

Contents

Preface to the First Edition	xvii
Preface to the Second Edition	xix
Acknowledgments	xxi
Contributors	xxiii

Section I: Foundational Science and Instrumentation of Auditory Evoked Potentials

1. Introduction to Auditory Evoked Potentials	3
<i>Samuel R. Atcherson and Tina M. Stody</i>	
1.1 Introduction	3
1.2 What's in this Text?	3
1.3 Overview of Auditory Evoked Potentials	3
1.4 Classification of Auditory Evoked Potentials	4
1.5 A Brief History of Auditory Evoked Potentials	5
1.6 Competencies in Auditory Evoked Potential Measurement	6
References	6
2. Basic Instrumentation, Acquisition, and Recording Considerations	7
<i>Tina M. Stody and Samuel R. Atcherson</i>	
2.1 Introduction	7
2.2 Signal versus Noise	7
2.3 Digital Signal Processing	7
2.4 Time and Frequency Domain	8
2.5 Instrumentation	8
2.5.1 Stimulus Generator	8
2.5.2 Transducers	8
2.5.3 Trigger	9
2.6 Acquisition Parameters	9
2.6.1 Differential Amplification	9
2.6.2 Filtering	10
2.6.3 Signal Averaging	12
2.7 Electrodes	12
2.7.1 Electrode Impedance	13
2.7.2 Electrode Types	13
2.7.3 Electrode Placement	13
2.7.4 Number of Electrodes versus Number of Channels	14
2.8 Recording Considerations for Auditory Evoked Potentials	15
2.8.1 Electrode Array and Number of Channels	15
2.8.2 Time Window	15
2.8.3 Sampling Rate	16
2.8.4 Number of Sweeps (Stimulus Repetitions)	16
2.8.5 Stimulation Rate	17
2.8.6 Filter Settings	17
2.8.7 Amplification	17
2.8.8 Artifact Rejection	18
2.8.9 Electromagnetic Artifacts	18
2.9 General Subject Factors	18
2.9.1 Age	18
2.9.2 Gender	19
2.9.3 Muscle Activity	19
2.9.4 Attention	19
2.9.5 Temperature	19
References	19

3.	Principles of Analysis and Interpretation	21		
	<i>Samuel R. Atcherson and Tina M. Stoody</i>			
3.1	Introduction	21	3.3.3	Collecting Normative Data
			3.3.4	Analysis Techniques During Signal Averaging ...
3.2	Transient versus Steady-State Responses ...	21		
3.3	Analyses in the Time Domain	22	3.4	Analysis in the Frequency Domain: Auditory Steady-State Response
3.3.1	Analysis Techniques Following Signal Averaging	22		References
3.3.2	Other Time-Domain Techniques	27		30
4.	Fundamental Principles of Neuroanatomy and Neurophysiology Related to Auditory Evoked Potentials	31		
	<i>Samuel R. Atcherson and Sheryl S. Shoemaker</i>			
4.1	Introduction	31	4.4	General Principles of the Auditory Nervous System
4.2	Brief Review of the Peripheral and Central Auditory Neural Systems	31	4.4.1	Synchrony
4.2.1	Cochlear Mechanics	32	4.4.2	Phase Locking
4.2.2	Monaural Contributions to the Auditory System	33	4.5	Peripheral and Central Auditory System Considerations for AEPs
4.2.3	Binaural Interaction in the Auditory System ...	33	4.5.1	Exogenous versus Endogenous Potentials
4.3	General Neurophysiology Concepts	33	4.6	Sonomotor Reflexes
4.3.1	Basic Neuronal Anatomy and Physiology	33		References
4.3.2	Potentials at the Source	34		38
4.3.3	Dipoles	34		
4.3.4	Near- and Far-Field Potentials	35		

Section II: Background Auditory Evoked Potentials

5.	Electrocochleography	43		
	<i>Andrew Stuart[†]</i>			
5.1	Overview	43	5.4	Electrocochleogram Analyses
5.2	Historical Aspects	43	5.4.1	Latency
5.3	ECochG Components/Generators	44	5.4.2	Amplitude
5.3.1	Cochlear Microphonic	44	5.4.3	Spectra
5.3.2	Summating Potential	44	5.5	Conclusion
5.3.3	Compound Action Potential	45		References
5.3.4	Recording ECochG	45		52
5.3.5	Acquisition Parameters	45		
5.3.6	Stimulus Parameters	47		

6.	The Auditory Brainstem Response				55
	<i>Samuel R. Atcherson</i>				
6.1	Introduction	55	6.5	Measurement Parameters	61
6.2	Brief History	55	6.5.1	Overall Waveform Morphology	61
6.3	Description	55	6.5.2	Latency	61
6.3.1	Waveform Morphology	55	6.5.3	Amplitude	61
6.3.2	Neural Generators	56	6.6	Subject Effects	63
6.4	Effects of Various Stimulus and Recording Parameters on the Auditory Brainstem Response	57	6.6.1	Maturation and Aging Effects	63
6.4.1	Stimulus Types	57	6.6.2	Gender	63
6.4.2	Stimulus Polarity	59	6.6.3	Hearing Sensitivity	63
6.4.3	Stimulus Intensity	59	6.7	Useful and Promising Applications	63
6.4.4	Stimulation Rate	59	6.7.1	Weighted Averaging	63
6.4.5	Transducer Types and Artifact	59	6.7.2	Maximum Length Sequence	64
6.4.6	Monaural versus Binaural Presentation	60	6.7.3	Objective Detection Techniques	64
6.4.7	Contralateral Masking	60		References	64
6.4.8	Typical Setup	60			
6.4.9	Electrode Montage	61			
7.	Frequency-Following Responses				67
	<i>Shaum P. Bhagat</i>				
7.1	Introduction	67	7.5.2	Electrode Placement	71
7.2	Basic Properties of the Frequency-Following Response	67	7.5.3	Recording Parameters	71
7.3	Origins of the Frequency-Following Response	67	7.6	Frequency-Following Response Correlates of Cochlear Nonlinearities	72
7.4	Signal Effects on the Frequency-Following Response	67	7.6.1	Primary-Tone Frequency	73
7.4.1	Signal Duration	69	7.6.2	Primary-Tone (f_2/f_1) Ratio	73
7.4.2	Signal Frequency	70	7.6.3	Contralateral Noise	73
7.4.3	Signal Intensity	70	7.6.4	Primary-Tone Level	75
7.5	Recording the Frequency-Following Response	70	7.6.5	Recommendations for Recording Distortion Product Frequency-Following Responses	75
7.5.1	Monaural versus Binaural Stimulation	71	7.7	Frequency-Following Responses as Neuronal Indicators of Brainstem Speech Processing	76
				References	78
8.	Auditory Steady-State Responses				79
	<i>Jackie M. Davie, Derek Petti, and Elizabeth D. Leigh</i>				
8.1	Introduction	79	8.3	Terminology	80
8.2	Historical Overview of ASSR	79	8.3.1	Steady-State Response	80

Contents

8.3.2	Carrier Frequency	80	8.6.5	Response Detection	87
8.3.3	Modulation Frequency	80	8.6.6	Reporting Findings	87
8.3.4	Amplitude Modulation	80			
8.3.5	Frequency Modulation	81	8.7	Subject Effects	88
8.3.6	Mixed Modulation	81	8.7.1	Sleep State and Attention	88
8.3.7	Cosine Stimulus	81	8.7.2	Maturation Effects	88
8.3.8	Frequency (Fourier) Analysis	81			
8.3.9	Phase Coherence	81	8.8	Clinical Applications	88
8.4	Neural Generators	82	8.8.1	Threshold Estimation	88
8.5	Stimulus Parameters	82	8.8.2	Suprathreshold Applications	89
8.5.1	Modulation Rate and Depth	82	8.9	Case Studies	89
8.5.2	Broadband and Narrowband Chirp Stimuli	82	8.9.1	Case 1	89
8.5.3	Intensity	83	8.9.2	Case 2	89
8.5.4	Single versus Multiple-Frequency ASSR	83	8.9.3	Case 3	90
8.5.5	Bone-Conducted ASSR	83	8.9.4	Case 4	91
8.6	Measurement Parameters	84	8.9.5	Case 5	91
8.6.1	Equipment and Supplies	84	8.10	Conclusion	91
8.6.2	Test Setting and Patient Preparation	85			
8.6.3	Recording Parameters	85		References	92
8.6.4	Clinical Testing Procedures	85			
9.	Middle Latency Responses				95
	<i>Ashley W. Harkrider</i>				
9.1	Overview	95	9.3.3	Assessing Cochlear Implant Candidacy and Function	98
9.2	Components of the MLR	95	9.4	Clinical Considerations for MLR Recording ...	100
9.2.1	Na Component	96	9.4.1	Recommended Protocol	100
9.2.2	Pa Component	96	9.4.2	Number of Electrode Channels Available for Recording	100
9.2.3	Nb Component	96	9.4.3	Participant State	101
9.2.4	Pb Component	96	9.4.4	Test Environment	104
9.3	Clinical Applications	96			
9.3.1	Behavioral Threshold Estimation	96		References	104
9.3.2	Neurodiagnostic MLRs	97			
10.	Cortical Event-Related Potentials				107
	<i>Curtis Billings, Letitia White-Minnis, and Samuel R. Atcherson</i>				
10.1	Introduction	107	10.3	Mismatch Negativity	113
10.2	Late Auditory Evoked Potential	108	10.3.1	Description of the Waveform	113
10.2.1	Description of the Waveform	108	10.3.2	Neural Generators	113
10.2.2	Neural Generators	108	10.3.3	Stimulus and Recording Parameters	114
10.2.3	Stimulus and Recording Parameters	109	10.3.4	Measurement Parameters	114
10.2.4	Measurement Parameters	110	10.3.5	Subject Effects	114
10.2.5	Subject Effects	110	10.3.6	Clinical Applications	115
10.2.6	Clinical Applications	111			

10.4	P3 Cognitive Potential	115	10.4.5	Subject Effects	116
			10.4.6	Clinical Applications	117
10.4.1	Description of the Waveform	115			
10.4.2	Neural Generators	115	10.5	Conclusions	117
10.4.3	Stimulus/Recording Parameters	115		References	117
10.4.4	Measurement Parameters	116			
11.	Vestibular Evoked Myogenic Potentials				123
	<i>Bre Myers</i>				
11.1	Background/Historical Information	123	11.4.1	Cervical Vestibular Evoked Myogenic Potential Waveform	126
11.1.1	Myogenic versus Sensory Recordings	124	11.4.2	Ocular Vestibular Evoked Myogenic Potential Waveform	128
11.2	Vestibular Evoked Myogenic Potential Pathways	124	11.5	Clinical Considerations	128
11.2.1	Cervical Vestibular Evoked Myogenic Potential	124	11.5.1	Subject Effects	128
11.2.2	Ocular Vestibular Evoked Myogenic Potential	124	11.6	Clinical Interpretation	130
11.3	Stimulus/Collection Parameters	124	11.7	Clinical Application	130
11.3.1	Stimulus Parameters	124	11.8	Conclusion	131
11.3.2	Electrode Arrays	125		References	131
11.3.3	Collection Parameters	126			
11.4	Waveform Characteristics	126			

Section III: Clinical Applications and Relevant Case Studies

12.	Clinical Utility of Electrocochleography				135
	<i>Alfarghal Mohamad and Rosario La Gumina</i>				
12.1	Introduction	135	12.3.5	ECochG in Third Window Syndrome: Superior Canal Dehiscence Syndrome and Perilymphatic Fistula	139
12.2	ECochG Components	135	12.3.6	ECochG in Auditory Neuropathy Spectrum Disorder	140
12.3	Interpretation of ECochG Results	135	12.3.7	Cochlear Synaptopathy (Hidden Hearing Loss)	140
12.3.1	ECochG in Ménière's Disease	137	12.4	Conclusions	140
12.3.2	Dehydration (Glycerol) Test	138		References	143
12.3.3	Overlap Between Ménière's Disease and Vestibular Migraine	138			
12.3.4	The 3-T Magnetic Resonance Imaging in Ménière's Disease	139			
13.	Automated Auditory Brainstem Response Testing for Newborn Hearing Screening				145
	<i>Leigh Biagio-de Jager and De Wet Swanepoel</i>				
13.1	Introduction	145	13.2	Newborn Hearing Screening Test Performance	145

13.3	Stimulus Parameters	147	13.6.5	Sweeps and Replications	152
13.3.1	Stimuli	147	13.7	Objective Response Detection	152
13.3.2	Rate	147	13.7.1	Testing in Time Domain	153
13.3.3	Polarity	148	13.7.2	Testing in Frequency Domain	154
13.3.4	Intensity	148	13.7.3	Machine Learning	154
13.4	Transducers	148	13.8	Patient Considerations	154
13.5	Transducer Calibration	149	13.8.1	Age	154
13.6	Recording Parameters	150	13.8.2	Hearing Loss	155
13.6.1	Electrode Types	150	13.9	Conclusion	155
13.6.2	Electrode Montage	150		References	155
13.6.3	Filters	150			
13.6.4	Noise Reduction Techniques	151			
14.	Contemporary Protocol for Frequency-Specific ABR Assessment in Infants and Young Children	159			
	<i>Marlene Bagatto and Jace Wolfe</i>				
14.1	Introduction	159	14.7.3	Cross-Check Principle	164
14.2	Setting the Stage	159	14.7.4	Click Evoked ABR	165
14.3	State of Consciousness	160	14.8	Using Tone Burst ABR Threshold Estimations for Hearing Aid Fitting	165
14.4	A Well-Defined Plan	160	14.9	Case Studies	166
14.5	Tone Burst ABR Test Strategy	160	14.9.1	Case 1	166
14.6	Bone Conduction ABR Assessment	162	14.9.2	Case 2	167
14.7	Clinical Tips	163	14.10	Conclusion	169
14.7.1	Waveform Analysis	163		References	169
14.7.2	Three Types of ABR Waveforms	163			
15.	Differential Diagnosis of Auditory Neuropathy Spectrum Disorder	171			
	<i>Christina L. Runge, Sarah Klajbor, Hilary Gazeley, and Hayden Engstrom</i>				
15.1	Potential Sites of Lesion	171	15.4	Case Studies of Auditory Neuropathy Spectrum Disorder	173
15.2	Candidacy for ANSD Testing	171	15.4.1	Case 1: Bilateral Auditory Neuropathy Spectrum Disorder	173
15.3	Evoked Potentials for Diagnosis of ANSD	171	15.4.2	Case 2: ANSD and SNHL	174
15.3.1	Otoacoustic Emissions	172	15.4.3	Case 3: Unilateral Auditory Neuropathy Spectrum Disorder	174
15.3.2	Cochlear Microphonic and Auditory Brainstem Response	172		References	177
15.3.3	Middle Ear Muscle Reflexes	173			
15.3.4	Magnetic Resonance Imaging in ANSD	173			

16.	Evaluation of Balance and Falls Risk Assessment	179			
	<i>Jamie M. Bogle</i>				
16.1	Introduction	179	16.5	Disease Presentation	182
16.2	Background	179	16.5.1	Acquired Vestibulopathy	182
16.3	VEMP Clinical Protocol Considerations	179	16.5.2	Congenital Vestibulopathy	185
16.3.1	Stimulus: Air versus Bone Conduction	179	16.5.3	Central Vestibulopathy	186
16.3.2	Electromyographic Activity	180	16.6	Conclusions	187
16.3.3	Electrode Location	181		References	187
16.4	Typical Presentation	181			
17.	Evaluating Central Auditory Function	191			
	<i>Teri James Bellis and Samuel R. Atcherson</i>				
17.1	Introduction	191	17.6.1	Recording Parameters and Electrode Montage ..	195
17.2	Limitations of Auditory Evoked Potentials in the Evaluation of Central Auditory Function	191	17.6.2	Response Analysis	195
17.3	When Should Auditory Evoked Potentials Be Used?	192	17.6.3	Common Central Auditory Function Uses of the Late Latency Response	195
17.4	Auditory Brainstem Response	192	17.7	P300 Event-Related Potential	196
17.4.1	Electrode Montage and Recording Parameters	192	17.7.1	Electrode Montage and Recording Parameters ..	196
17.4.2	Response Analysis	193	17.7.2	Response Analysis	196
17.4.3	Common Central Auditory Function Uses of the Auditory Brainstem Response	193	17.7.3	Common Central Auditory Function Uses of the P300	196
17.4.4	Complex Auditory Brainstem Response	194	17.8	Other Influences on Central Auditory Function	196
17.5	Middle Latency Response	194	17.9	Case Studies	197
17.5.1	Recording Parameters and Electrode Montage ..	194	17.9.1	Vestibular Schwannoma (Case 1)	197
17.5.2	Response Analysis	194	17.9.2	Traumatic Brain Injury (Case 2)	198
17.5.3	Common Central Auditory Function Uses of the Middle Latency Response	194	17.9.3	Type 2 Diabetes Mellitus (Case 3)	198
17.6	Late Latency Response	195		References	199
18.	Surgical Applications of Auditory Evoked Potentials	201			
	<i>Gregory R. Mannarelli II</i>				
18.1	Mechanisms of Change in Intraoperative AEPs	201	18.2	Auditory Monitoring Modalities	202
18.1.1	Ischemia/Decreased Perfusion	201	18.3	Monitoring Applications	202
18.1.2	Stretching the Nerve/Cerebellar Retraction	201	18.3.1	Hearing Preservation in CPA tumors	202
18.1.3	Anesthesia	202	18.3.2	Monitoring Cerebellar Retraction/Microvascular Decompression	203
18.1.4	Hypothermia	202			

18.3.3	Monitoring Vertebrobasilar Perfusion and/or Brainstem Function	203	18.5.5	Intraoperative Interventions to a Change in Signals	208
18.3.4	Monitoring Cochlear Function	204	18.5.6	Intraoperative Case Log.	208
18.4	The Utility of AEPs in IONM.	205	18.5.7	Optimizing Signals in the Operating Room	208
18.4.1	Improving Outcomes	205	18.5.8	Interpreting Signal Changes	210
18.4.2	Outcome Predictions	206	18.6	Other Intraoperative Monitoring Modalities	210
18.5	Pre-, Peri-, and Postoperative Considerations for AEP Monitoring	207	18.6.1	Free Running and Stimulated Electromyography	210
18.5.1	Preoperative Planning	207	18.6.2	Somatosensory Evoked Potentials	211
18.5.2	Setting Up the Patient	207	18.6.3	Transcranial Motor Evoked Potentials.	211
18.5.3	Running AEP Intraoperatively.	207	18.6.4	Electroencephalogram Monitoring.	212
18.5.4	When to Alert the Surgeon	208	References.	212	
19.	Animal Audiology Applications.	215			
	<i>Kristine E. Sonstrom Malowski, Kathryn Bright, Tina M. Stoody, Jennifer E. Weber, and Peter M. Skip Scheifele</i>				
19.1	Introduction.	215	19.4.2	Estimation of Hearing Thresholds for Canines	217
19.2	History of Animal Audiology and FETCHLAB.	215	19.4.3	Auditory Middle Latency Response.	219
19.3	Who Should Evaluate Animal Hearing?	216	19.4.4	Mismatch Negativity	220
19.4	Canine Evoked Potentials.	216	19.5	Equine Brainstem Evoked Potentials	221
19.4.1	Canine BAER Screening	216	19.6	Other Animals	221
			References.	222	
 Section IV: Clinical Practice and Management					
20.	Patient Preparation, Data Interpretation, and Documentation	227			
	<i>Tina M. Stoody</i>				
20.1	Introduction.	227	20.3.2	Electrode Application	229
20.2	Clinician Preparation.	227	20.4	Data Collection.	231
20.2.1	Case History Review.	227	20.5	After the Test Session	232
20.2.2	Patient Instructions Before Testing	227	20.6	Documentation and Results	233
20.2.3	Supplies and Equipment	227	References.	233	
20.3	Patient Preparation	228			
20.3.1	Patient Orientation.	228			
21.	Stimulation Calibration and Generation.	235			
	<i>Samuel R. Atcherson and Naveen K. Nagaraj</i>				
21.1	Introduction.	235	21.2	Stimuli for Auditory Evoked Potentials.	235

21.3	Calibration of Acoustic Stimuli	235	21.4.2	Steps for Calibrating Acoustic Transients with Calibration Equipment.	240
21.3.1	Methods of Stimulus Calibration.	237	21.5	Generating Custom Stimuli	240
21.4	Other Stimulus Parameters for Consideration	239	21.6	Recording and Editing a Speech Stimulus ...	242
21.4.1	Steps for Conducting Behavioral Calibration of Acoustic Transients	239		References	243
Index					245