

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

Index

- Abrasion of skin before electrode
 - placement, 120
- Absolute voltages, 103
- AC current, 336
 - oscillations in, 113
- Accessories in ERP lab, 309–310, 311b–312b
- Action potentials, 23, 27–29
- Active electrodes, 101–104, 105f
- Adjacent response (ADJAR) filters for overlap, 149
- Adrian, E. D., 3
- Advantages of ERP technique, 21–22, 34
- Ag/AgCl electrodes, 117
- Aine, C., 276, 293
- Alcaini, M., 39
- Aliasing, 127, 177
- Alpha waves, 164f, 168–169
 - measurements of, 156
 - noise from, 177, 317
 - as noise source, elimination of, 213
- Amperes, 333
- Amplifiers
 - blocking of, 164f, 167–168
 - calibrator for, 310
 - and common mode rejection, 120–121
 - differential, 103
 - electrode-amplifier-computer connections, 307–308
 - filters in, 113
 - gain setting on, 125, 128
 - headbox for, 308
 - high-pass filter setting on, 125–126
 - input impedance of, 121
 - recommended types of, 314–315
 - saturation of, 167–168
- Amplitude
 - area, 139, 229–230
 - attenuation by filters, 178–181
 - of frequencies, 187–191
 - half-amplitude cutoff, 179, 180, 314, 321
 - and latency variability problem, 135–139
 - local peak, 231, 341n
 - mean, 229, 234–235. *See also* Mean amplitude
 - measurements of, 57, 229–237, 229f
 - in oscillations, 142–143
 - of P3 component, factors affecting, 43–44
 - peak, 139, 229, 230–234. *See also* Peak amplitude
 - peak-to-peak, 237. *See also* Peak-to-peak amplitude
 - relation to latency, 52, 53f, 55–56
- Analog filters, 176
- Analog-to-digital converters (ADC), 125, 315
 - sixteen-bit, 126
- ANOVA, 250–254. *See also* Statistical analyses
- Anterior cingulate cortex, 47
- Area amplitude, 13, 229–230
- Area-based measures compared to peak-based, 139–140
- Arnell, K. M., 87, 88
- Artifact(s), 12
 - aliasing, 127, 177
 - in low-pass filtered waveforms, 209, 210f
 - oscillations caused by filters, 183f, 184
 - peaks added by filters, 179
 - stimulus-related, 324
 - tearing, 328
- Artifact correction, 152, 170–173
 - problems with, 172–173
- Artifact rejection, 101, 151–170, 321, 340n
 - alpha waves, 164f, 168–169
 - amplifier saturation or blocking, 164f, 167–168
 - choice of sensitive measure, 154

- Artifact rejection (cont.)
 - in electrooculograms, 154–155, 155f
 - eye movements, 162–166
 - eyeblinks, 158–162
 - and filtering before or after averaging, 219, 340n–341n
 - general process, 152–154
 - muscle and heart activity, 169–170
 - slow voltage shifts, 166–167
 - threshold choice, 157–158
 - for between-subject studies, 157
 - for individual subjects, 158
- Assumptions
 - ANOVA, violation of, 250, 258–260
 - averaging, 134–135
- Attention
 - auditory selective, 75–80, 77f, 340n
 - and locus of selection, 75
 - and physical stimulus confounds, 70b–71b
 - systems in detection of color and motion, 13–17
- Attention effects, 297b
- Attentional blink paradigm, 87–88, 88f
- Auditory brainstem responses, 7
- Auditory selective attention, 75–80, 77f, 340n
- Auditory sensory responses, 38–39
- Auditory stimuli
 - artifacts from, 324
 - timing of, 323
- Automation of processing, 321
- Average across all electrodes as reference, 109–111, 110f
- Average mastoids reference deviation, 107–108
- Averaging, 131–151
 - application of, 132f
 - assumptions in, 134–135
 - basic procedures in, 9–10, 12, 131–135
 - of dipole orientations, 31
 - distortions caused by, 56–57
 - electrooculogram waveforms in, 165–166
 - and filtering before or after artifact rejection, 219
 - grand averages in, 17–21, 27. *See also* Grand averages
 - and latency variability problem, 135–139, 136f, 138f
 - area measures in, 139–140
 - response-locked averages in, 140
 - time-locked spectral averaging in, 142–145, 144f
 - Woody filter technique in, 141–142
 - and noise in waveforms, 131, 133
 - on-line, 317
 - and overlap problem, 145–149, 146f
 - in transient and steady-state responses, 149–151, 150f
 - reliability of, 18–20, 19f
 - residual EEG noise in, 99
 - response-locked, 138f, 140, 307, 320
 - baselines in, 237
 - signal-to-noise ratio in, 133–134
 - stimulus-locked, 138f, 140
 - time-locked, for spectral information, 142–145, 144f
 - of voltages at time points, 192f, 193–195
- Axford, J. G., 36
- Background music, use of, 312b
- Baillet, S., 271, 320
- Band-pass filters, 178, 191
- Baselines, 236–237
 - prestimulus, 236
 - and response-locked averages, 237
- Bayes theorem/Bayesian inference, 294, 295
- Behavioral response devices, 306–307
- Belliveau, J. W., 285
- Bentin, S., 38
- Bereitschaftspotential, 47
- Berg, P., 171, 172
- Berger, H., 3
- Bertrand, O., 32, 58, 111
- BESA. *See* Brain electrical source analysis
- Bessel filters, 215
- Bipolar recordings
 - artifacts and noise sources in, 170
 - in eye movements, 162
 - in eyeblinks, 162
- Blink. *See* Eyeblinks
- Bloch's law, 341n
- Blocking, amplifier, 164f, 167–168
- Blurring of voltage distribution, 32
- BOLD signal, 23
- Boundary element model, 271

- Brain electrical source analysis (BESA), 271–273, 273f. *See also* Equivalent current dipole, localization methods
- Brainard, D. H., 324, 330
- Brainstem evoked responses, 7, 38
 - auditory, 7, 38
 - cutoff frequency in, 208
- BrainStorm package for data analysis, 320
- Brandeis, D., 142
- Braren, M., 5
- Bright and dim stimuli, comparative
 - effects of, 71, 73–74, 252, 253f
- Broadbent, D. E., 75
- Brown, C. M., 46
- C1 component, visual, 35–36, 58–59
- Cables, noise from, 114, 116, 305, 308, 312b
- Calibration of recording system, 128–129
- Calibrator for amplifiers, 310, 314
- Capacitance, 117, 336
- Carmel, D., 38
- Carmichael, L., 3
- Cathode-ray tube. *See* CRT monitors
- Causal filters
 - high-pass, 221f, 222–223
 - low-pass, 210f, 214–215
 - frequency response function, 210f, 214–215
 - impulse response function, 210f, 214
- Chair, recliner, 169, 306
- Chalklin, V., 109
- Channel mapping, 317
- Chelazzi, L., 297b
- Chin rests, 167, 169, 306, 340n
- Chun, M. M., 88
- Clark, V. P., 36, 59
- Clean data, importance of, 86–87, 99–101, 185
- CNV. *See* Contingent negative variation
- Cognitive neuroscience
 - ERP findings in, 94
 - reference sites in, 106–108
- Cohen, D., 278
- Coles, M. G. H., 35, 43, 48, 65, 83, 170, 171, 172, 235
- Color-defined targets, detection of, 13–17
- Comerchero, M. D., 42
- Common mode rejection, 120–121, 314
- Communication with subjects in
 - experiments, 311b
- Component-independent experimental designs, 66–94
 - avoiding confounds and misinterpretations in, 66–74
 - examples of
 - auditory selective attention, 75–80, 77f
 - dual-task performance, 87–94, 88f, 90f
 - partial information transmission, 80–87, 84f
- Computers, 303–305
 - for amplifier settings, 315
 - in artifact detection, 156–157
 - digitization software, 315–318. *See also* Digitization
 - electrode-amplifier-computer connections, 307–308
 - event codes for, 305
 - software for. *See* Software
- Conductance, 334
- Conduction, volume, 32
- Confounds
 - avoidance of, 66–74
 - examples of, 70b–71b
- Constraints, 281–283, 283f
 - and minimum norm solution, 283–286
- Context updating hypothesis, 42–43
- Contingent negative variation, 4–5, 49
- Continuous performance task, 7
- Continuous recording, 316
- Contralateral sites, N2pc component in, 15–17, 41, 65
- Converging evidence, 296–297, 297b
- Convolution
 - mathematical properties of, 215–216
 - and noise affecting latency measures, 241
 - in time domain, 197–199, 198f, 200, 201–203, 202f
 - equivalent to multiplication in
 - frequency domain, 200–201, 201f, 216
 - of unity impulse response function, 217
- Cortical folding patterns, 20, 31
- Cortically constrained distributed source localization, 281–283, 283f
- Costa, L. D., 47
- Costs of recording techniques, 24, 26
- Courchesne, E., 42

- CRT monitors, 324–332
 - basic operation of, 325–327, 326f
 - compared to LCD monitors, 330–332
 - timing in, 324, 327–329
 - errors of, 328–329
- Cuffin, B. N., 278, 298
- Curran, T., 38
- Current, electrical, 333–334
 - alternating (AC), 336
 - direct (DC), 335
- Current density, 111–112
- Current source density (current density), 111–112
- Cutoff frequency, 177, 186, 314
 - for brainstem evoked responses, 208
 - and digitization rate, 127, 177
 - half-amplitude, 179, 180f, 314, 321
 - in gaussian filter, 212–213
 - in high-pass filters, 125
 - in low-pass filters, 127–128, 208
 - and sampling rate, 128
- Dale, A. M., 285
- Data acquisition system, 303–318, 304f
- Data analysis systems, 318–322
 - suggested features in, 320–322
- Davis, H., 2, 4, 10b
- Davis, P. A., 4, 10b
- DC current, 335
- DC recordings, 185
 - in saccades, 163, 166
- Deblurring, 32
- Deecke, L., 47
- Definition of ERP component, 58–59
- Dehaene, S., 47, 86b, 94
- de Jong, R., 86b
- Delays between stimuli, and overlapping
 - waveforms, 147, 148
- Delorme, A., 319
- Desimone, R., 297b
- Desmedt, J. E., 109
- Deutsch, D., 75
- Deutsch, J. A., 75
- Dien, J., 111
- Difference waves
 - to isolate components, 63–65, 298–299
 - and isolation of lateralized readiness
 - potential, 83
 - for overlap problems, 91, 94–95, 247
- Differential amplifiers, 103
- Differential step function in eyeblink
 - artifact rejection, 162
- Digital filters, 176
 - convolutions in, 201–203, 202f
 - equation for, 193, 195
 - impulse response functions in, 196
 - lack of phase shift with, 181
- Digitization, 124–126
 - event codes in, 305, 315
 - filters in, 181, 182, 185
 - rate of, and cutoff frequency of filter, 127, 177
 - software for, 315–318
 - testing of, 317–318
- Dipoles
 - equivalent current, 31, 269
 - forward problem, 268
 - inverse problem, 33–34, 269
 - modeling procedures to isolate ocular
 - activity, 172
 - neuron, 29
 - summation of, 31
 - seeded, 276
- Direct coupled (DC) recordings, 126
- Di Russo, F., 36, 150f, 272, 274f
- Disadvantages of ERP technique, 22–23, 26
- Distortions
 - from averaging, 56–57
 - from filters, 170, 175, 182–185, 183f, 204–223
- Distributed source localization methods, 269, 281–289
 - added value of magnetic recordings, 286–289, 287f
 - cortically constrained models, 281–283, 283f
 - minimum norm solution, 283–286
- Donchin, E., 9b, 42, 43, 44, 58, 94, 170, 171, 172, 262
- Double filtering, frequency response
 - function of, 216
- Dual-task performance, study of, 87–94, 88f, 90f
- Duncan-Johnson, C. C., 22, 43
- Earlobe reference sites, 106–107, 308
- Early selection hypothesis, 75–79
- Earth as reference point, 102

- Edge detection algorithms for artifact detection, 165
- EEG. *See* Electroencephalogram
- EEGLAB package for data analysis, 319–320
- Eimer, M., 41
- Electrical activity in neurons, 27–32
- Electrical noise in environment, 112–116, 305, 306, 308, 309
 - filtering of, 182
 - low-pass filters in, 208
- Electrical potential, 40, 101–104, 333
- Electricity
 - basic principles of, 333–337
 - relation to magnetism, 336–337, 336f
- Electrocardiogram (EKG) artifacts, 164f, 170
- Electrode(s), 116–124
 - active, 101–104, 105f
 - caps for, 313
 - in geodesic sensor net, 122
 - ground, 102, 103
 - interactions between condition and electrode site, 254–258, 256f
 - large arrays of, 121
 - perspective on, 123–124, 124b
 - problems with, 122
 - placing and naming of sites in 10/20 system, 118b–119b
 - recommended types of, 313
 - reference, 103, 104–112, 105f, 308
 - silver/silver-chloride, 117
 - tin, 117
- Electrode-amplifier-computer connections, 307–308
- Electroencephalogram (EEG)
 - amplifier settings, 125–126
 - blocking and skin potential artifacts in, 164f, 169
 - fields compared to MEG fields, 286–288
 - flat-line signal from slow voltage shifts, 125, 167, 168
 - historical aspects of, 3–4
 - residual noise in, 99
- Electromotive force, 333
- Electromyogram (EMG), 164f, 169, 306
- Electrooculogram (EOG)
 - artifact corrections, 171
 - artifact rejections, 154–155, 155f, 157
 - averaged waveforms, 165–166
 - eyeblick detection, 158–160, 159f
 - in saccades, 163, 164f
 - voltages produced by eye movements, 163
- EMG. *See* Electromyogram
- Endogenous components, 11
- EOG. *See* Electrooculogram
- Epoch-based recording, 316
- Equivalent current dipole, 31
 - localization methods, 269, 271–280, 293–294
 - BESA technique in, 271–273, 273f
 - multi-start approach in, 276, 294
 - numbers and locations of dipoles in, 273–276
 - operator dependence of, 275, 277
 - shortcomings of, 276–278
 - simulation study of, 278–280, 341n
 - source waveforms in, 273, 274f
- Eriksen, C. W., 80, 296
- ERMF. *See* Event-related magnetic fields
- ERPology, 5–6
- Error detection, 46–47
- Error-related negativity, 47
- Event codes, 305, 315
 - timing of, 322–324
- Event-related magnetic fields (ERMFs), 23, 24t, 33, 286, 299
 - combined with ERP data, 286–289
- Event-related potentials (ERPs)
 - advantages and disadvantages of, 21–23
 - combined with magnetic data, 286–289
 - compared to other measures, 23–27, 24t
 - components of, 34–49, 59–61
 - definition of, 58–59, 339n–340n
 - history of, 3–7
 - origin of term, 4, 6–7
 - steady-state, 150–151, 150f
 - transient, 149–150, 150f
- Evoked potentials (EPs), 6
- Evoked response, 7
 - brainstem, 7, 38, 208
 - visual, 7
- Exogenous components, 11
- Experiment design and interpretation
 - ambiguities avoided in, 61–66
 - component-independent designs in, 66
 - confound and misinterpretations in, 66–71

- Experiment design and interpretation (cont.)
 - avoidance of, 72–74
 - definition of ERP component in, 57–61
 - examples of, 75–94
 - focus in, 62
 - isolation of components in, 63–65
 - large components in, 63
 - rules for, 52–57, 74, 92, 96–97
 - strategies for, 62–66, 94–95, 98
 - waveform peaks *versus* latent ERP components in, 51–57
 - well-studied components used in, 62
- Experimental effect compared to raw ERP waveforms, 55
- Experimentwise error, 252
- Eye movements
 - artifact correction, 170–173
 - detection and rejection of artifacts, 162–166
 - suppressed during recordings, 311b
- Eyeblinks, 12
 - artifact correction, 170–173
 - assessment with electrooculogram, 154–155, 155f
 - attentional blink paradigm, 87–88, 88f
 - detection and rejection of artifacts, 158–162
 - differential step function in, 162
 - step function in, 161
 - polarity reversal in, 159–160, 159f, 161
 - reducing occurrence of, 160
 - suppressed during recordings, 311b
 - and voltage deflection levels, 153–154
- Face stimuli, N170 wave in, 37–38
- Falkenstein, M., 47
- Falsification, 295
- Fan, S., 36, 59, 94
- Faraday cage, 114, 115f, 305, 310
- Felleman, D. J., 340n
- Ferree, T. C., 123
- 50-Hz noise, 113
- 50 percent area latency measure, 139, 239–242, 240f
 - compared to median reaction time, 246
 - disadvantages of, 242
- Filter(s)
 - adjacent response (ADJAR), 149
 - and amplitude attenuation, 178–181
 - analog, 176
 - attenuating low frequencies, 177–178
 - band-pass, 178
 - frequency response functions, 191
 - Bessel, 215
 - causal
 - high-pass, 221f, 222–223
 - low-pass, 210f, 214–215
 - cutoff frequency of, 177, 186, 314. *See also* Cutoff frequency
 - digital, 176
 - lack of phase shift with, 181
 - distortions from, 170, 175, 182–185, 183f, 204–223
 - with high-pass filters, 219–223
 - with low-pass filters, 207–215, 210f
 - with notch filters, 204–207, 206f
 - frequency-domain, 175
 - transformed into time domain, 188f, 190
 - frequency response function, 179, 180f, 188f, 190
 - gaussian, 210f, 212–214. *See also* Gaussian filters
 - half-gaussian, 21
 - high-pass, 178, 314
 - to attenuate low frequencies, 195
 - avoidance of, 187
 - causal, 221f, 222–223
 - cutoff frequency, 125
 - distortions from, 219–223
 - in eye movement recordings, 163
 - frequency response function, 179, 191
 - gaussian, 218f, 219–220, 221f
 - linear, 219
 - noncausal, 222
 - for overlap problem, 149
 - reducing slow voltage shifts, 167, 178
 - settings for, 125–126
 - time constants, 179, 180f, 181
 - time-domain implementation of, 216–219
 - windowed ideal, 220, 221f
- impulse response. *See also* Impulse response function
 - finite, 175, 200
 - infinite, 200
 - and latency shift, 181
 - line-frequency, 113, 182, 186, 208

- low-pass, 127–128, 178, 314
 - causal, 210f, 214–215
 - compared to mean amplitude measures, 234
 - cutoff frequency, 127–128, 208
 - distortions from, 207–215, 210f
 - frequency response function, 179, 191
 - noncausal, 214
 - windowed ideal, 208–209, 210f, 213
- need for, 176–178
- noncausal
 - high-pass, 222
 - low-pass, 214
- notch, 178, 182, 186, 315
 - frequency response functions, 191
 - temporal distortions from, 204–207, 206f
- phase response function, 179
- recursive, 200
- running average, 210f, 211–212, 213–214
- settings for, 125–126, 315
- suppressing high frequencies, 177
- time-domain, 175
 - distortions from, 204–223
- transfer function, 178–179
- windowed ideal, 208–209, 210f, 213, 220, 221f
- Filtering, 175–224
 - as frequency-domain procedure, 187–193, 188f
 - problem with, 191–193
 - and peak amplitude measures, 232
 - recommendations for, 181, 185, 186–187, 223–224
 - as time-domain procedure, 193–200, 194f
 - Woody technique, 141–142
- Finite element models, 270–271
- Finite impulse response filters, 175
- Flat-line signal in EEG, in slow voltage shifts, 125, 167, 168
- fMRI
 - activation centers in, 276
 - BOLD signal in, 23
 - compared to ERP source localization, 290–291
 - compared to event-related potentials, 16
 - compared to other recording techniques, 24t, 267
 - correspondence with ERP data, 285
 - spatial gaussian filters in, 212
- Folds, cortical, 20, 31
- Foolproof techniques, 34
- Forward problem, 33, 268
- Forward solution, 269–271
 - boundary element model in, 271
 - finite element models in, 270–271
- Fourier analysis, 58, 187
 - transient waveforms represented in, 192
- Fourier transform, 143, 189, 200–201, 340n
 - in detection of EMG activity, 169
 - inverse, 189, 201, 201f
- Fractional area latency, measurement of, 239–242, 240f, 248
- Frame buffers in video cards
 - in CRT monitors, 325, 329
 - in LCD monitors, 330
- Frequencies
 - amplitude of, 187–191
 - cutoff. *See* Cutoff frequency
 - phases of, 191
- Frequency domain, 317
 - relation to time domain, 182, 184, 187, 200–204, 201f, 202f
 - and distortion from filters, 192–193
- Frequency-domain filters, 175, 187–193, 188f
 - problem with, 191–193
- Frequency response function of filters, 179, 180f, 188f, 190
 - with causal filters, 214–215
 - with double filtering, 216
- Friston, K. J., 285
- Full width at half maximum (FWHM), in gaussian function, 212–213
- Functional magnetic resonance imaging. *See* fMRI
- FWHM. *See* Full width at half maximum
- Gain settings on amplifiers, 125, 128
- Galambos, R., 2, 4, 10b, 42, 149, 162
- Ganis, G., 38, 45
- Garner, W. R., 296
- Gasser, T., 171, 172
- Gaussian filters
 - high-pass, 218f, 219–220, 221f
 - low-pass, 210f, 212–214
 - frequency response function, 210f, 212
 - full width at half maximum value, 212

- Gaussian filters (cont.)
 - impulse response function, 210f, 212
 - temporal distortion from, 213–214
- Gaussian impulse response functions, 321
 - and noise affecting latency measures, 241
- Gauthier, I., 38
- Gazzaniga, M. S., 46
- Gehring, W. J., 46, 47
- Generator site changes, effects of, 255–257
- Geodesic sensor net, 122
- George, J. S., 285, 294
- George, N., 38
- Gevens, A., 32
- Gibbs, F. A., 3
- Girelli, M., 13, 70b
- Glaser, E. M., 175
- Go/No-Go trials, and lateralized readiness potential, 81, 84–85
- Gorodnitsky, I. F., 172
- Grand averages, 17–21, 27
 - with bright and dim stimuli, 253f
 - and mean amplitude measures, 235
 - and peak amplitude measures, 232, 233
- Gratton, G., 48, 170, 171, 172, 173
- Gray, C. M., 135
- Greenhouse-Geisser epsilon adjustment, 259–260, 341n
- Ground circuit, 102–103
- Ground electrode, 102, 103
- Gustatory responses, 40

- Hackley, S. A., 39, 80–86
- Hagoort, P., 46
- Hake, H. W., 296
- Half-amplitude cutoff, 179, 180f, 314, 321
 - in gaussian filter, 212–213
- Half-gaussian filters, 221f, 222
- Hämäläinen, M. S., 283, 284
- Hansen, J. C., 100–101, 168, 239, 248, 340n
- Hansen's axiom, 100, 112, 152, 185–187, 208, 213
- Headbox, 308
- Headphones, shielding of, 324
- Heart activity, detection of, 164f, 169
- Heffley, E. F., 58, 262
- Heinze, H., 276, 297b
- Helmholtz, H., 34, 269

- Heterogeneity of variance and covariance, 259
- High-pass filters. *See* Filter(s), high-pass
- Hijacking ERP components, 94–95
- Hillyard, S.
 - on auditory selective attention, 75–80
 - on C1 wave, 36, 59
 - on converging evidence, 297b
 - on eye movements, 162
 - on 50 percent area latency, 242
 - on fractional area latency, 239, 248
 - on hijacking ERP components, 94
 - on impedance of skin, 121
 - laboratory at UCSD, 2, 10b, 100
 - on language-related components, 45, 46
 - on latency jitter, 135
 - on mismatch negativity, 39
 - on modality-specific P3 wave subcomponents, 35
 - on N1 wave, 37
 - on N2 family, 40, 41
 - on N2pc component, 14
 - on overlap patterns, 148, 149
 - on P3 family, 42
 - on replication of results, 251b
 - on slow voltage shifts, 167
 - on steady-state ERPs, 151
 - on subtle confounds, 70b
 - on target letter shapes, 68
 - on transient responses, 150f
- Hillyard principle, 68–69, 74, 97
- Holcomb, P. J., 45, 46
- Holroyd, C. B., 47
- Homogeneity-of-covariance assumption, 258–259
- Hopf, J.-M., 37, 287f, 297b
- Hopfinger, J. B., 149, 151
- Huang, M., 276, 293
- Humphries, C., 172

- Ideal filters, windowed
 - high-pass, 220, 221f
 - low-pass, 208–209, 210f, 213
- Ignored stimuli
 - processing of, 22
 - responses to, 75–77
- Ikui, A., 40
- Ilmoniemi, R. J., 283, 284, 286
- Impedance, 117–119, 314, 335–336

- and common mode rejection, 120–121, 314
- measurements of, 119
- problems from, 120–122
- reduction of, 119–120
- and signal quality with high-impedance systems, 122–123
- and skin potentials, 121
- Impedance meter, 309–310
- Impulse response filters
 - finite, 175, 200
 - infinite, 200
- Impulse response function, 196–200, 198f, 321
 - of causal filters, 214
 - convolution in time domain, 197–199, 198f, 200, 201–203, 202f
 - gaussian, 321
 - high-pass, 218f, 219–220, 221f
 - and noise affecting latency measures, 241
 - high-pass
 - creation of, 217–219, 218f
 - gaussian, 218f, 219–220, 221f
 - unity, 217, 218f
- Independent components analysis (ICA), 58, 60, 242, 263
 - in artifact correction, 172
- Inductance, 117
- Inference, strong, 295
- Interactions with electrode site, 254–258, 256f
- Intercom system, 310
- Interrupt
 - vertical retrace, 328
 - video blanking, 328
- Invasiveness of recording techniques, 24–25, 24t
- Inverse Fourier transform, 189, 201, 201f
- Inverse problem, 33–34, 269
 - minimum norm solution in, 285
- Ipsilateral waveforms, N2pc component in, 15–17
- Isreal, J. B., 44
- Ito, S., 47
- Jackknife technique to measure onset
 - latency differences, 249
- Jaskowski, P., 42
- Jasper, H. H., 3, 118b
- Jeffreys, D. A., 36, 37
- Jennings, J. R., 259
- Jitter, latency. *See* Latency, variability of
- John, E. R., 5
- Johnson, R., Jr., 43, 44, 58
- Joyce, C. A., 166, 172
- Jung, T. P., 172
- Keppel, G., 258
- Klem G. H., 119b
- Knight, R. T., 42
- Kok, A., 18, 43
- Koles, Z. J., 292
- Kopell, B. S., 22
- Kornhuber, H. H., 47
- Kramer, A. F., 61, 225
- Kutas, M., 38, 43, 44, 45, 46, 62, 94, 172, 257
- Labeling conventions for ERP components, 10–11, 35
- Laboratory setup, 303–332
 - accessories, 309–310, 311b–312b
 - amplifier types, 314–315
 - behavioral response input devices, 306–307
 - computers, 303–305
 - data acquisition system, 303–318, 304f
 - data analysis system, 318–322
 - digitization software, 315–318
 - electrode-amplifier-computer connections, 307–308
 - electrode types, 313
 - recording chamber, 309
 - seating, 305–306
 - stimulus presentation system, 322–332
- Language comprehension
 - assessment of, 22
 - and semantic mismatch
 - in attentional blink paradigm, 89
 - difference waves in, 54
- Language-related ERP components, 45–46
 - and N400 component in word identification, 89–93
- Latency
 - 50% area, 139
 - fractional area, 239–242, 240f, 248

- Latency (cont.)
 - and labeling problems, 35
 - local peak, 238
 - measurements of, 57, 237–249
 - compared to reaction time effects, 243–247, 244f
 - onset, 66, 247–249. *See also* Onset
 - latency or time
 - P3 wave, factors affecting, 44–45
 - peak, 22–23, 52, 237–239
 - relation to amplitude, 52, 53f, 55–56
 - shift caused by filters, 181
 - variability of, 135–139, 136f, 139f
- Latent ERP components
 - assessment of, 51–57
 - avoiding ambiguities and misinterpretations in, 61–74
 - examples of, 53f
- Lateralized readiness potential (LRP), 48, 65
 - isolation with difference waves, 82–83
 - and partial information transmission, 80–87
 - usefulness of, 86b
- Lawson, D., 117
- LCD monitors, 330–332, 331f
- Leahy, R. M., 271, 278, 298, 299
- Lehmann, D., 284
- Lennox, W. G., 3
- Leuthold, H., 45
- Lewis, P. S., 271
- Lights, electrical noise from, 114
- Lindsley, D. B., 49
- Line-frequency filters, 113, 180f, 182, 186, 208
- Line-frequency noise, 113, 317
- Linear filters, high-pass, 219
- Lins, O. G., 117, 162, 163, 171, 172, 173
- Liu, A. K., 285
- Local field potential recordings, 28
- Local peak amplitude, 231, 341n
- Local peak latency, 238
- Localization methods, 34, 60, 267–300
 - distributed source approaches in, 269, 281–289
 - equivalent current dipoles and BESA approach in, 269, 271–280
 - forward problem and solution in, 268–271
 - as model but not measurement of electrical activity, 289–292
 - and principles of scientific inference, 295–297
 - probabilistic approaches in, 292–294
 - recommendations for, 294–300
 - reporting range of solutions in, 292–294, 293f
- Locus of selection, and attention, 75
- LORETA. *See* Low-resolution electromagnetic tomography
- Loveless, N. E., 49
- Low-pass filters, 127–128, 178, 314. *See also* Filter(s), low-pass
- Low-resolution electromagnetic tomography (LORETA), 284–285, 298
- LRP. *See* Lateralized readiness potential
- Luck, S. J.
 - on advantages of ERPs, 22
 - on converging evidence, 297b
 - on detection of color and motion, 13
 - on difference waves, 64, 65
 - on dual-task performance, 89–94
 - on 50 percent area latency, 242
 - on latency jitter, 135
 - on minimum norm solution, 285
 - on modality-specific P3 wave
 - subcomponents, 35
 - on N2 family, 40, 41
 - on N2pc component, 14
 - on overlap patterns, 149
 - on P1 wave, 36
 - on P2 wave, 37
 - on P3 family, 43, 45
 - on reaction times, 246
 - on steady-state ERPs, 151
 - on subtle confounds, 70b
 - on target letter shapes, 68
- Machizawa, M. G., 41
- Magliero, A., 44
- Magnetic fields, 30f, 32–33, 287f
 - event-related. *See* Event-related magnetic fields
- Magnetic resonance imaging (MRI), 298
 - in cortically constrained distributed source localization, 282
 - functional. *See* fMRI

- Magnetism, relation to electricity, 336–337, 336f
- Magnetoencephalogram (MEG), 33
 - fields compared to EEG fields, 286–288
- Makeig, S., 58, 143, 172, 319
- Mangun, G. R., 37, 149
- MANOVA, 262
- Mastoid reference sites, 106–107, 308
 - average mastoids reference derivation, 107–108
 - linked mastoids reference, 107
- MATLAB program, 148, 319–320, 330
- Matthews, B. H. C., 3
- McCarthy, G., 43, 44, 46, 94, 255, 257
- McClelland, J. L., 80
- McPherson, W. B., 45
- Mean amplitude
 - compared to peak amplitude, 73
 - measurement of, 229, 234–235
 - advantages of, 234–235
 - compared to low-pass filtering, 234
 - problems with, 235
- Measuring ERP amplitudes, 229–237, 229f
 - area amplitude, 229–230
 - baselines in, 236–237
 - mean amplitude, 229, 234–235
 - peak amplitude, 229, 230–234
 - peak-to-peak, 237
- Measuring ERP latencies, 57, 237–249
 - compared to reaction time effects, 243–247, 244f
 - fractional area latency, 239–242, 240f
 - onset latency, 247–249
 - peak latency, 237–239
- MEG. *See* Magnetoencephalogram
- Michel, C. M., 284
- Microphones, 310
- Miller, J., 48, 80–86, 248, 249
- Miltner, W., 278
- Minimum norm solution in distributed
 - source localization, 283–286
 - combined constraints in, 285
 - depth-weighted, 284, 298
 - LORETA technique in, 284–285
- Mirror symmetry of dipoles in simulation
 - study of BESA, 278–279, 341n
- Mismatch negativity (MMN), 39
- Mismatch, semantic
 - in attentional blink paradigm, 89
 - difference waves in, 54
- Models of electrical activity compared to measurements, 289–292
- Moecks, J., 171, 172
- Monitoring, real-time, 316, 317
- Moore, C. M., 86b
- Moran, J., 297b
- Mosher, J. C., 271
- Motion-defined targets, detection of, 13–17
- Motor ERPs in eyeblinks and eye movements, 173
- Movement-related components, 48
- Moving-window techniques in time-locked spectral averaging, 143
- MRI. *See* Magnetic resonance imaging
- Multiphasic waveforms, latency variability affecting, 136f, 140
- Multiple electrode sites, and ANOVA results, 254
- Multiple peaks, analysis of, 262–263
- Multiple signal characterization (MUSIC), 271
- Multi-start approach to source localization, 276, 294
- Multi-unit recordings, 28
- Muscle activity
 - detection of, 164f, 169
 - low-pass filtering of noise from, 208
 - post-auricular reflex in, 324
- Music as background in recording, 312
- N1 component, 10–11
 - auditory, 39, 79
 - modality-specific, 35
 - visual, 37
- N2 component, 10–11, 40–41
 - basic N2, 40
 - modality-specific, 35
- N2a, 41
- N2b, auditory and visual, 40, 41
- N2pc, 14, 15–17, 41, 65, 297b
 - isolation of, 15–17
 - and physical stimulus confounds, 70b–71b
- N10 component, 40
- N170 component, visual (faces), 37–38
- N200 component, 11b
- N280 component, 46

- N400 component, 11b
 - discovery of, 62
 - in dual-task performance, 89–93
 - in experimental manipulations, 61–65
 - in semantic violations, 45–46
 - and word identification, 93
- Näätänen, R., 35, 39, 40, 59
- Nagamine, T., 48
- Naming components, 10–11
- Negative-upward plotting, 9
- Negative variation, contingent, 4–5, 48
- Neurons, electrical activity in, 27–32
- Niese, A., 94
- Noise, 12, 339n
 - affecting peak amplitude measures, 231–232
 - from alpha waves, 177, 317
 - elimination of, 213
 - in averaged waveforms, 131, 133
 - and common mode rejection, 120–121
 - electrode impedance affecting, 123
 - environmental sources of, 112–116, 305, 306, 308, 309
 - filtering of, 180f, 182, 208
 - and 50 percent area latency measure, 241
 - and importance of clean data, 86–87, 99–101, 185
 - in LCD monitors, 332
 - line-frequency, 317
 - filtering of, 113, 180f, 182, 186, 208
 - and onset time, 247
 - and peak latency measures, 238, 241
 - reduction with filters, 177
 - from skin potentials, 121
 - sources of, 100
- Noncausal filters
 - high-pass, 222
 - low-pass, 214
- Nonlinear measures
 - peak amplitude, 232, 233
 - peak latency, 238
- Nonsphericity, 259
- Non-uniqueness problem in distributed
 - source localization, 281–283
- Normalization of data, 257–258
- Norman, D. A., 75
- Notch filters, 178, 182, 186, 315
 - frequency response functions, 191
 - temporal distortions from, 204–207, 206f
- Null hypothesis, acceptance or rejection of, 253
- Number of trials, and signal-to-noise ratio, 123, 133–134
- Nunez, P. L., 34, 107
- Nyquist theorem, 127, 176
- Oddball experiment, 7
 - signal averaging in, 134
- Offline filtering, recommendations for, 181, 185, 186–187
- Offset time, filters affecting, 183, 183f
- Ohms, 334
 - in impedance measurements, 119
- Ohm's law, 166, 335
- Olfactory responses, 40
- On-line averaging, 317
- Onset latency or time, 66
 - differences measured between two conditions, 249
 - filters affecting, 183, 183f
 - of lateralized readiness potential, 85
 - measurement of, 247–249
- Operator dependence of equivalent current
 - dipole localization, 275, 277
- Orientation of dipoles, averaging of, 31
- Oscillations
 - amplitude, measurement of, 142–143
 - artifactual, caused by filters, 183f, 184
 - voltage, sources of, 113
- Osman, A., 80, 86b, 248
- Osterhout, L., 46
- Overlap, 145–149, 146f
 - adjacent response (ADJAR) filters for, 149
 - in analysis of multiple peaks, 262, 263
 - area-based measures in, 140
 - difference waves for, 91, 94–95
 - and expansion of time between stimuli, 148
 - high-pass filtering of, 149
 - isolation of components in, 247
 - management of, 148–149
 - in mean amplitude measures, 235
 - in peak amplitude measures, 232–233
 - simulation of, 148
 - subtraction of, 149
- Overshoots caused by filters, 218f, 219–220

- p-values
 - and .05 criterion, 250
 - adjustment in violation of ANOVA assumptions, 259–260
- P1 component, 10–11
 - visual, 36
 - modality-specific, 35
- P2 component, 10–11
 - amplitude measurements, 263
 - visual, 37
- P3 component, 10–11, 42–45, 339n
 - amplitude of, 43–44
 - in attentional blink context, 93–94
 - context updating hypothesis of, 42–43
 - discovery of, 5
 - elicited by bright and dim stimuli, 73, 252
 - latency of, 44–45
 - modality-specific, 35
 - P3a, 42
 - P3b, 42
 - signal averaging in oddball experiment, 134
 - and stimulus evaluation time, 93–94
 - and uncertainty, 42–43, 48
- P100 component, 11b
- P300 component, 11b
- P600 component, 46
- Partial information transmission, study of, 80–87, 84f
- Pascual-Marqui, R. D., 284
- Patterson, T., 248, 249
- Peak(s), 10–11
 - artifactual, added by filters, 179
 - compared to components, 52, 230, 233, 239
 - multiple, analysis of, 262–263
 - relation to latent components, 51–57, 53f
 - shapes of, 53f, 54
 - X-within-Y-of-peak function, 168
- Peak amplitude, 139, 229
 - compared to mean amplitude, 73
 - in filtered waveforms, 232
 - local, 231, 341n
 - measurement of, 229, 230–234
 - noise affecting, 231–232
 - as nonlinear measure, 232, 233
 - simple, 231, 341n
- Peak-based measures compared to area-based, 139–140
- Peak latency, 22–23, 52
 - local, 238
 - measurement of, 237–239
 - noise affecting, 238, 241
 - as nonlinear measure, 238–239
 - precautions with, 239
- Peak-to-peak amplitude
 - in electrooculogram, 155–156, 157
 - measurements of, 237
 - in saccade detection, 165
 - in slow voltage shifts, 167
- Pelli, D. G., 324, 330
- Pernier, J., 32, 58, 111
- Perrin, F., 32, 58, 111, 321
- PET scans. *See* Positron-emission tomography
- Phase(s)
 - of frequencies, 191
 - plots of, 189, 340n
 - response function of filters, 179
 - shift caused by filters, 181
- Phillips, C., 285
- Physical stimulus confounds
 - avoidance of, 74
 - effects of, 67–74, 70b–71b
- Picton, T. W.
 - on auditory selective attention, 76
 - on brain electrical source analysis, 271
 - on ERP components, 35, 59
 - on impedance, 167
 - on N1 component, 39
 - on N2 family, 40
 - on overlap, 149
 - on P3 family, 43
 - on plotting ERP data, 225
 - on skin potentials, 121
 - on tin electrodes, 117
- Pixels, 325
- Platt, J. R., 295
- Plonsey, R., 34, 269
- Plotting ERP data
 - examples of, 226–227, 226f
 - line types in, 228
 - multiple electrode sites in, 225–226, 228
 - negative upward and positive downward, 9, 10b
 - recommendations for, 225–229, 321
 - voltage and time scales in, 226

- Polarity
 - and definition of ERP component, 58, 59
 - reversal in eyeblinks, 159–160, 159f, 161
- Polich, J., 18, 42, 43, 117
- Pooled error term, use of, 261
- Pop-out stimuli, 14
- Popper, K., 295
- Positive-downward plotting, 9
- Positron-emission tomography (PET)
 - compared to ERP source localization, 289–292
 - compared to event-related potentials, 16
 - compared to other recording techniques, 24t, 267
- Posner, M. L., 47
- Post-auricular reflex, 324
- Postsynaptic potentials, 28
 - summation of, 29–31
- Potential(s), 40, 101–104, 333
 - event-related. *See* Event-related potentials (ERPs)
 - readiness, 47–48
 - skin, 121
 - vertex positive, 37–38
- Potter, M. C., 88
- Prestimulus interval, and baseline voltage, 236
- Primary auditory cortex, 38
- Primary visual cortex, 35–36
- Principal components analysis (PCA), 58, 59–60, 242, 263
- Pritchard, W. S., 43
- Probabilistic approaches to localization, 292–294
- Probability, and P3 amplitude, 44
- Psychological confounds, effects of, 68
- PsychToolbox, 330
- Raster beam, 325, 326f
- Raymond, J. E., 87, 88
- Reaction time. *See also* 50 percent area latency measure
 - in bright or dim conditions, 71, 74
 - compared to ERP latencies, 243–247, 244f
 - differences, 22, 23
- Readiness potential, 47–48
 - lateralized, 48, 65
- Real-time control in programming, 322
- Real-time monitoring, 316, 317
- Recliner, 169, 306
- Recording, 99–129
 - active and reference electrodes in, 101–112
 - amplification in, 128–129
 - continuous, 315
 - digitization process in, 124–126
 - direct coupled (DC), 126, 185
 - in saccades, 163, 166
 - and electrical noise in environment, 112–116
 - electrodes and impedance in, 116–124
 - epoch-based, 316
 - filters in
 - high-pass, 125–126
 - low-pass, 127–128
 - importance of clean data in, 86–87, 99–101, 185
 - interactions with subjects in, 311b–312b
 - sampling period in, 127
- Recording chamber, 309
- Recursive filters, 200
- Reference electrodes, 103, 104–112, 105f, 308
 - artifacts and noise sources in, 170
 - average across all electrodes, 109–111, 110f
 - mastoid process sites, 106–107, 308
 - average deviation, 107–108
 - linked mastoids reference, 107
 - site selections, 104–112, 105f
 - alternatives to, 109–112, 110f
 - criteria for, 106
- Reflexes, stimulus-related, 324
- Refresh rate of CRT monitor, 325
- Regan, D., 2, 35
- Reliability of ERP waveforms, 17–21, 19f
- Replication as best statistic, 250–251, 251b
- Requin, J., 48
- Residual variance, 272
- Resistance, 334, 335
 - of skull, 33, 339n
- Resource allocation, and P3 amplitude, 44
- Response density waveforms, 246–247
- Response devices, types of, 306–307
- Response-locked averaging, 138f, 140, 307, 320
 - baselines in, 237
- Response-related ERP components, 47–49

- Retina, integration time of, 327, 341n
- Riehle, A., 48
- Ritter, W., 6, 37, 41, 47
- Robson, T., 324
- Rohrbaugh, J. W., 49
- Rossion, B., 38
- Ruchkin, D. S., 175
- Rugg, M. D., 35, 285
- Rules for experimental design, 52–57, 74, 92, 96–97
- Running average filters
 - impulse response function of, 210f, 211–212, 213
 - temporal distortion from, 213–214
- Saccades
 - detection and rejection of artifacts, 162–166
 - electrooculogram in, 163, 164f
 - visual ERP responses in, 163
- Sampling period, 127
- Sampling rate, 127
 - and cutoff frequency, 128
- Sanford, A. J., 49
- Saturation, amplifier, 167–168
- Scalp current density (SCD), 111
- Scalp distribution
 - in brain electrical source analysis (BESA), 272
 - and definition of ERP component, 58, 59
 - distortion of, 236–237
 - in experimental effects or in raw ERP waveforms, 55
 - and inverse problem, 269
 - topographic maps of, 321
 - voltage at different neural generator sites affecting, 254–257, 256f, 258
- Scalp ERPs, 29–31, 39f
- Schendan, H. E., 38
- Scherg, M., 117, 171, 172, 271
- Schmidt, D. M., 285, 294
- Schmolesky, M. T., 275
- Schultz, D. W., 80
- Schwent, V. L., 76
- Scientific inference, principles of, 295–4297
- Seating arrangements for subjects, 169, 305–306
- Seeded dipoles, 276
- Selective attention, auditory, 75–80, 77f, 340n
- Semantics
 - affecting ERP components, 45
 - mismatch in
 - in attentional blink context, 89
 - difference waves in, 54
- Sensory disorders, steady-state response
 - in, 151
- Sensory responses
 - auditory, 38–49
 - evoked by nontarget stimuli, 78
 - visual, 35–38
 - in eyeblinks and eye movements, 173
- Sereno, M. I., 45, 285
- Setting up ERP lab, 303–332. *See also*
 - Laboratory setup
- Shapes of peaks and components, 53f, 54
- Shapiro, K. L., 43, 64, 87, 88, 89–94, 149
- Sheatz, G. C., 4
- Shibasaki, H., 48
- Shielding
 - of cables, 114, 116, 305, 308, 312b
 - of headphones, 324
- Shifts
 - latency, 181
 - phase, 181
 - slow voltage, 166–167, 178, 182
- Shocks
 - from improper grounding, 101–102
 - for somatosensory stimulation, 324
- Side lobes with running average filter, 211
- Signal averaging. *See* Averaging
- Signal-to-noise ratio, 16
 - in averaging, 133–134
 - of difference waves, 65
 - number of trials affecting, 123, 133–134
 - for target and nontarget waveforms, 69, 71
- Silver/silver-chloride electrodes, 117
- Simple peak amplitude, 231, 341n
- Simson, R., 41
- Simulated head, 114–116, 115f
- Simulation study of equivalent current
 - dipole localizations, 278–280, 341n
- Single-unit recordings, 28
- 60-Hz noise, 113
 - filtering of, 188f, 190, 202f, 203–204
- 60-Hz notch filters, temporal distortions
 - from, 204–207, 206f

- Skin potentials, 121, 164f, 166–167
 - high-pass filters for, 125, 178, 182
- Slow voltage shifts, 166–167, 178, 182
- Snyder, A., 267
- Software
 - for data analysis, 318–322
 - data from simulated head, 116
 - for digitization, 315–318
 - testing of, 317–318
 - for stimulus presentations, 322, 330
- Soltani, M., 42
- Somatosensory stimulation, 40
 - artifacts from, 324
- Sommer, W., 45
- Source analysis procedures in artifact correction, 172
- Source localization. *See* Localization
 - methods
- Source waveforms, 273, 274f
- Spatial layout of EEG display, 317
- Spatial resolution of recording techniques, 24t, 25–26
- Speakers, powered, 310
- Spectral averaging, time-locked, 142–145, 144f
- Sphericity, 258
- Spike density waveforms, 246
- SQUID probe, 33
- Squires, K. C., 42
- Squires, N. K., 42
- Static electricity, 102
- Statistical analyses, 250–264, 321
 - follow-up comparisons, 260–262
 - interactions between conditions and electrode sites in, 254–258, 256f
 - for multiple components, 262–263
 - normalization of data in, 257–258
 - results described in, 255b
 - standard approach in (ANOVA), 251–254
 - type I errors in, 250, 253
 - type II errors in, 253–254
 - violation of ANOVA assumptions, 250, 258–260
- Steady-state responses to stimuli, 150–151, 150f
- Step function
 - in eyeblink artifact rejection, 161, 162
 - in saccade detection, 165
 - in slow voltage shifts, 167
- Stimulus confounds
 - avoidance of, 74
 - effects of, 67–74, 70b–71b
- Stimulus evaluation time, P3 wave in, 93–94
- Stimulus-locked averages, 138f, 140
- Stimulus presentation system, 322–332
 - artifacts in, 324
 - timing of event codes in, 322–324
- Strategies for experimental design, 62–66, 94–95, 98
- Strong inference, 295
- Stroop paradigm, 21–22
- Stuss, D. T., 35
- Summation of electrical potentials, 29–31
- Sutton, S., 5
- Swaab, T. Y., 46
- Sweating, and skin potentials, 121, 166, 178
- Syndulko, K., 49
- Syntax affecting ERP components, 46
- Szücs, A., 246
- Tallon-Baudry, C., 143, 145
- Target and nontarget differences, effects of, 67–71
- Target probability, and P3 amplitude, 43
- Tearing artifact, 328
- Teder-Sälejärvi, W. A., 150f
- Temporal jitter, filtering properties of, 147
- Temporal resolution of recording
 - techniques, 24t, 25–26
- 10/20 system for placing electrodes, 118b–119b
- Testing of digitization system, 317–318
- Text files, 317, 321
- Thayer, J. F., 262
- Thorpe, S., 66
- Time constants of filters, 179, 180f, 181
- Time delays between stimuli, and overlapping waveforms, 147, 148
- Time domain, 175, 317
 - distortions from filters, 192–193, 204–223, 206f, 210f
 - in filtering, 193–200, 194f
 - implementation of high-pass filters, 216–219, 218f
 - impulse response function in, 196–200, 198f

- relation to frequency domain, 182, 184, 187, 200–204, 201f, 202f
 - weighting function in, 195–196
- Time-locked spectral averaging, 142–145, 144f
- Timing of event codes, 322–324
- Tin electrodes, 117
- Tomberg, C., 109
- Transfer function, 178–179
- Transient responses to stimuli, 149–150, 150f
 - and filtering, 340n
- Transient waveforms represented in
 - Fourier analysis, 192
- Transmission of partial information, responses to, 80–87, 84f
- Treisman, A. M., 75
- Tucker, D. M., 47, 122, 123
- Type I errors, 250, 253
- Type II errors, 253–254

- Ulrich, R., 248, 249
- Uncertainty, and P3 amplitude, 44
- Uniqueness problem in source
 - localization, 269
- Unity impulse response function, 217, 218f
- Urbach, T. P., 257

- Van Essen, D. C., 340n
 - van Shier, H. T., 47
- Variability
 - between-subject, 17–20
 - latency, 135–139, 136f, 139f
 - within-subject, 18
- Variance, residual, 272
- Vasey, M. W., 262
- Vasjar, J., 271
- Vaughan, H. G., 6–7, 41, 47
- Verleger, R., 42
- Vertex positive potential, 37–38, 40
- Vertex site, 37
- Vertical retrace interrupt, 328
- Very early components, auditory, 38–39
- Video blanking interrupt, 328
- Video cards, frame buffers in
 - in CRT monitors, 325, 329
 - in LCD monitors, 330
- Video monitors, noise from, 113

- Video splitter, 305
- Visual cortex, primary, 35–36
- Visual evoked potential, 7
- Visual evoked response, 7
- Visual inspection in artifact detection, 156, 158
- Visual sensory responses, 35–38
- Visual stimuli presentation
 - CRT monitors in, 324–332
 - LCD monitors in, 330–332, 331f
 - software packages for, 330
 - timing of, 323, 323f
- Vitacco, D., 298
- Vogel, E. K., 22, 36, 37, 41, 43, 64, 89–94, 149
- Voltage, 333
 - absolute, 103
 - between active and reference sites, 101–104
 - ADC range for, 125
 - averaged at time points, 192f, 193–195
 - baseline, 236
 - changes with skin potentials, 121
 - deflection from eyeblinks, 153–154
 - distribution
 - in forward problem, 268
 - in inverse problem, 269
 - and impedance, 117
 - and latent components, 52, 56
 - oscillating, sources of, 113
 - prestimulus, 236
 - at single site, 103
 - slow voltage shifts, 166–167, 178, 182
- Volume conduction, 32
- von Cramon, D., 271

- Wada, M., 40
- Walter, W. G., 4, 49
- Wastell, D. G., 141
- Wauschkuhn, B., 42
- Waveforms
 - distortion by filters, 170, 182–185, 183f
 - overlapping, 145–149, 146f. *See also* Overlap
 - response density, 246–247
 - source, 273, 274f
 - spike density, 246
- Weighting function for filtering, 195–196
 - reversed, 196

- Westerfield, M., 172
- Willoughby, A. R., 47
- Windowed ideal filter
 - high-pass, 220, 221f
 - low-pass, 208–209, 210f, 213
- Woldorff, M. G., 39, 69, 70b, 145, 148, 149, 214, 236
- Wood, C. C., 255, 257, 259, 285, 294
- Woodman, G. F., 22, 65
- Woody, C. D., 141
 - filter technique, 141–142
- Word identification, N400 component in, 89–93
- X-within-Y-of-peak function, 168
- Zubin, J., 5