Application of Recurrence Quantification to the Analysis of Brain Electrical Activity

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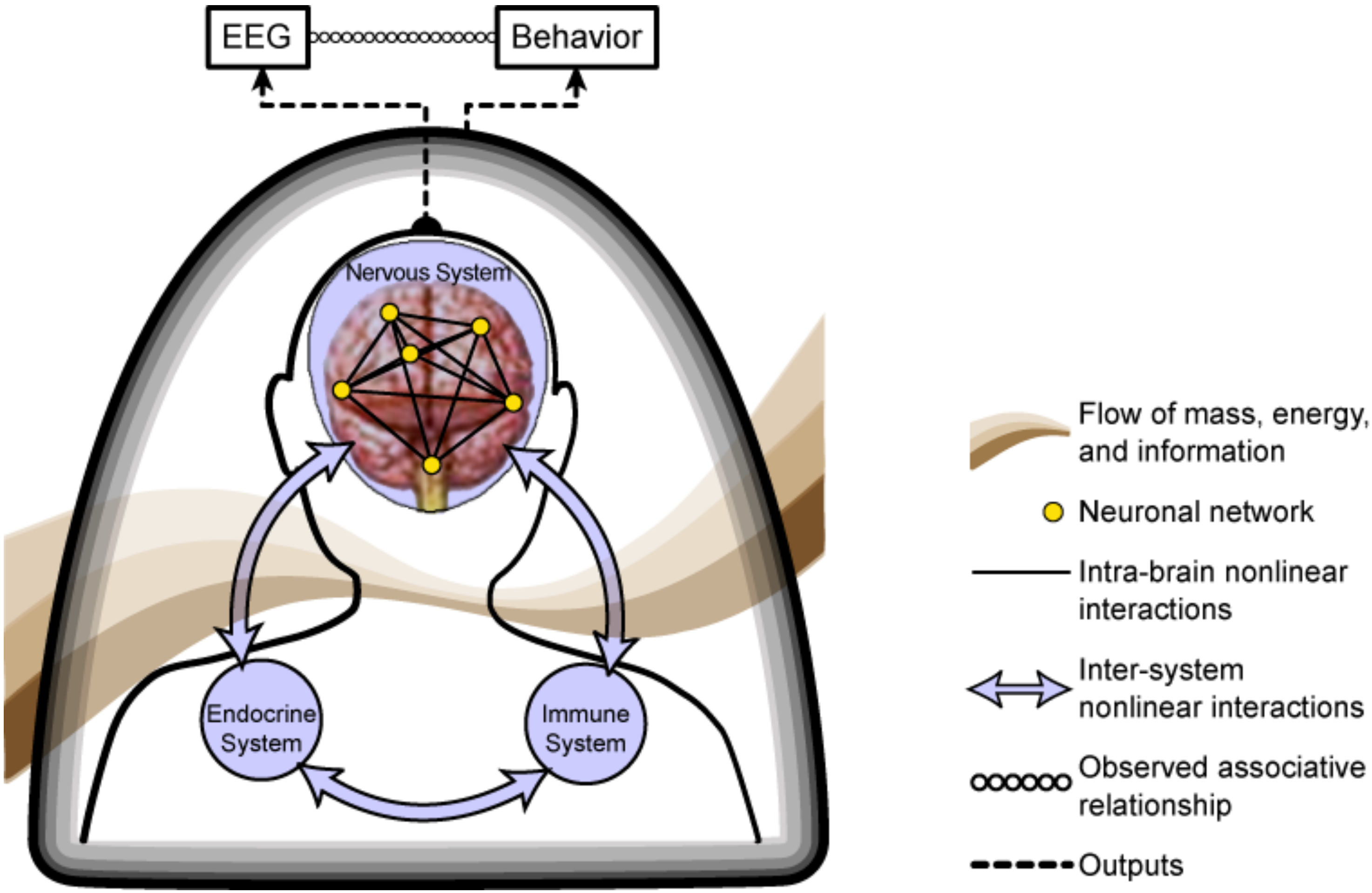
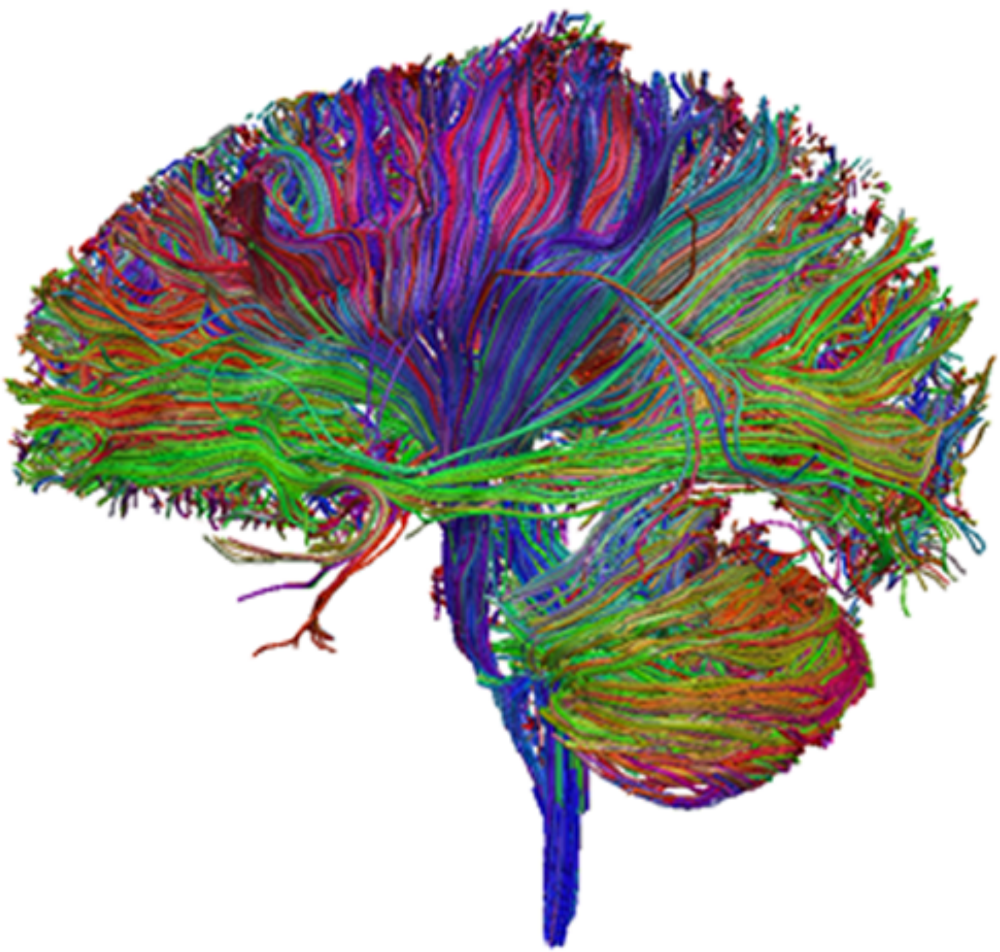
Objectives

- Brain structural complexity
- Recurrence analysis & brain electrical activity
- Applications

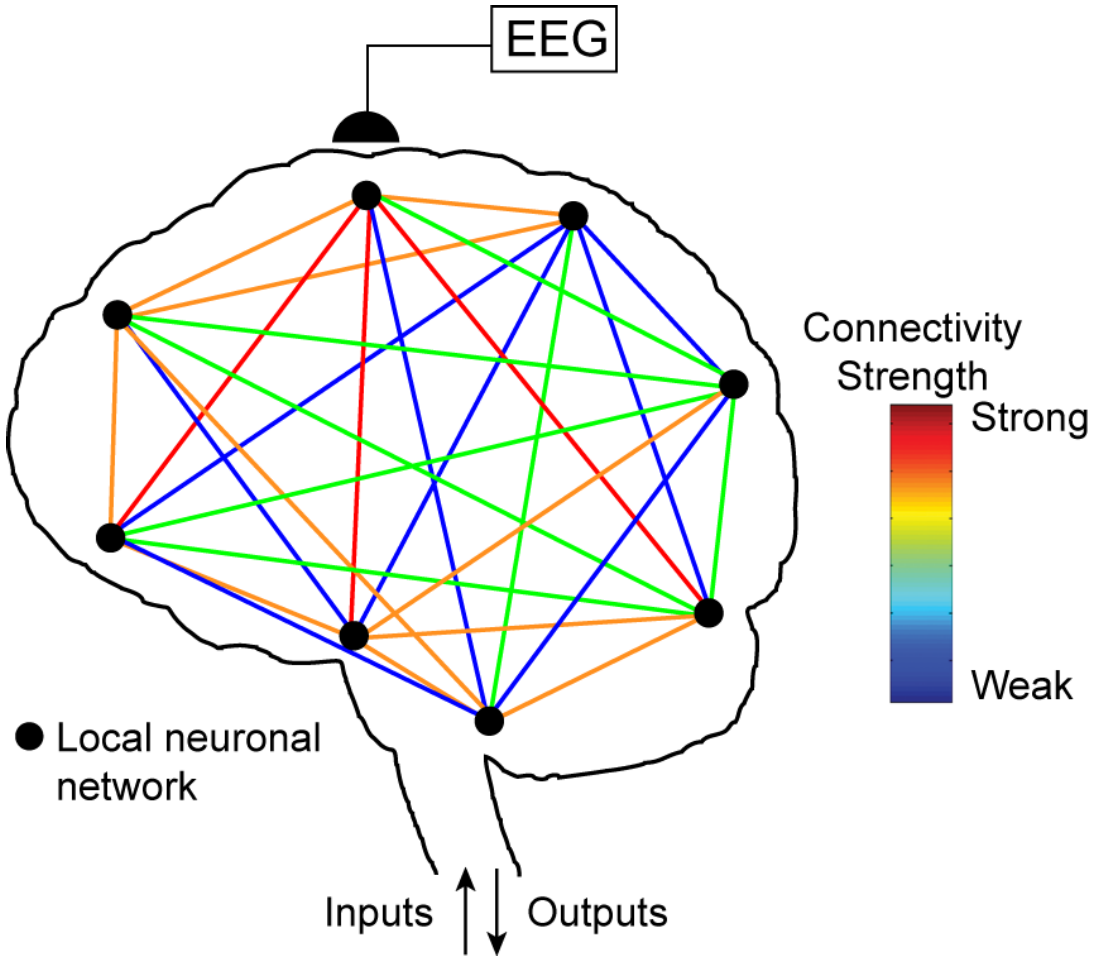
Master Control Function of Brain



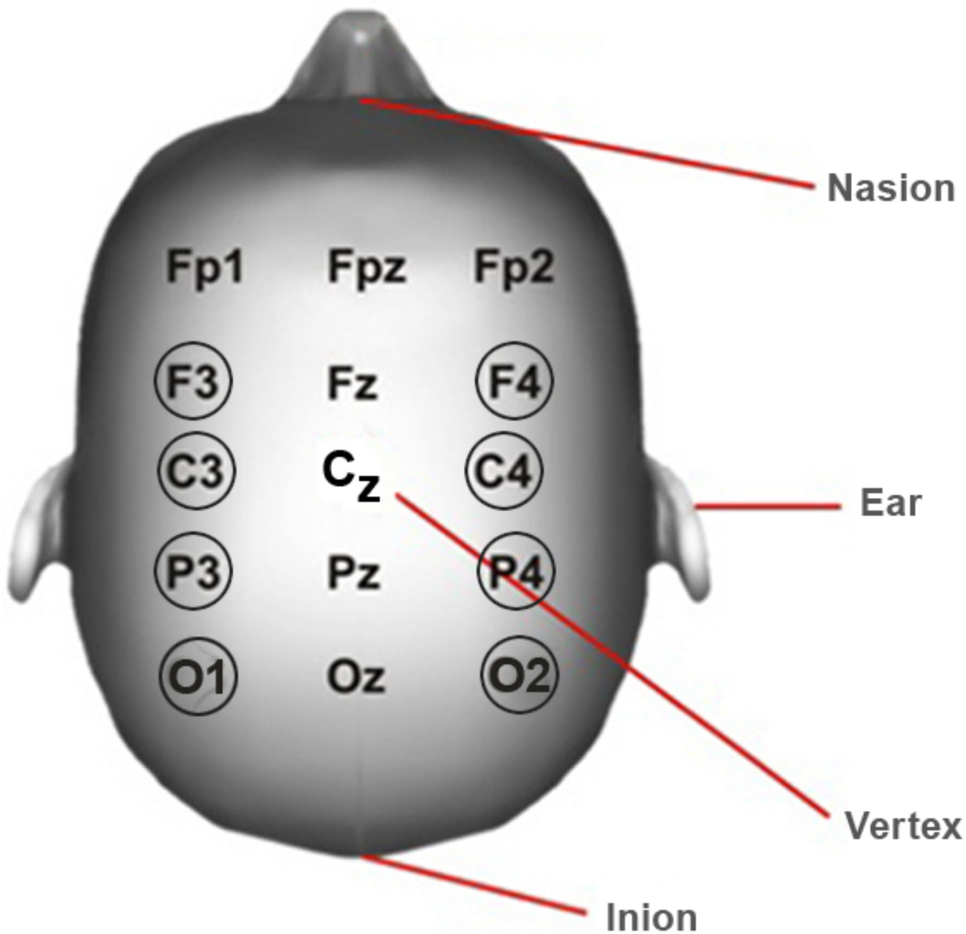
Brain Structural Complexity



Brain Functional Complexity

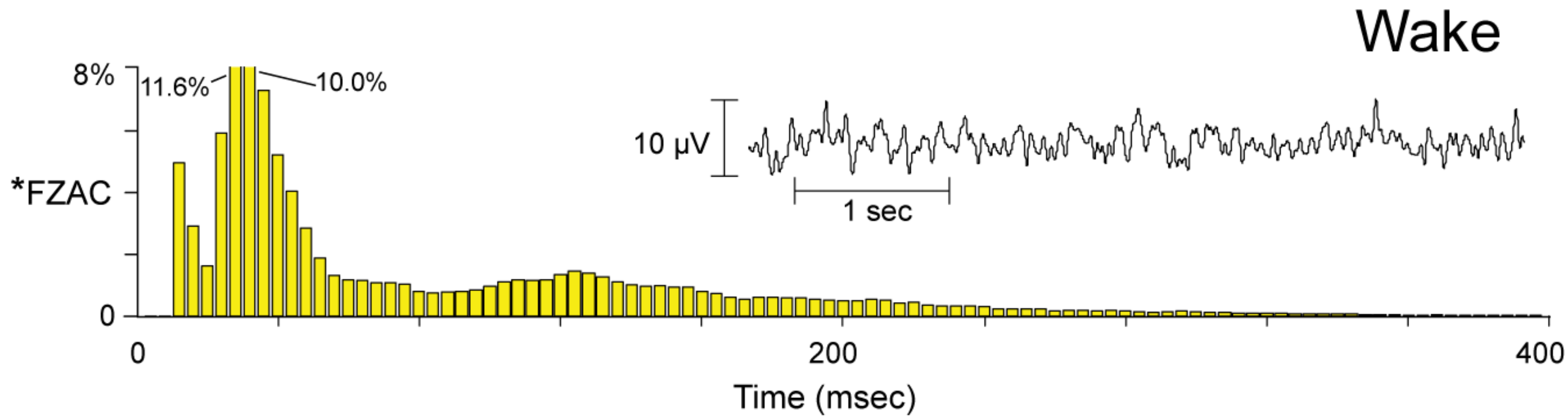


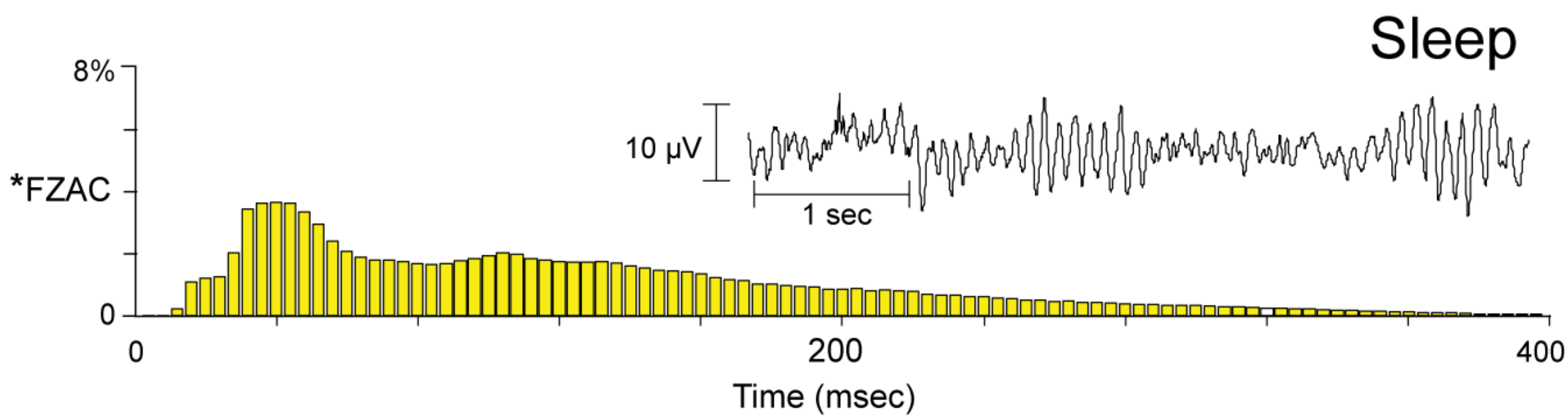
Standardized Scalp Locations and Labels Used for EEG Measurements



- Circled locations used for results presented here (particularly C3)

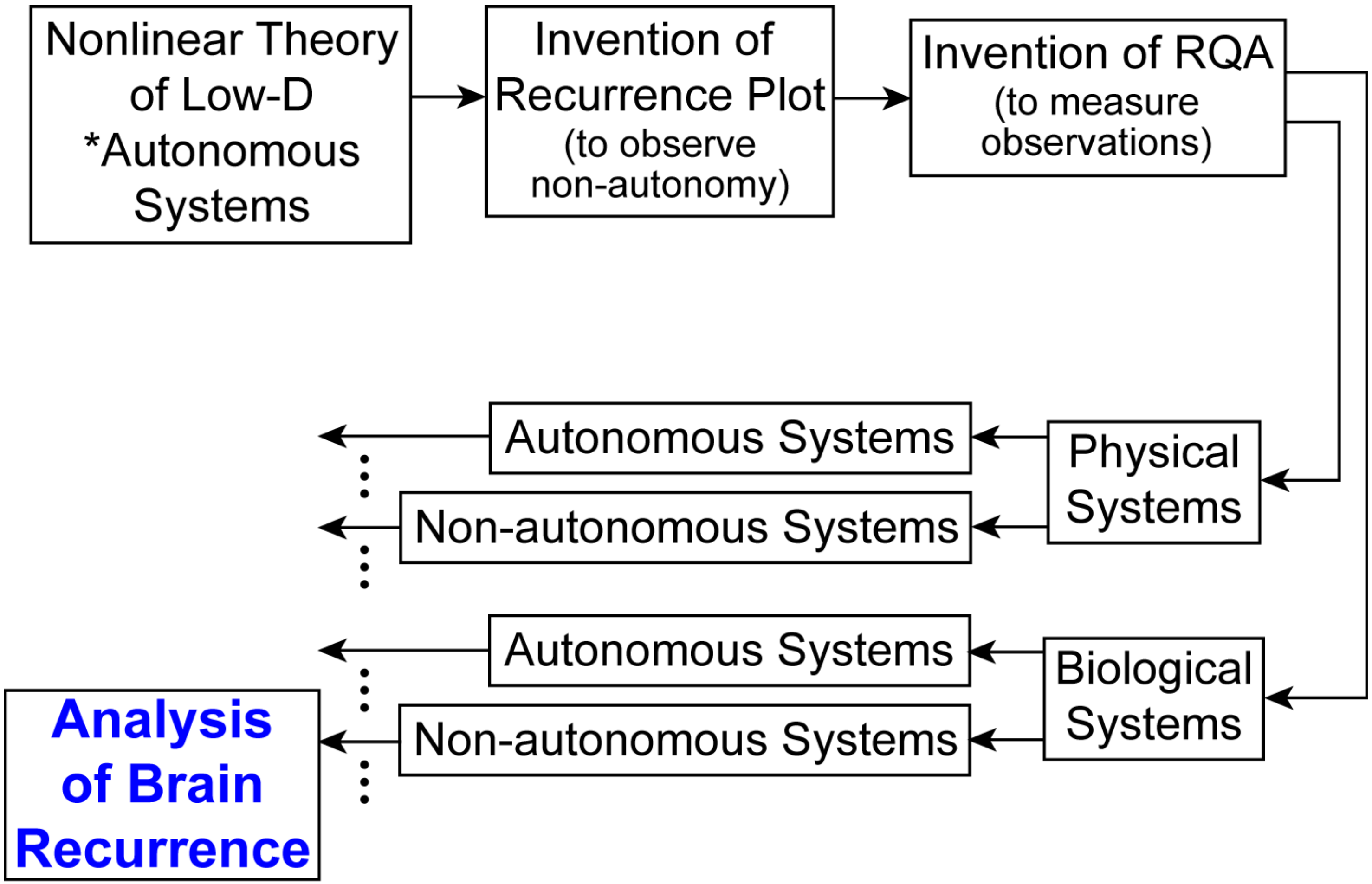
Nonstationarity in the Human EEG
(Normalized Histogram of 1-sec EEG Epochs)





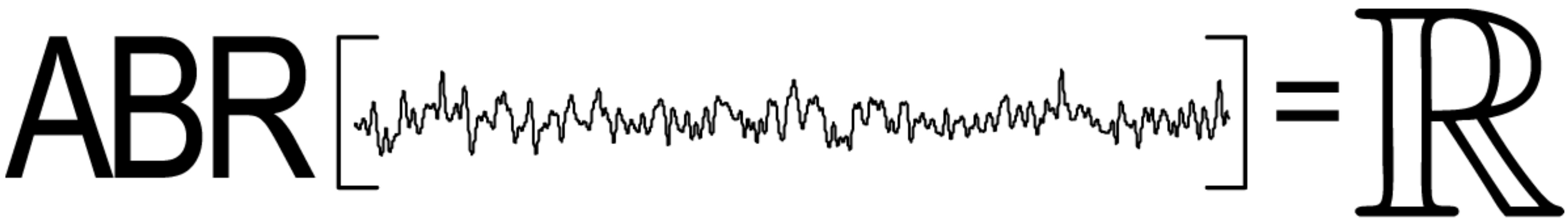
*First zero of the autocorrelation function

History of Brain Recurrence Analysis

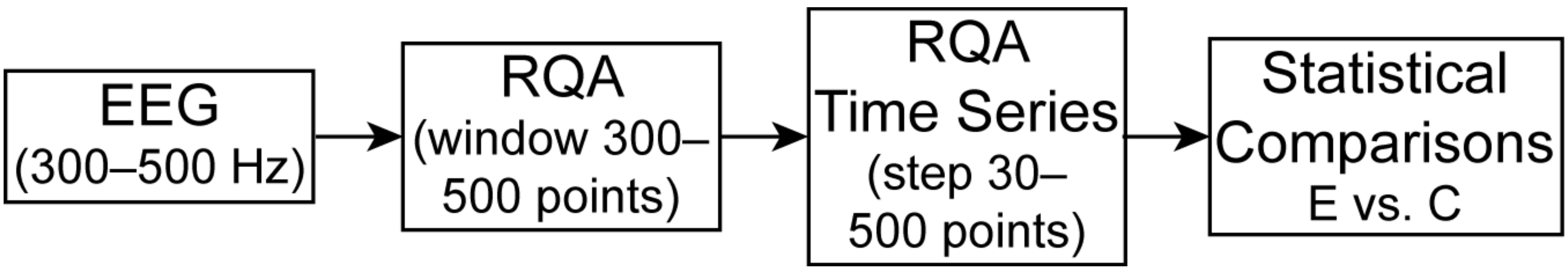


*Time does not appear explicitly in the governing differential law

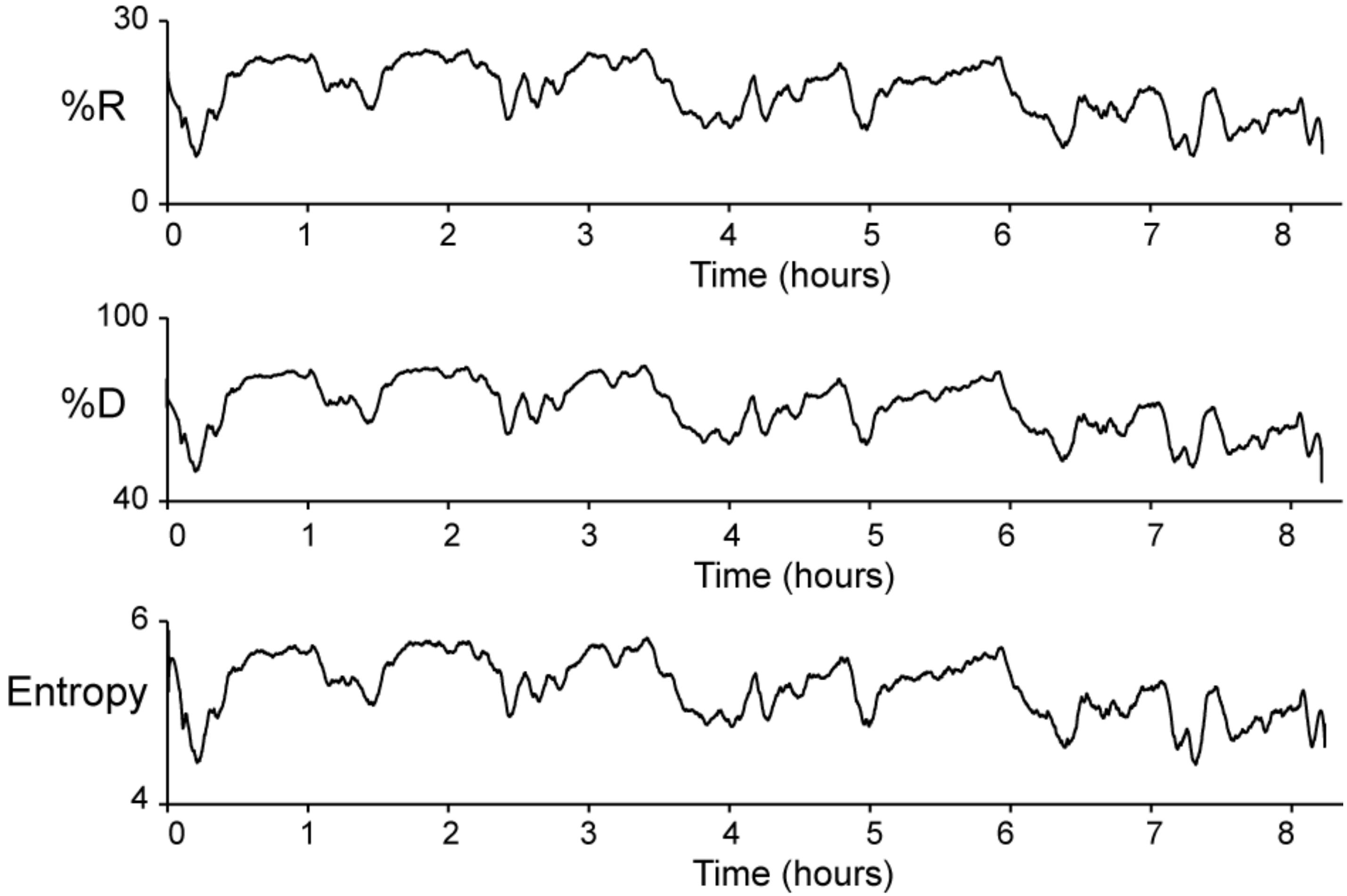
Definition of Analysis of Brain Recurrence (ABR)



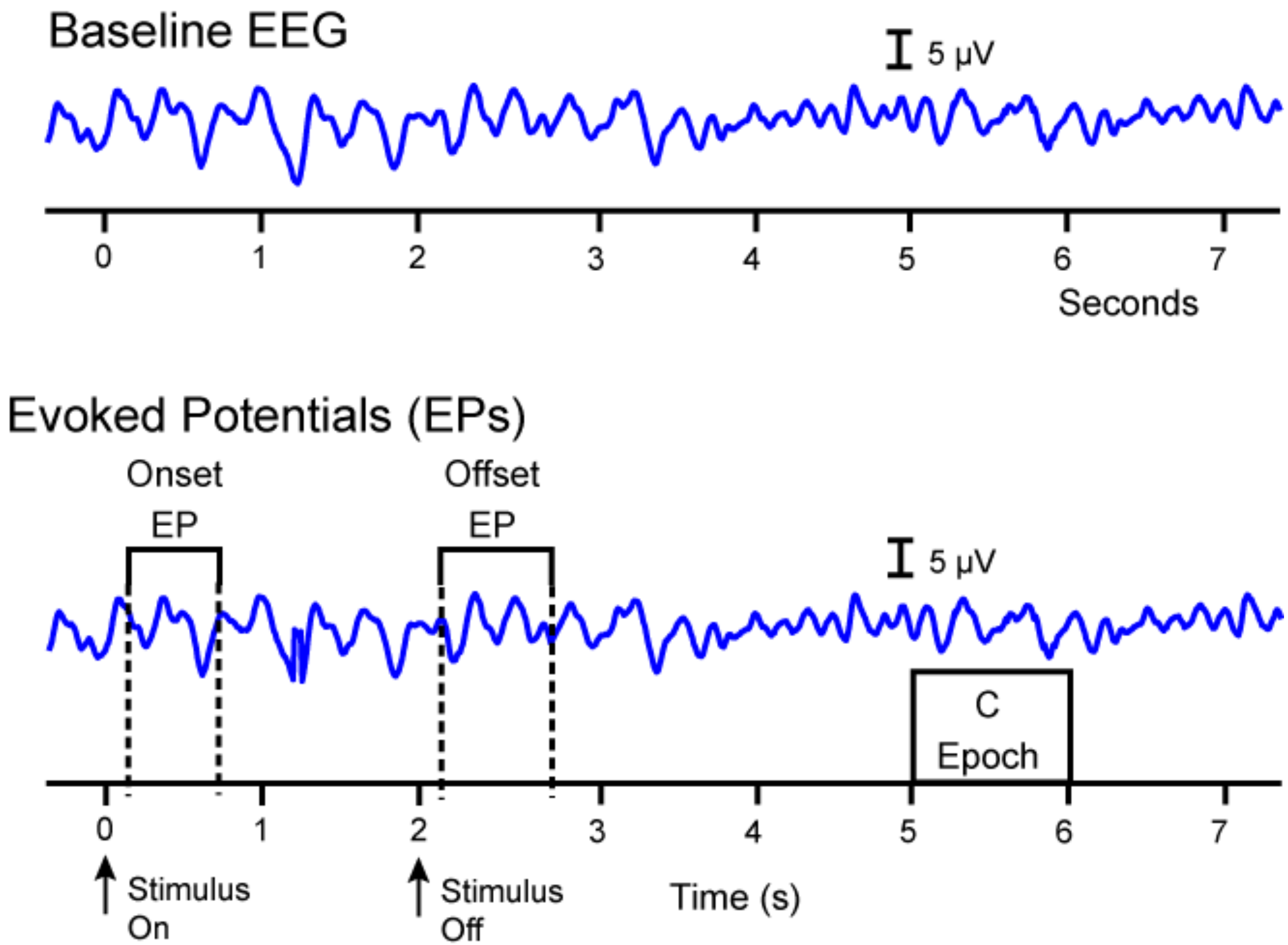
Elements of Analysis of Brain Recurrence



Recurrence Variables in ABR



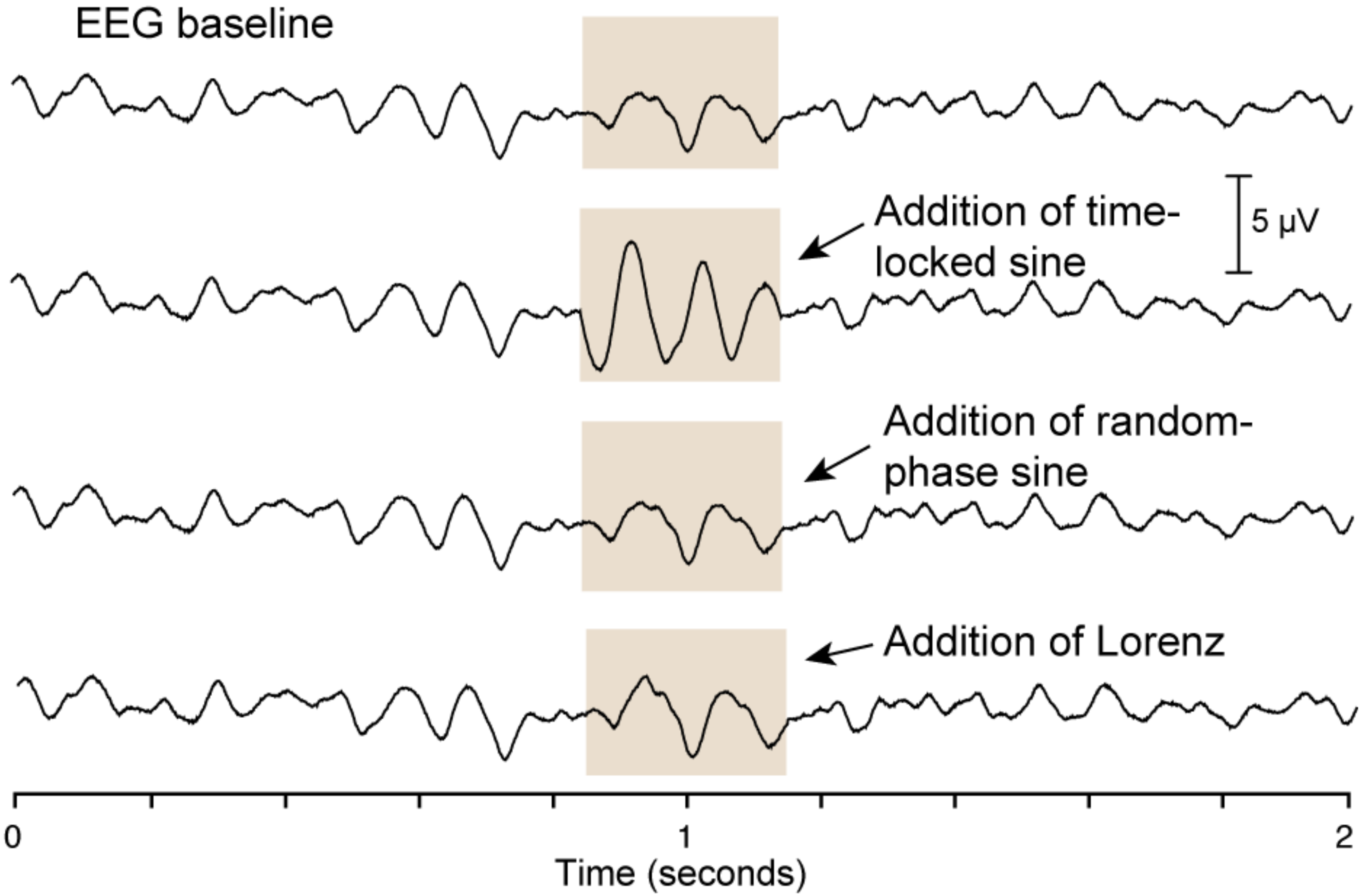
Experimental Designs in ABR



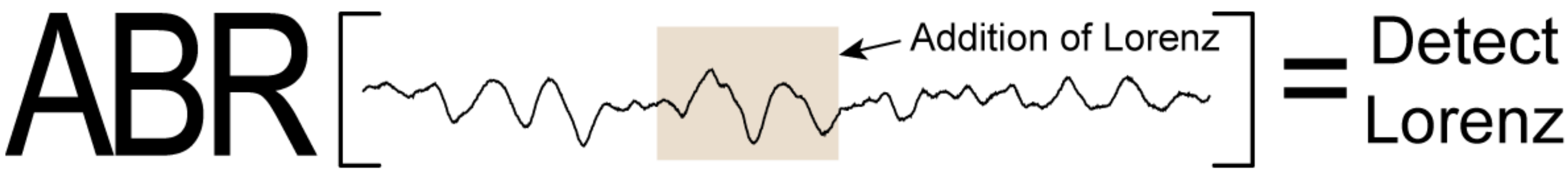
Statistical Considerations in ABR

- Statistical tests
  - Paired t test
  - Wilcoxon signed rank
- Statistical significance
  - Pair-wise
  - Family-wise
- Statistical methods
  - Linear discriminant analysis
  - Receiver operating characteristics
  - Support vector machines

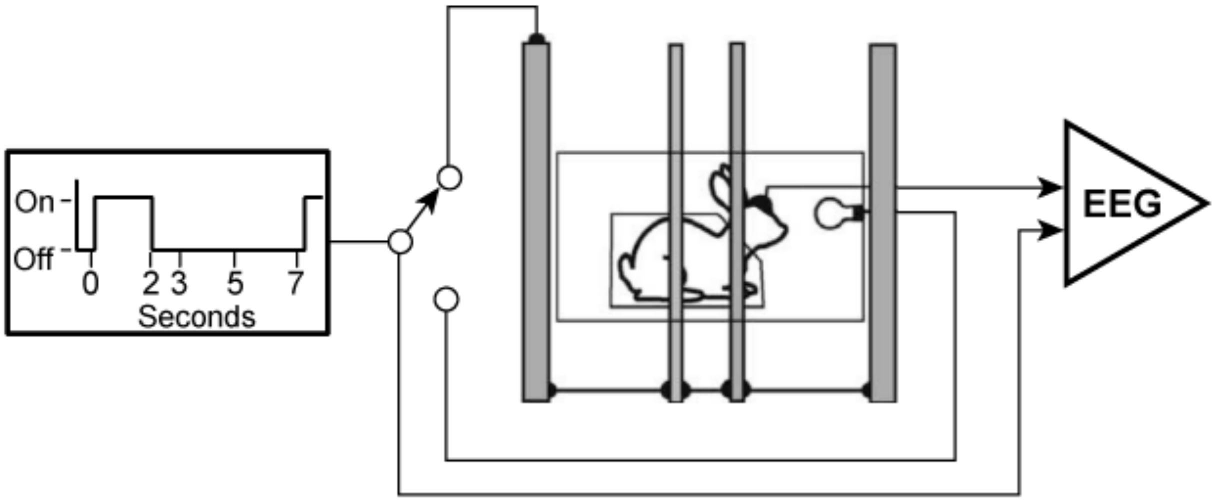
Inability of Linear Method to Detect Nonlinear Determinism

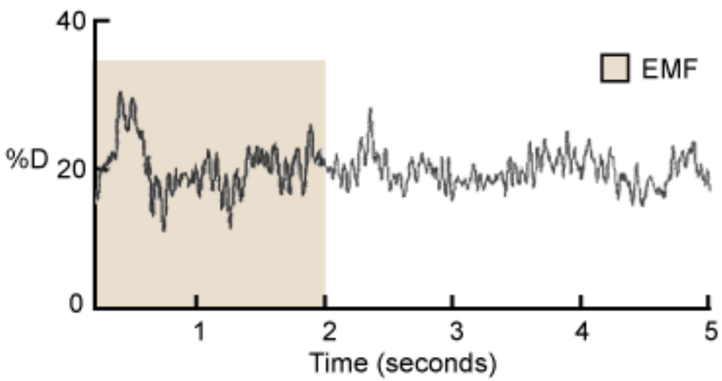


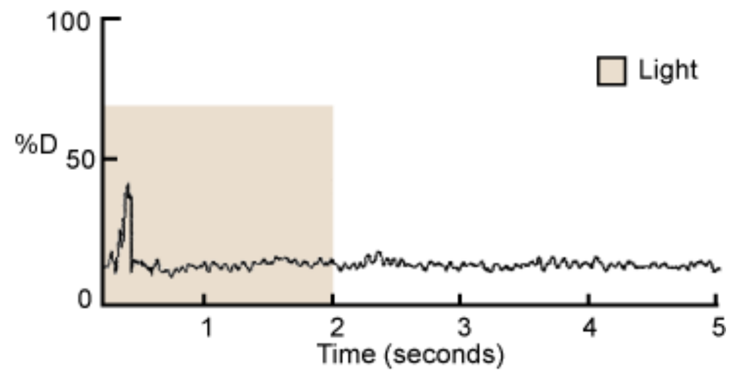
Recurrence Analysis of Model Systems



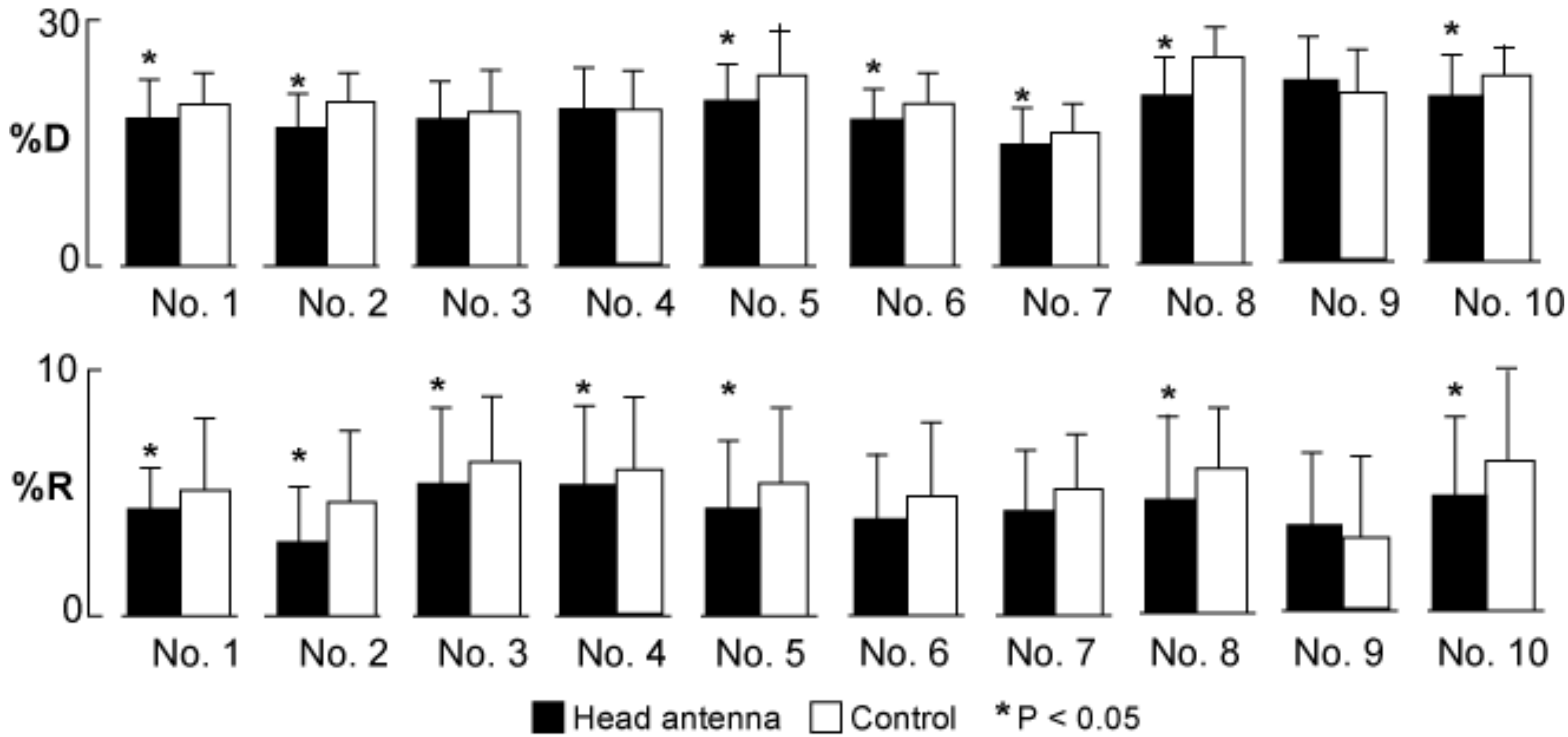
Initial Detection of EPs in Rabbits using ABR



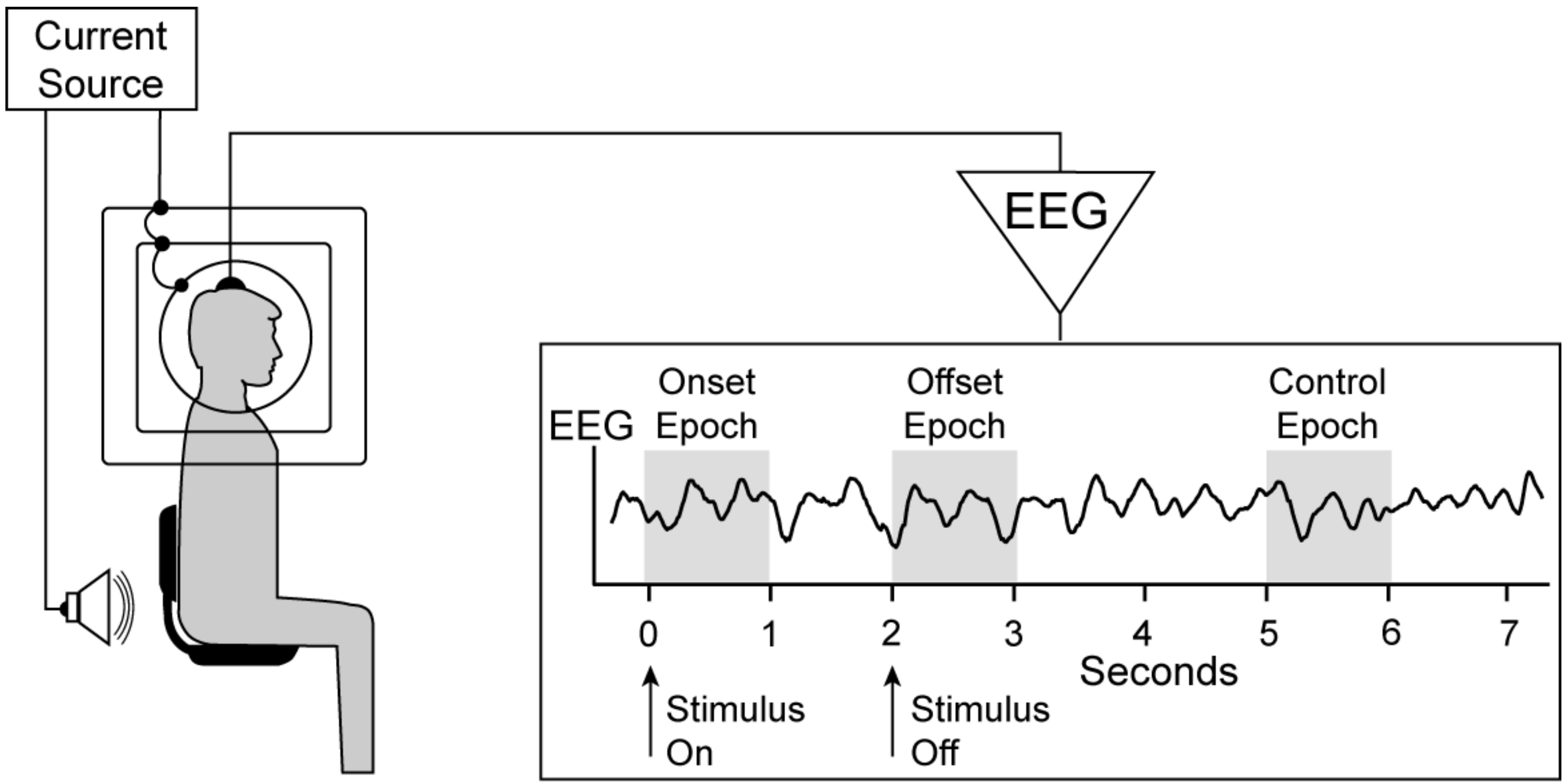




Average Results for %R and %D in Each of Ten Rabbits



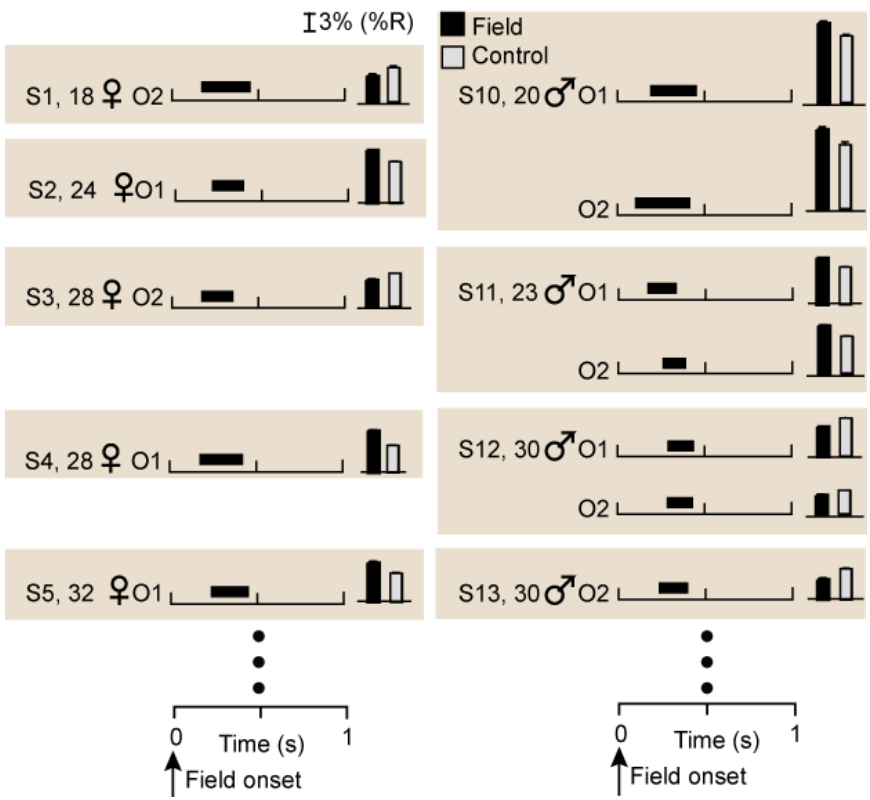
Experimental Arrangement for Human Studies of Evoked Potentials



Statistical Basis for Observations of Evoked Potentials

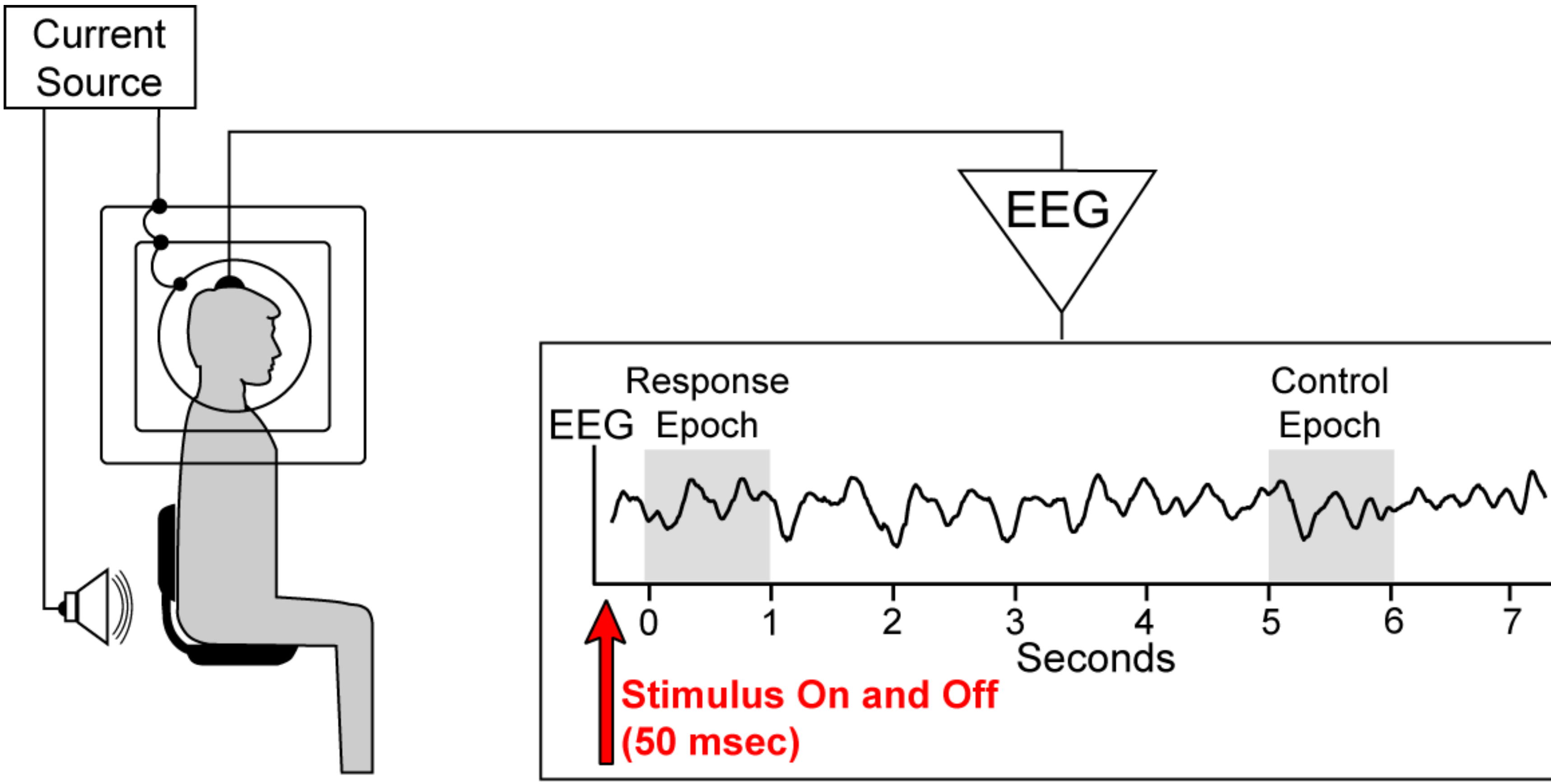
How does recurrence analysis detect transient changes in the EEG?

Detection of Nonlinear Magneto-sensory Evoked Potentials in Human Subjects



Detecting EPs Triggered by Brief Stimuli

(Standard Clinical Procedure)



Magnetosensory Evoked Potentials

Subject	Stimulus (Hz)	%R	%D	%R (8–10Hz)	%D (8–10Hz)	%R (9–12Hz)	%D (9–12Hz)	All Effects	No. Tests	Family-Wise Error
S1	60	O1 C4 P4	–	–	–	–	–	O1 C4 P4	6	0.001
(30F)	30	O2 C3	O2 C3	–	–	–	–	O2 O2 C3 C3	12	0.001
S2	60	O2	O2 P3	–	–	–	–	O2 O2 P3	12	0.004
(54M)	30	O1	X	C4	O1	–	–	O1 O1 C4	23	0.022
S3	60	X	C4 P3	X	O1	–	–	O1 C4 P3	22	0.047
(23M)	30	P3	P3	O2, C4	–	–	–	O2 C4 P3 P3	17	0.004
S4	60	O1	O1	C4	–	–	–	O1 O1 C4	17	0.009
(22M)	30	C3	C3	O1	–	–	–	O1 C3 C3	17	0.025
S5	60	X	X	O1	O1	C3	–	O1 O1 C3	29	0.042
(51F)	30	O1 P3	P3	–	–	–	–	O1 P3 P3	12	0.01
S6	60	C4	C4	X	X	P4	–	C4 C4 P4	27	0.14
(23M)	30	X	O1	X	X	O2 P3 P4	–	O1 O2 P3 P4	29	0.017
S7	60	X	X	O1 O2 C4 P3 P4	–	–	–	O1 O2 C4 P3 P4	18	0.001
(29F)	30	C4	C4	C3	–	–	–	C3 C4 C4	17	0.046

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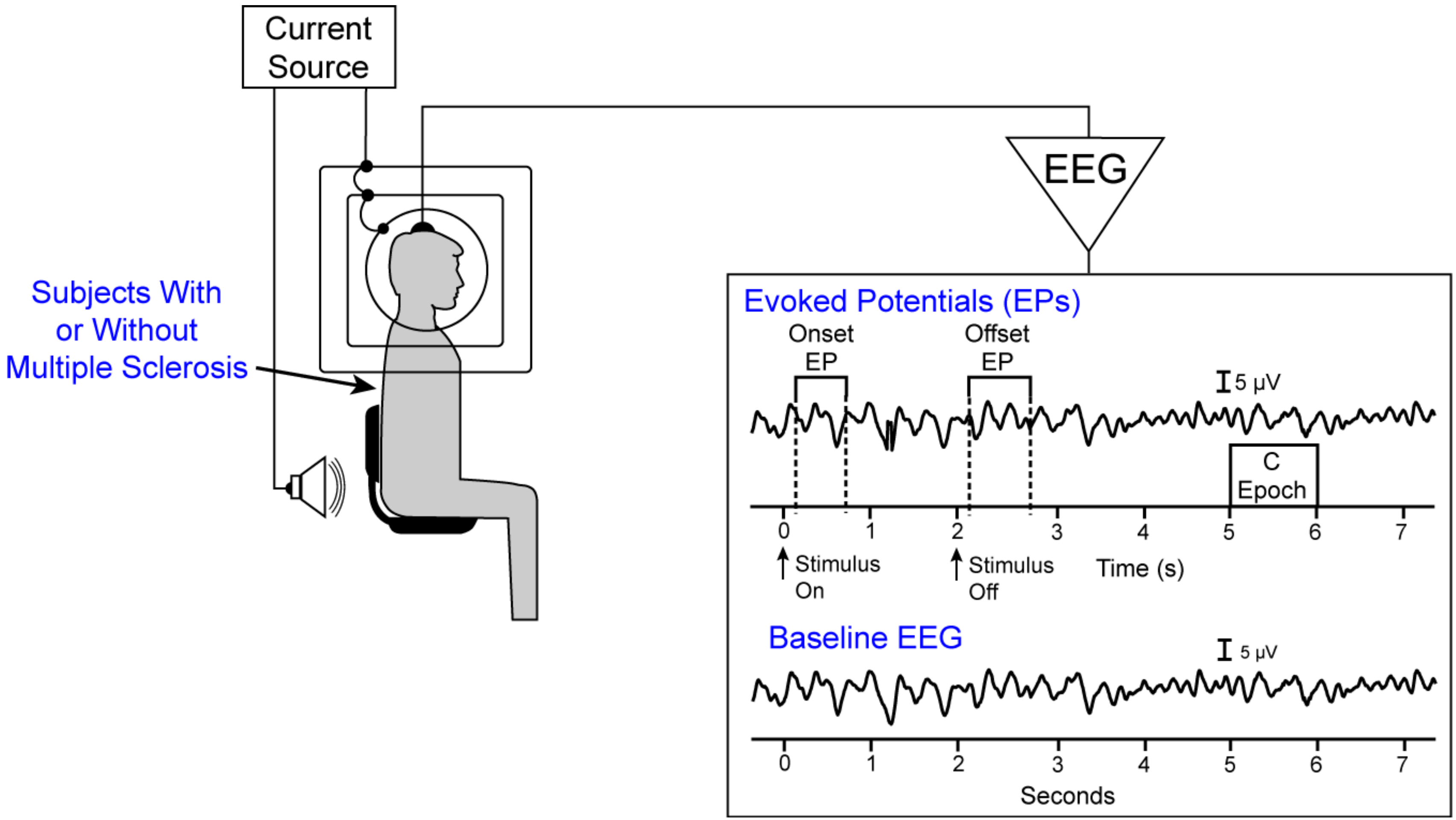
Arrangements for Detecting Presence of Neurological Disease



Onset-Induced Evoked Potentials in Patients with Multiple Sclerosis

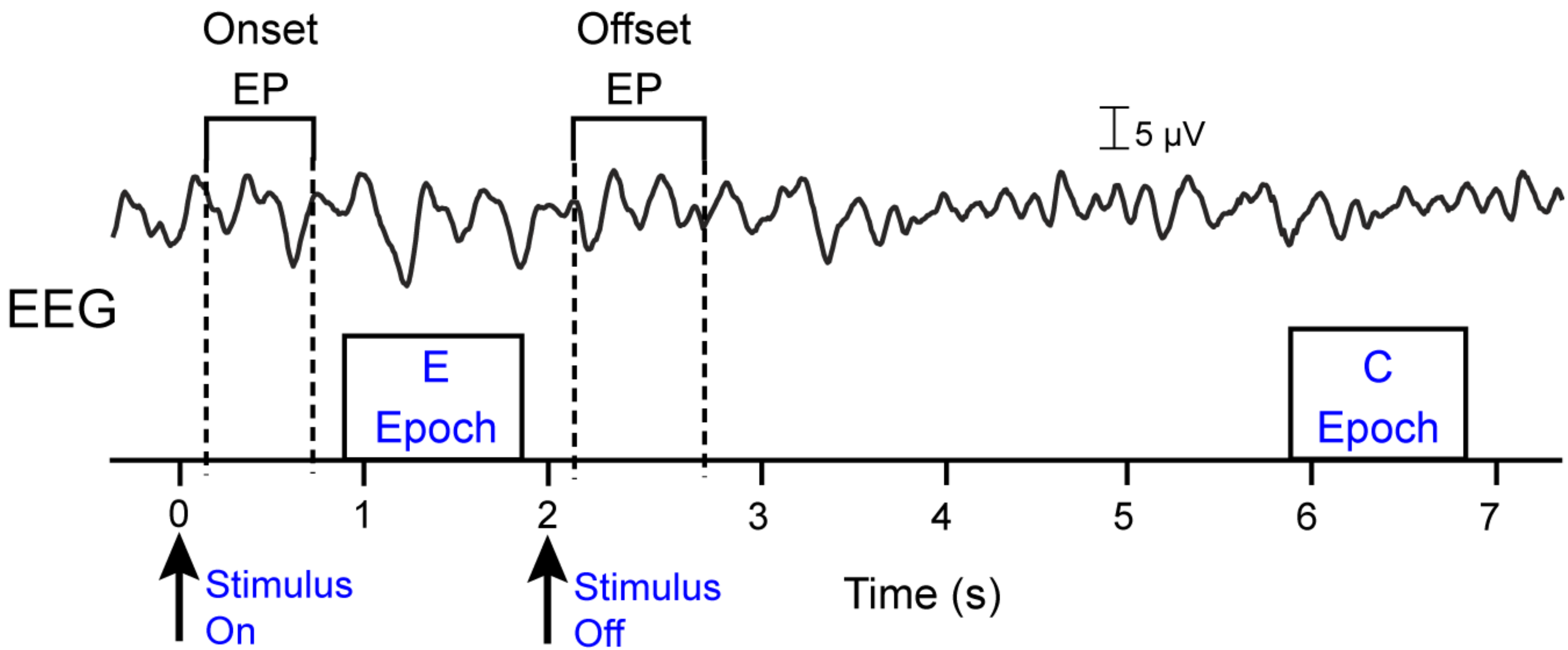
Subjects with multiple sclerosis

Subject	EEG Derivations	Family-Wise Error
1 (40)	—	—
2 (34)	—	—
3 (52)	—	—
4 (32)	O1 O2 C3 C3 C4	0.003
5 (19)	—	—
6 (30)	O2 O2 C3	0.029
7 (18)	—	—
8 (27)	C3 C4 P4	0.029
9 (50)	—	—
10 (31)	—	—
11 (38)	—	—

Controls (no medical complaints)

Subject	EEG Derivations	Family-Wise Error
1 (51)	O2 O2 C3	0.031
2 (66)	O2 C3 C3 P4	0.001
3 (22)	—	—
4 (26)	C3 C4 C4 P3	0.001
5 (23)	C3 C4 P4	0.001
6 (23)	C3 C3 C4 C4	0.001
7 (23)	O1 C3 C3 P3	0.004
8 (46)	O1 O1 C3	0.005
9 (23)	O1 O2 C4 C4 P3 P4	0.000
10 (25)	P3 P3 P4	0.084

Explication of Presence Effect



Detection of the Presence Effect

Sound Stimulus

Subject	Age/Gender	%D	%R	V_{rms}
S1	30/M	O1 C3 C4 P3	O1 C3 C4 P3	—
S2	45/M	O1 O2 C3 C4 P3 P4	O2 C3 C4 P3 P4	—
S3	23/F	O1 O2 C4 P4	—	—
S4	29/F	—	C3 C4 P4	—
S5	28/F	O1 C3 C4 P3	O1 P4	O1 C3 C4 P3

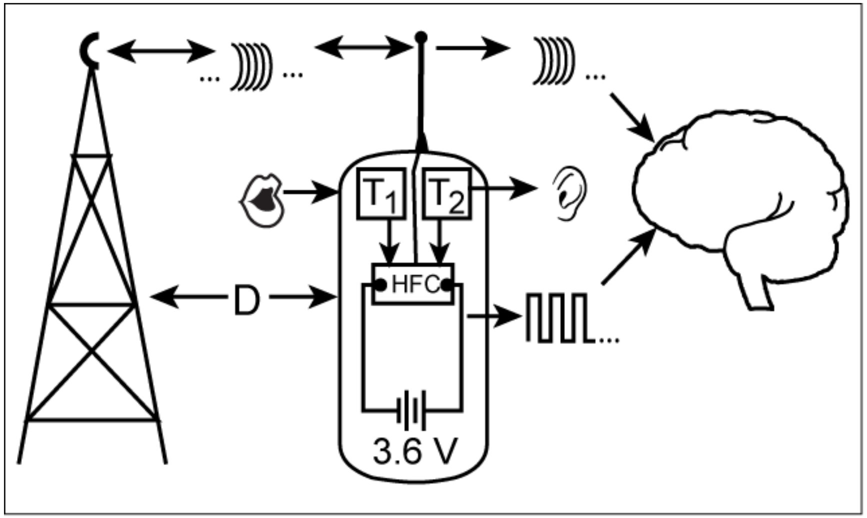
Field Stimulus

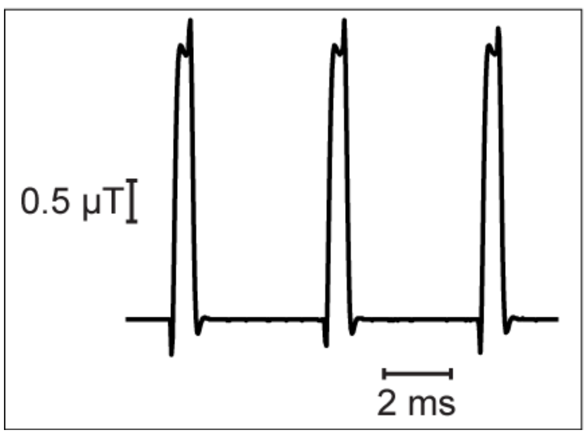
Subject	Age/Gender	%D	%R	V_{rms}
S6	18/F	O1 C3 C4 P3 P4	—	—
S7	30/M	O1 O2 C3 C4 P3 P4	O1 P3 P4	—
S8	50/F	O1 O2 C3 C4 P3 P4	—	—
S9	49/F	O1 O2 C3 C4 P3 P4	O1 O2 P3 P4	—
S10	46/F	O1 C3 C4 P3	—	—

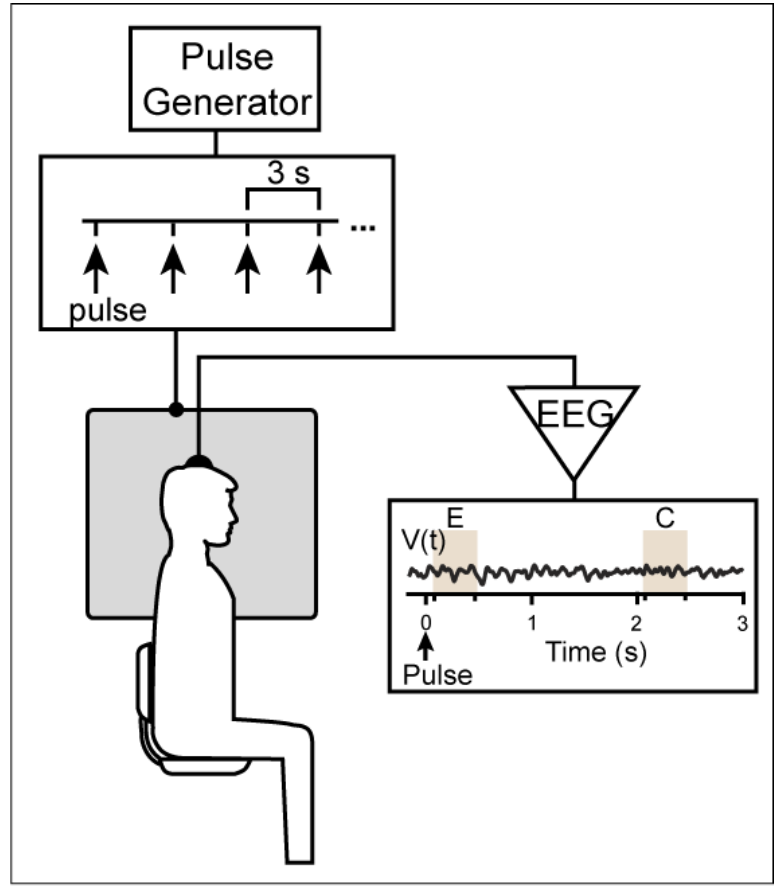
Light Stimulus

Subject	Age/Gender	%D	%R	V_{rms}
S11	51/F	C3 P4	—	—
S12	29/M	—	—	—
S13	50/M	—	O1 C4	C4 P4
S14	46/F	O1 O2 P3 P4	—	—
S15	31/F	O1 C4	—	—

Experimental Design for Detecting Effect of Cell-Phone Pulse on EEG







Evoked Potentials in Subjects Exposed to Cell-Phone Pulse

Subject	%R	%D	%R (8–10 Hz)	%D (8–10 Hz)	%R (9–12 Hz)	%D (9–12 Hz)	All Effects	No. Tests	Family-Wise Error
S1 (24/M)	P4	O1	X	X	O1 O2	—	O1 O1 O2 P4	27	0.010
S2 (53/F)	C4	C4	C3 P3	—	—	—	C3 C4 C4 P3	17	0.002
S3 (22/F)	C3	C3 P3	—	—	—	—	C3 C3 P3 P3	12	0.001
S4 (22/M)	P3	—	—	—	—	—	C3 C4 P3	6	0.001
S5 (22/F)	C3 C4 P3	X	X	O1 O2	—	—	O1 O1 O2	23	0.081
S6 (43/F)	O1	C4	—	—	—	—	O1 C4 C4	12	0.006
S7 (22/F)	O1 C4	P4	O2	O2	—	—	O2 O2 P4	23	0.031
S8 (50/F)	X	X	X	O2	P3 P4	—	O2 P3 P4	30	0.062
S9 (62/M)	X	X	X	X	X	C4	C4	36	NE
S10 (18/F)	X	X	C3	C3	X	O2	O2 C3 C3	34	0.078

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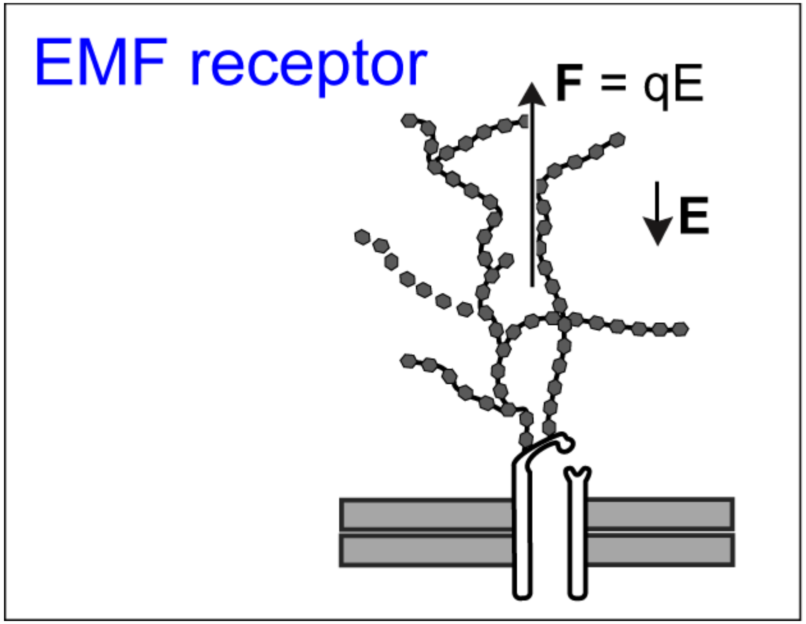
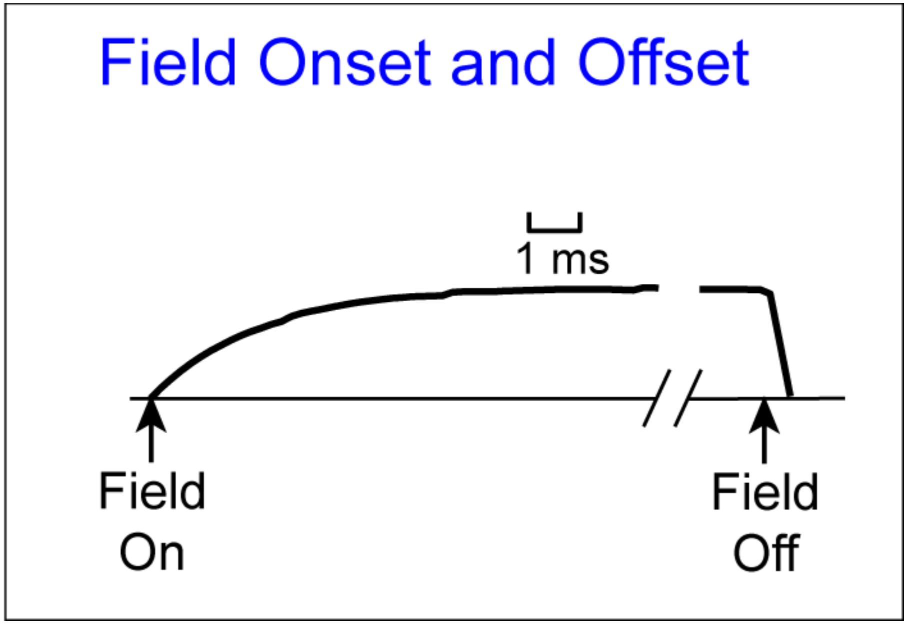
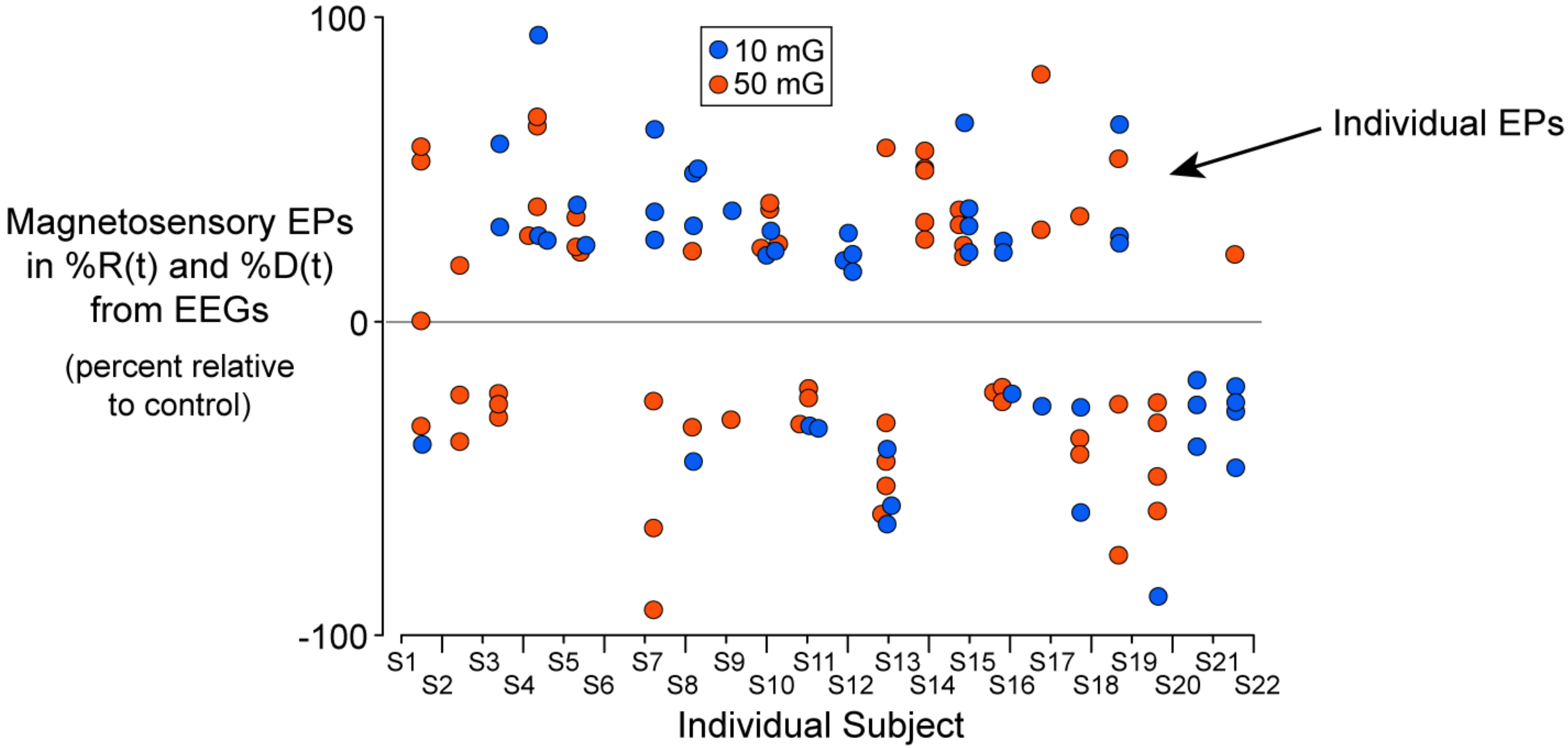
Mechanistic Basis of EMF Detection Studied using ABR

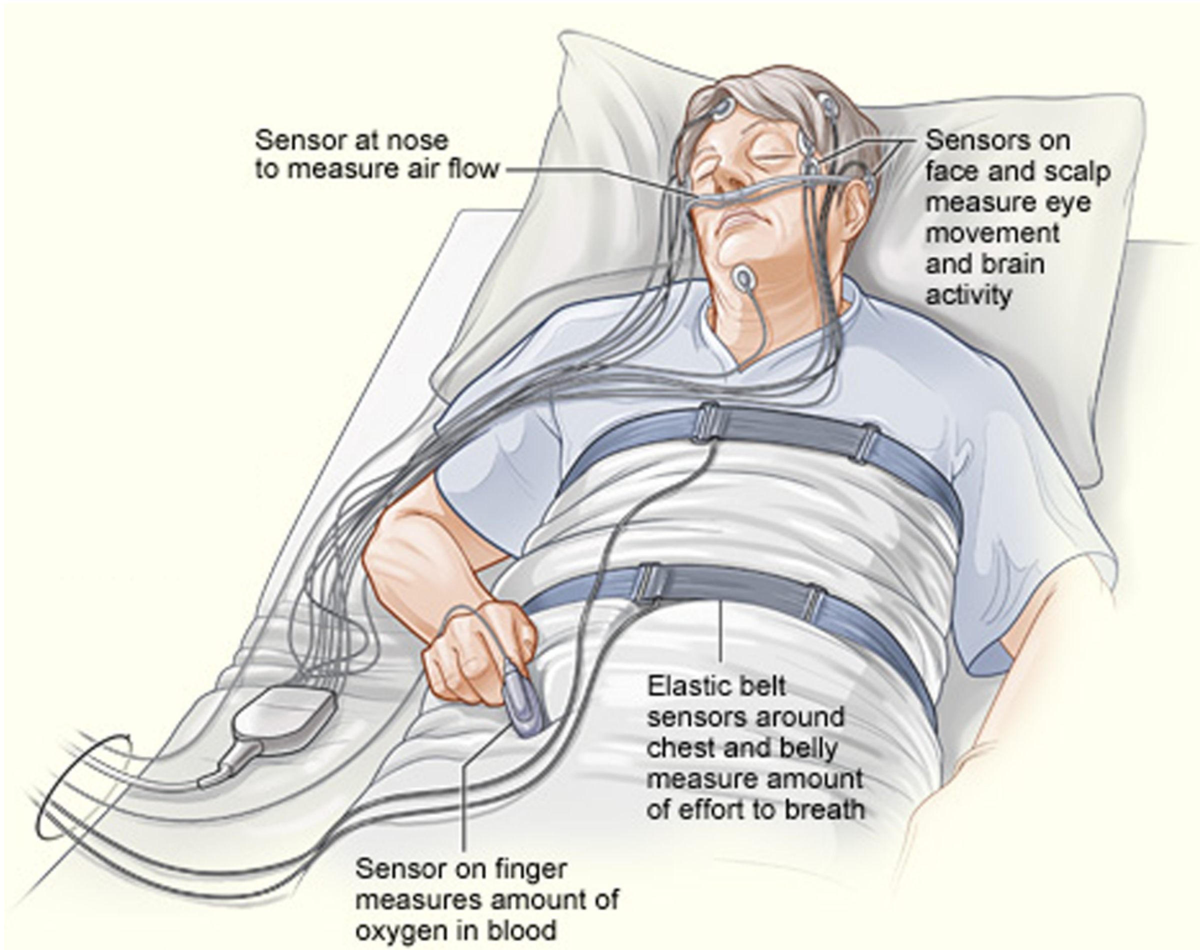




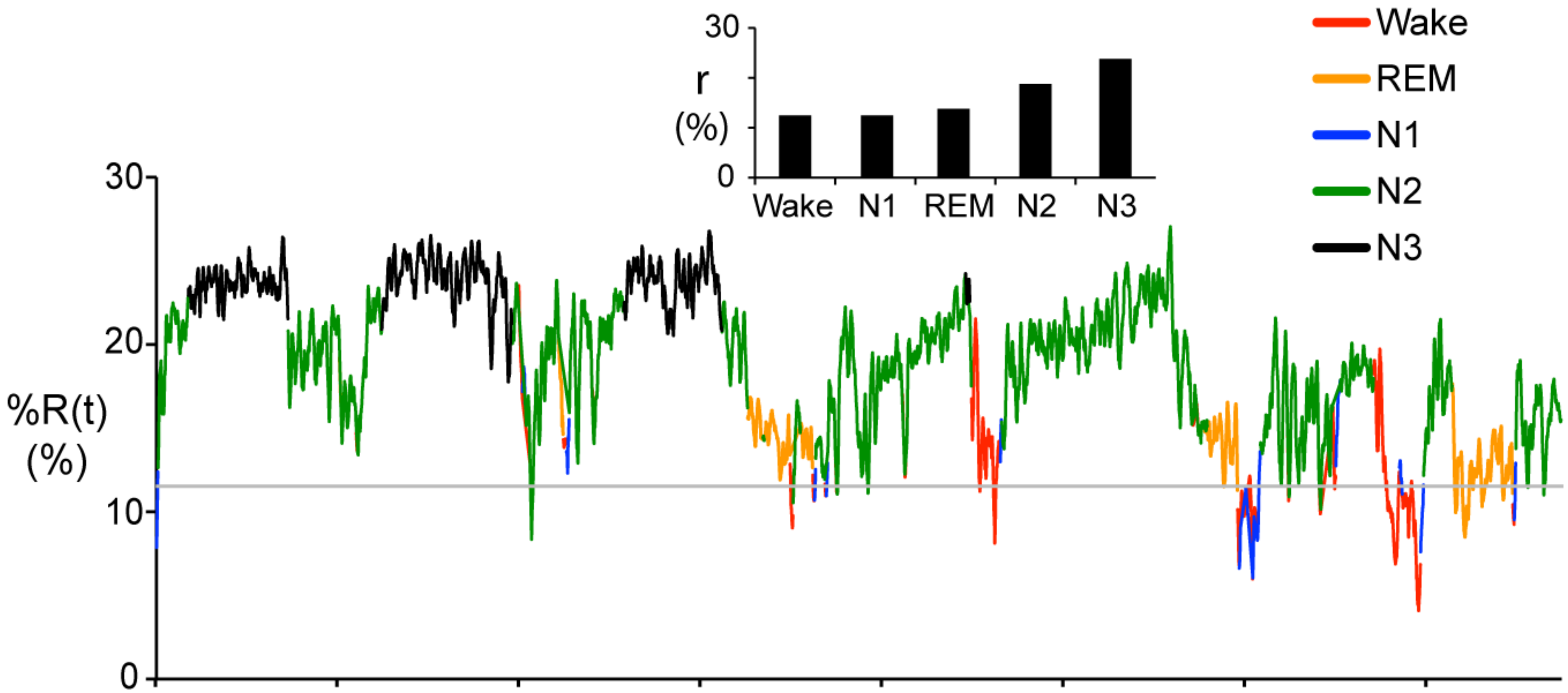
Public Health and Mechanistic Issues Involving EMF Detection using ABR



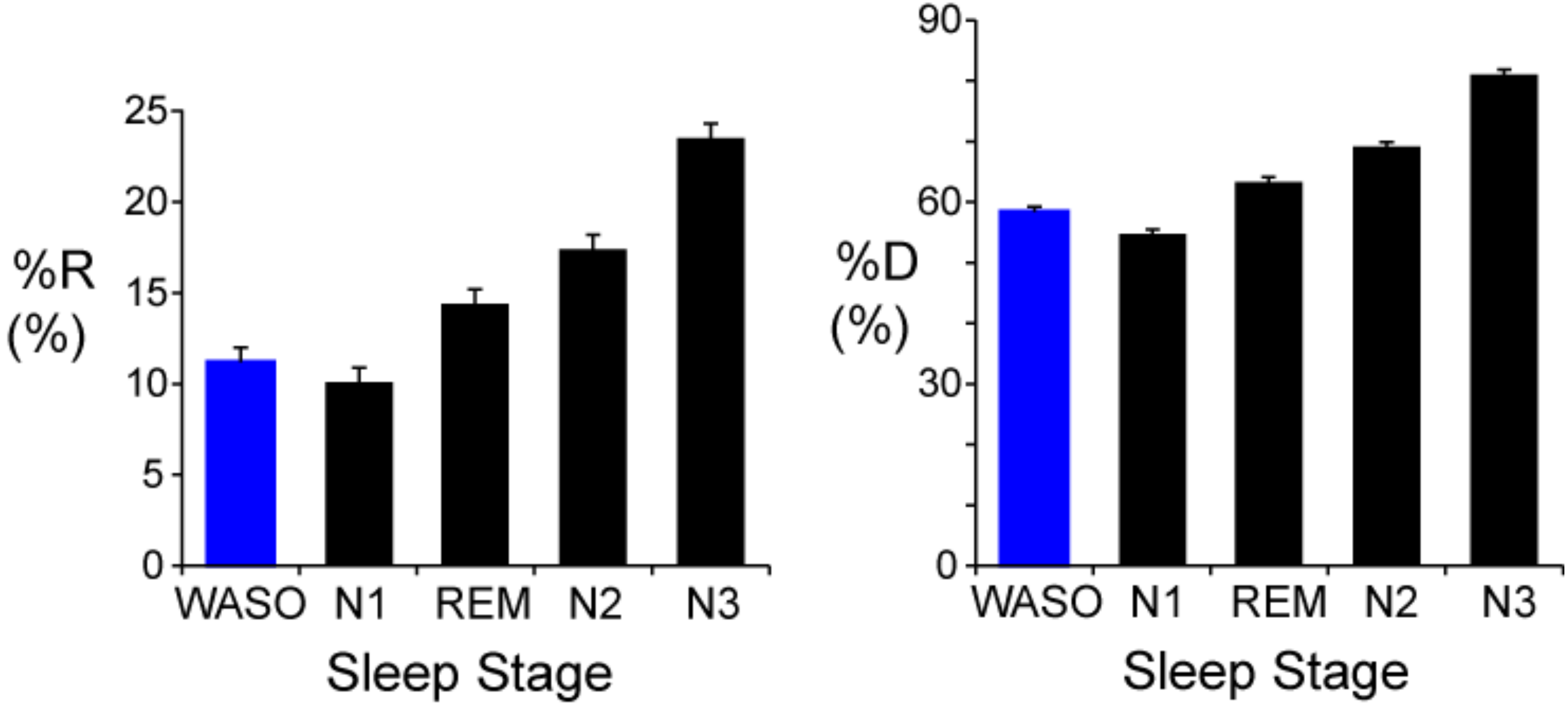
Data Routinely Obtained During an Overnight Sleep Study



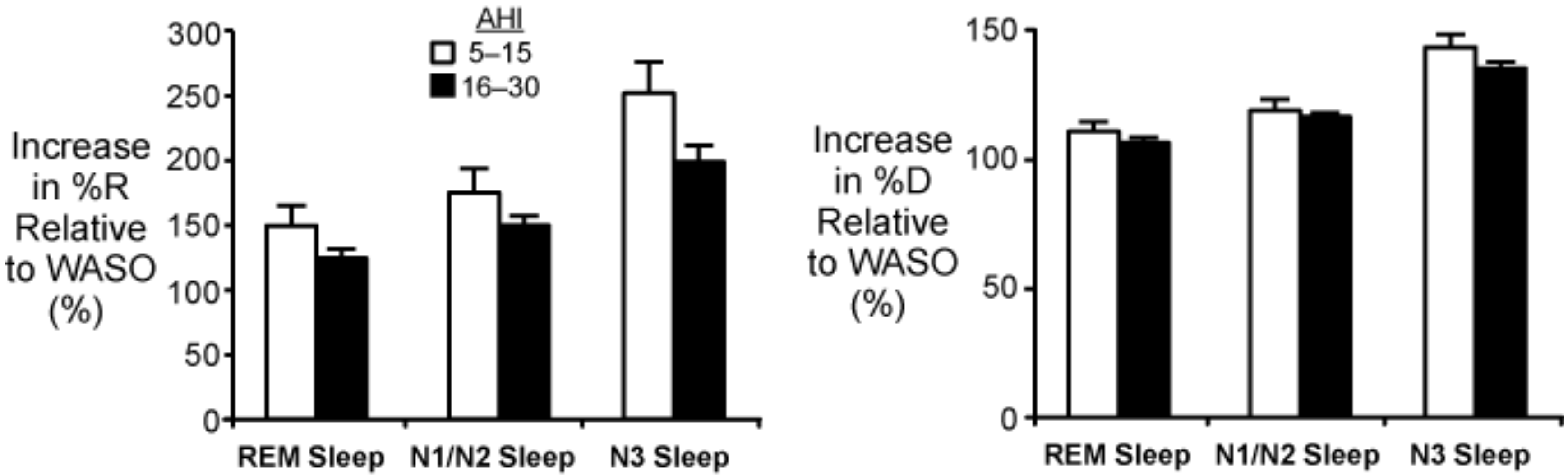
Application of ABR to Sleep EEG



Averages of %R and %D During Sleep (N = 20)

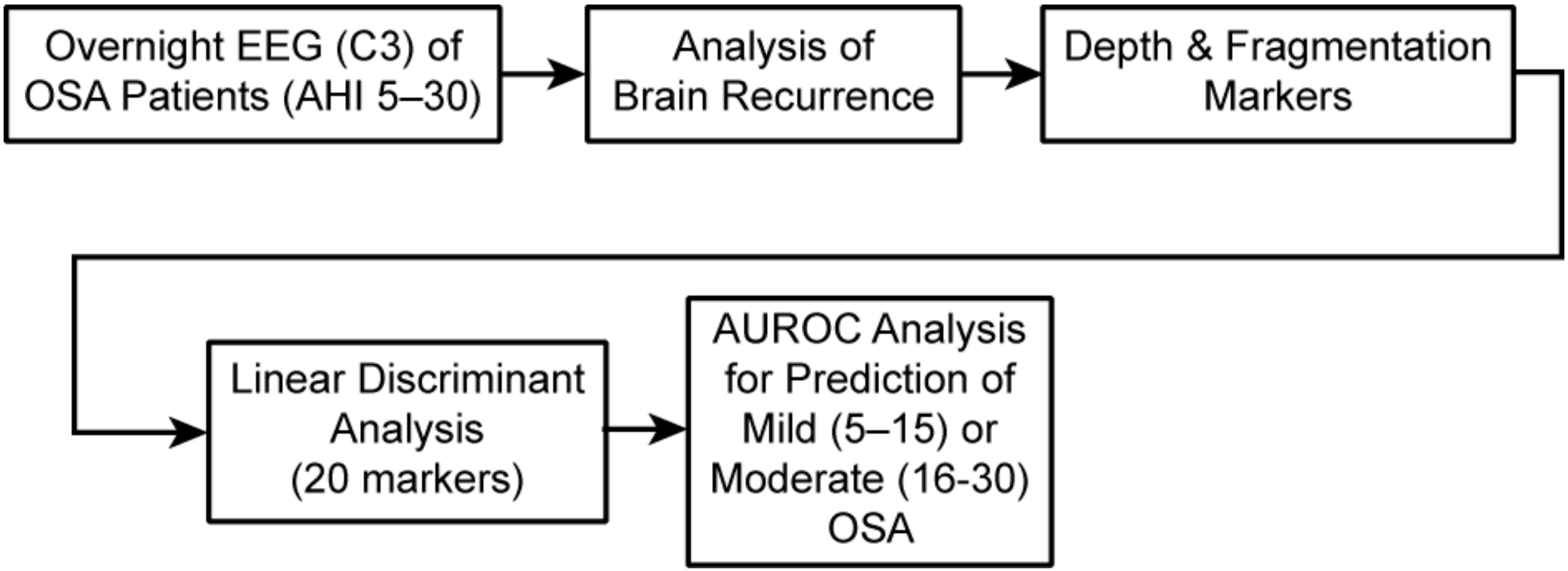


Relation between EEG Recurrence and Severity of Sleep Apnea



N = 10 in each group

LDA & AUROC of ABR Markers from EEG

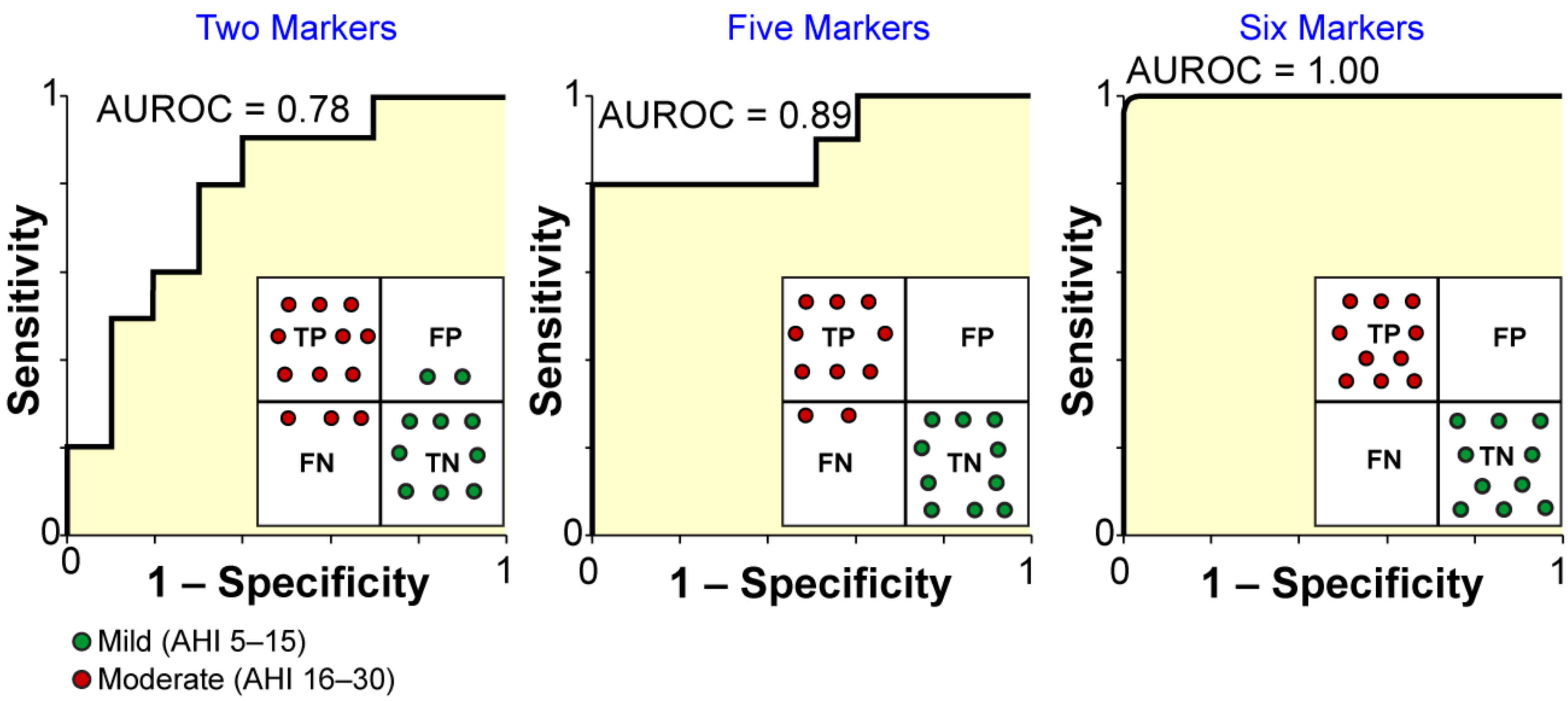


Abbreviations:

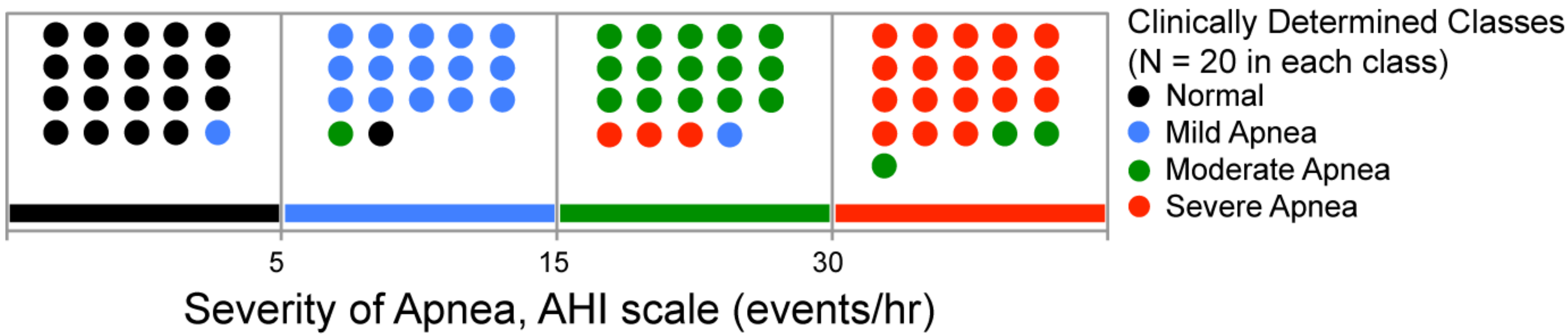
AUROC Area under receiver operating characteristics curve

LDA Linear discriminant analysis

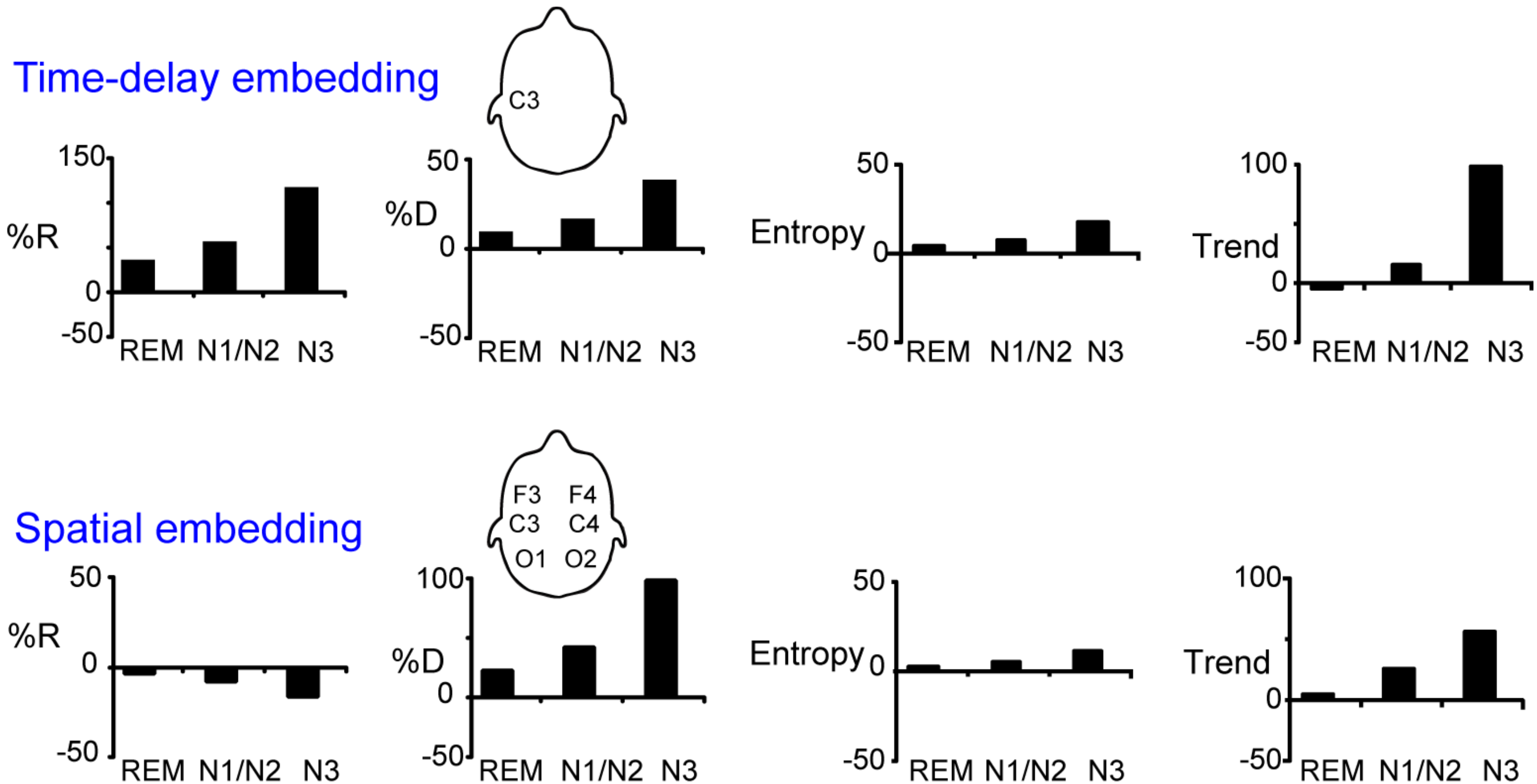
Results for Diagnosing Apnea
(Binary Classification)



Use of Support Vector Machines to Diagnose the Severity of Apnea



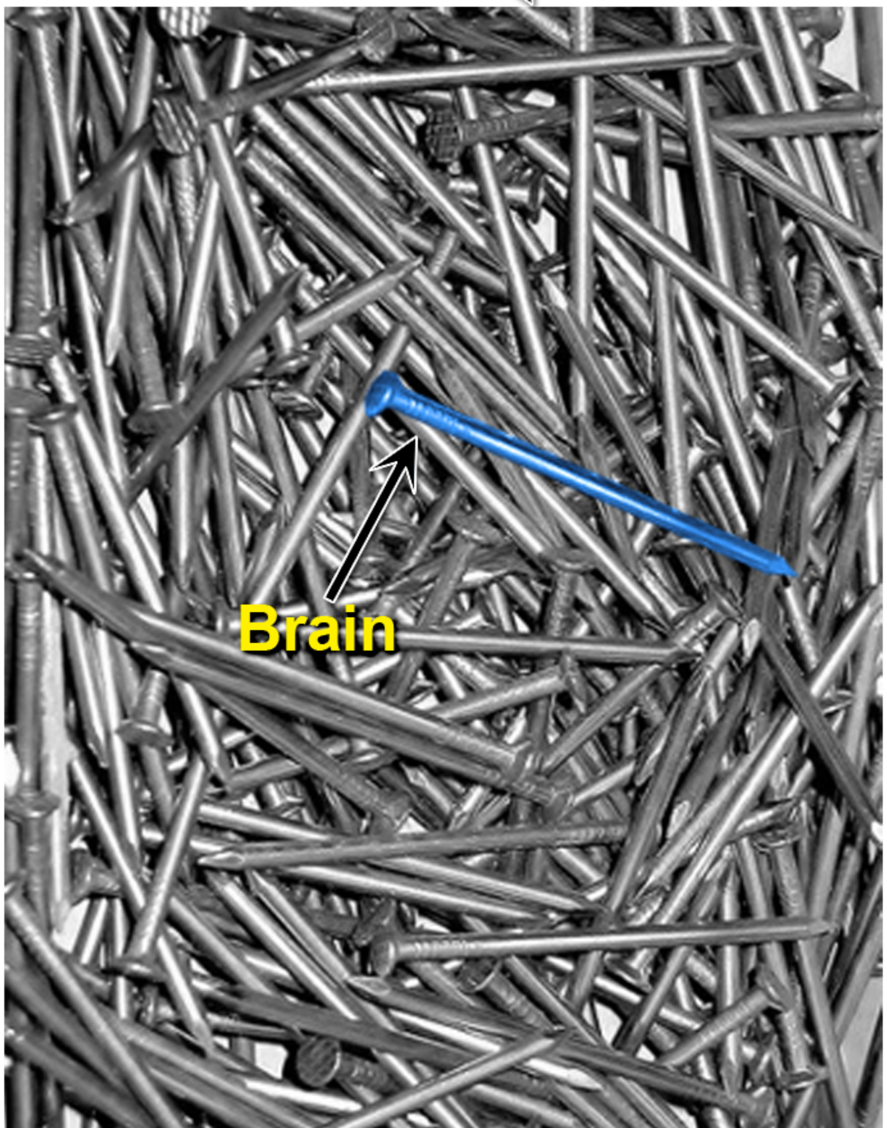
Comparison of Time-Delay and Spatial Embedding of Sleep EEG



- N = 20
- Normalized by WASO values

Conclusion

Systems that Produce Time-Series Data



Methods for Analyzing Time-Series Data