Perrin, F., Pernier, J., Bertrand, O., & Echallier, J. F. (1989). Spherical splines for scalp potential and current density mapping. *Electroencephalography and Clinical Neurophysiology*, 72, 184–187.
- Phillips, C., Rugg, M. D., & Friston, K. J. (2002). Anatomically informed basis functions for EEG source localization: Combining functional and anatomical constraints. *Neuroimage*, 16, 678–695.
- Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology*, 9, 456–479.
- Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Jr., Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. P., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, 37, 127–152.
- Picton, T. W., & Hillyard, S. A. (1972). Cephalic skin potentials in electroencephalography. *Electroencephalography and Clinical Neurophysiology*, 33, 419–424.
- Picton, T. W., Hillyard, S. A., & Galambos, R. (1974). Cortical evoked responses to omitted stimuli. In M. N. Livanov (Ed.), *Basic Problems in Brain Electrophysiology* (pp. 302–311). Moscow: Nauka.
- Picton, T. W., Linden, R. D., Hamel, G., & Maru, J. T. (1983). Aspects of averaging. *Seminars in Hearing*, 4, 327–341.
- Picton, T. W., Lins, O. G., & Scherg, M. (1995). The recording and analysis of event-related potentials. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology*, Vol. 10 (pp. 3–73). New York: Elsevier.
- Picton, T. W., & Stuss, D. T. (1980). The component structure of the human event-related potentials. In H. H. Kornhuber & L. Deecke (Eds.), *Motivation, Motor and Sensory Processes of the Brain* (pp. 17–49). North-Holland: Elsevier.
- Platt, J. R. (1964). Strong inference. *Science*, 146, 347–353.
- Plonsey, R. (1963). Reciprocity applied to volume conductors and the EEG. *IEEE Transactions on Biomedical Engineering*, 19, 9–12.
- Polich, J. (2004). Clinical application of the P300 event-related brain potential. *Physical Medicine & Rehabilitation Clinics of North America*, 15, 133–161.
- Polich, J., & Comerchero, M. D. (2003). P3a from visual stimuli: Typicality, task, and topography. *Brain Topography*, 15, 141–152.
- Polich, J., & Kok, A. (1995). Cognitive and biological determinants of P300: An integrative review. *Biological Psychology*, 41, 103–146.
- Polich, J., & Lawson, D. (1985). Event-related potentials paradigms using tin electrodes. *American Journal of EEG Technology*, 25, 187–192.
- Popper, K. (1959). *The Logic of Scientific Discovery*. London: Hutchinson.
- Potter, M. C. (1976). Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory*, 2, 509–522.
- Pritchard, W. S. (1981). Psychophysiology of P300. *Psychology Bulletin*, 89, 506–540.
- Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, 18, 849–860.
- Regan, D. (1989). *Human Brain Electrophysiology: Evoked Potentials and Evoked Magnetic Fields in Science and Medicine*. New York: Elsevier.
- Ritter, W., Simson, R., Vaughan, H. G., & Friedman, D. (1979). A brain event related to the making of a sensory discrimination. *Science*, 203, 1358–1361.

- Ritter, W., Vaughan, H. G. Jr., & Costa, L. D. (1968). Orienting and habituation to auditory stimuli: A study of short term changes in average evoked responses. *Electroencephalography and Clinical Neurophysiology*, 25, 550–556.
- Rohrbaugh, J. W., Syndulko, K., & Lindsley, D. B. (1976). Brain wave components of the contingent negative variation in humans. *Science*, 191, 1055–1057.
- Rosler, F., & Manzey, D. (1981). Principal components and varimax-rotated components in event-related potential research: Some remarks on their interpretation. *Biological Psychology*, 13, 3–26.
- Rossion, B., Curran, T., & Gauthier, I. (2002). A defense of the subordinate-level expertise account for the N170 component. *Cognition*, 85, 189–196.
- Rossion, B., Delvenne, J. F., Debatisse, D., Goffaux, V., Bruyer, R., Crommelinck, M., & Guérit, J. M. (1999). Spatio-temporal localization of the face inversion effect: An event-related potentials study. *Biological Psychology*, 50, 173–189.
- Rossion, B., Gauthier, I., Goffaux, V., Tarr, M. J., & Crommelinck, M. (2002). Expertise training with novel objects leads to left-lateralized facelike electrophysiological responses. *Psychological Science*, 13, 250–257.
- Ruchkin, D. S., & Wood, C. C. (1988). The measurement of event-related potentials. In T. W. Picton (Ed.), *Human Event Related Potentials* (pp. 121–137). Amsterdam: Elsevier.
- Schendan, H. E., Ganis, G., & Kutas, M. (1998). Neurophysiological evidence for visual perceptual categorization of words and faces within 150 ms. *Psychophysiology*, 35, 240–251.
- Scherg, M., Vajsar, J., & Picton, T. (1989). A source analysis of the human auditory evoked potentials. *Journal of Cognitive Neuroscience*, 1, 336–355.
- Scherg, M., & von Cramon, D. (1985). A new interpretation of the generators of BAEP waves I–V: Results of a spatio-temporal dipole model. *Electroencephalography and Clinical Neurophysiology*, 62, 290–299.
- Schmidt, D. M., George, J. S., & Wood, C. C. (1999). Bayesian inference applied to the electromagnetic inverse problem. *Human Brain Mapping*, 7, 195–212.
- Schmolsky, M. T., Wang, Y., Hanes, D. P., Thompson, K. G., Leutgeb, S., Schall, J. D., & Leventhall, A. G. (1998). Signal timing across the macaque visual system. *Journal of Neurophysiology*, 79, 3272–3278.
- Shapiro, K. L., Arnell, K. M., & Raymond, J. E. (1997). The attentional blink. *Trends in Cognitive Science*, 1, 291–296.
- Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 357–371.
- Shibasaki, H. (1982). Movement-related cortical potentials. In *Evoked Potentials in Clinical Testing* (Vol. 3, pp. 471–482). Edinburgh: Churchill Livingstone.
- Simson, R., Vaughan, H. G., & Ritter, W. (1977). The scalp topography of potentials in auditory and visual discrimination tasks. *Electroencephalography and Clinical Neurophysiology*, 42, 528–535.
- Snyder, A. (1991). Dipole source localization in the study of EP generators: A critique. *Electroencephalography & Clinical Neurophysiology*, 80, 321–325.
- Soltani, M., & Knight, R. T. (2000). Neural origins of the P300. *Critical Reviews in Neurobiology*, 14, 199–224.
- Squires, K. C., & Donchin, E. (1976). Beyond averaging: The use of discriminant functions to recognize event related potentials elicited by single auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, 41, 449–459.

- Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, 38, 387–401.
- Sutton, S. (1969). The specification of psychological variables in average evoked potential experiments. In E. Donchin & D. B. Lindsley (Eds.), *Averaged Evoked Potentials: Methods, Results and Evaluations* (pp. 237–262). Washington, D.C.: U.S. Government Printing Office.
- Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked potential correlates of stimulus uncertainty. *Science*, 150, 1187–1188.
- Sutton, S., Tueting, P., Zubin, J., & John, E. R. (1967). Information delivery and the sensory evoked potential. *Science*, 155, 1436–1439.
- Szűcs, A. (1998). Applications of the spike density function in analysis of neuronal firing patterns. *Journal of Neuroscience Methods*, 81, 159–167.
- Tallon-Baudry, C., Bertrand, O., Delpuech, C., & Pernier, J. (1996). Stimulus specificity of phase-locked and non-phase-locked 40 Hz visual responses in humans. *Journal of Neuroscience*, 16, 4240–4249.
- Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature*, 381, 520–522.
- Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review*, 76, 282–299.
- Tucker, D. M. (1993). Spatial sampling of head electrical fields: The geodesic sensor net. *Electroencephalography & Clinical Neurophysiology*, 87, 154–163.
- Urbach, T. P., & Kutas, M. (2002). The intractability of scaling scalp distributions to infer neuroelectric sources. *Psychophysiology*, 39, 791–808.
- Van Petten, C., & Kutas, M. (1987). Ambiguous words in context: An event-related potential analysis of the time course of meaning activation. *Journal of Memory & Language*, 26, 188–208.
- van Schie, H. T., Mars, R. B., Coles, M. G., & Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience*, 7, 549–554.
- van Turenhout, M., Hagoort, P., & Brown, C. M. (1998). Brain activity during speaking: From syntax to phonology in 40 milliseconds. *Science*, 280, 572–574.
- Vasey, M. W., & Thayer, J. F. (1987). The continuing problem of false positives in repeated measures ANOVA in psychophysiology: A multivariate solution. *Psychophysiology*, 24, 479–486.
- Vaughan, H. G., Jr. (1969). The relationship of brain activity to scalp recordings of event-related potentials. In E. Donchin & D. B. Lindsley (Eds.), *Average Evoked Potentials: Methods, Results and Evaluations* (pp. 45–75). Washington, D.C.: U.S. Government Printing Office.
- Vaughan, H. G., Jr., Costa, L. D., & Ritter, W. (1968). Topography of the human motor potential. *Electroencephalography and Clinical Neurophysiology*, 25, 1–10.
- Verleger, R. (1988). Event-related potentials and cognition: A critique of the context updating hypothesis and an alternative interpretation of P3. *Behavioral Brain Science*, 11, 343–427.
- Verleger, R. (1997). On the utility of P3 latency as an index of mental chronometry. *Psychophysiology*, 34, 131–156.
- Verleger, R., Gasser, T., & Moecks, J. (1982). Correction of EOG artifacts in event-related potentials of the EEG: Aspects of reliability and validity. *Psychophysiology*, 19, 472–480.

- Verleger, R., Jaskowski, P., & Wauschkuhn, B. (1994). Suspense and surprise: On the relationship between expectancies and P3. *Psychophysiology*, 31, 359–369.
- Vitacco, D., Brandeis, D., Pascual-Marqui, R., & Martin, E. (2002). Correspondence of event-related potential tomography and functional magnetic resonance imaging during language processing. *Human Brain Mapping*, 17, 4–12.
- Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology*, 37, 190–123.
- Vogel, E. K., & Luck, S. J. (2002). Delayed working memory consolidation during the attentional blink. *Psychonomic Bulletin & Review*, 9, 739–743.
- Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a post-perceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 1656–1674.
- Vogel, E. K., & Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, 428, 748–751.
- Wada, M. (1999). Measurement of olfactory threshold using an evoked potential technique. *Rhinology*, 37, 25–28.
- Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. *Nature*, 203, 380–384.
- Wastell, D. G. (1977). Statistical detection of individual evoked responses: An evaluation of Woody's adaptive filter. *Electroencephalography & Clinical Neurophysiology*, 42, 835–839.
- Winkler, I., Kishnerenko, E., Horvath, J., Ceponiene, R., Fellman, V., Huotilainen, M., Naatanen, R., & Sussman, E. (2003). Newborn infants can organize the auditory world. *Proceedings of the National Academy of Sciences*, 100, 11812–11815.
- Woldorff, M. (1988). Adjacent response overlap during the ERP averaging process and a technique (Adjar) for its estimation and removal. *Psychophysiology*, 25, 490.
- Woldorff, M. (1993). Distortion of ERP averages due to overlap from temporally adjacent ERPs: Analysis and correction. *Psychophysiology*, 30, 98–119.
- Woldorff, M., & Hillyard, S. A. (1991). Modulation of early auditory processing during selective listening to rapidly presented tones. *Electroencephalography and Clinical Neurophysiology*, 79, 170–191.
- Woldorff, M. G., Gallen, C. C., Hampson, S. A., Hillyard, S. A., Pantev, C., Sobel, D., & Bloom, F. E. (1993). Modulation of early sensory processing in human auditory cortex during auditory selective attention. *Proceedings of the National Academy of Science*, 90, 8722–8726.
- Woldorff, M. G., Hackley, S. A., & Hillyard, S. A. (1991). The effects of channel-selective attention on the mismatch negativity wave elicited by deviant tones. *Psychophysiology*, 28, 30–42.
- Wood, C. C., & McCarthy, G. (1984). Principal component analysis of event-related potentials: Simulation studies demonstrate misallocation of variance across components. *Electroencephalography and Clinical Neurophysiology*, 59, 249–260.
- Woodman, G. F., & Luck, S. J. (2003). Serial deployment of attention during visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 29, 121–138.
- Woody, C. D. (1967). Characterization of an adaptive filter for the analysis of variable latency neuroelectric signals. *Medical and Biological Engineering*, 5, 539–553.