Aperiodic History: Annotated Bibliography
Analyses of the Aperiodic Exponent

This annotated bibliography include empirical analyses and methods for spectral analyses of aperiodic (1/f or 1/f-like) activity in neural field data (M/EEG, iEEG, LFP). Reports are listed chronologically.

Motokawa, K. (1949). Energy of Brain Waves and Energetics of the Brain. *The Tohoku Journal of Experimental Medicine*, *51*(1–2), 119–129. https://doi.org/10.1620/tjem.51.119

> Examines patterns of energy in brain activity and demonstrates an "exponential law of energy distribution in eeg" – seemingly the first report of such. Motivated by discussions of metabolism.

Smith, J., Negin, M., & Nevis, A. (1969). Automatic Analysis of Sleep Electroencephalograms by Hybrid Computation. *IEEE Transactions on Systems Science and Cybernetics*, *5*(4), 278–284. https://doi.org/10.1109/TSSC.1969.300220

> Proposes automatic procedures for analyzing sleep EEG data, and in doing so notes that 'background' data appears to follow a 1/f / pink noise distribution in the power spectrum.

Kingma, Y. J., Pronk, C. N. A., & Sparreboom, D. (1976). Parameter estimation of power spectra using Gaussian functions. *Computers and Biomedical Research*, *9*(6), 591–599. https://doi.org/10.1016/0010-4809(76)90018-5

> Proposes a method of fitting Gaussians to power spectra to measure oscillations, while also fitting of an exponential function to capture the pattern of decreasing power over increasing frequencies.

Dumermuth, G., Gasser, T., Germann, P., Hecker, A., Herdan, M., & Lange, B. (1977). Studies on EEG Activities in the Beta Band. *European Neurology*, *16*(1–6), 197–202. https://doi.org/10.1159/000114900

> With the goal of studying beta activity, introduces an analysis approach that measures the spectral baseline (effectively, the aperiodic exponent), and measuring peak activity above this.

> Note – a similar / overlapping project is reported in the following report (in French):

> > Dumermuth, G., Lange, B., & Herdan, M. (1983). Analyse spectrale de l'activite EEG rapide (beta). *Revue d'électroencéphalographie et de neurophysiologie clinique*, *13*(2), 122–127. https://doi.org/10.1016/S0370-4475(83)80070-7

Matthis, P., Scheffner, D., & Benninger, C. (1981). Spectral Analysis of the EEG: Comparison of Various Spectral Parameters. *Electroencephalography and Clinical Neurophysiology*, *52*(2), 218–221. https://doi.org/10.1016/0013-4694(81)90171-1

> A brief overview and comparison of different spectral parameters, with an example application to clinical EEG (brain tumor), including the discussion and measurement of the aperiodic exponent.

Feinberg, I., March, J. D., Floyd, T. C., Fein, G., & Aminoff, M. J. (1984). Log amplitude is a linear function of log frequency in NREM sleep EEG of young and elderly normal subjects.

Electroencephalography and Clinical Neurophysiology, *58*(2), 158–160.
https://doi.org/10.1016/0013-4694(84)90029-4

> Analyzes the log(frequency) vs. log(power) relationship in sleep EEG data, noting also that there is a different across age groups (perhaps the earliest reported age-related finding).

Dumermuth, G., & Molinari, L. (1987). Spectral Analysis of the EEG. *Neuropsychobiology*, *17*, 85–99. https://doi.org/10.1159/000118345

> Reports on a tutorial on spectral analysis of EEG data, including discussing spectral parameters – including a 'pink noise' (1/f) component, and peaks. Discusses measuring the aperiodic exponent.

Freeman, W. J., & van Dijk, B. W. (1987). Spatial patterns of visual cortical fast EEG during conditioned reflex in a rhesus monkey. *Brain Research*, *422*(2), 267–276.
https://doi.org/10.1016/0006-8993(87)90933-4

> Examines patterns of visual cortical activity in Rhesus monkeys, and notes that the LFP power spectra resemble a 1/f pattern with peaks in the 20-40 Hz range.

Pascual-Marqui, R. D., Valdes-Sosa, P. A., & Alvarez-Amador, A. (1988). A Parametric Model for Multichannel EEG Spectra. *International Journal of Neuroscience*, *40*(1–2), 89–99.
https://doi.org/10.3109/00207458808985730

> Proposes the Xi-Alpha model to measure frequency domain components in which Xi reflects a power across all frequencies and Alpha reflects the alpha oscillation, both fit with t-distributions.
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> Note: some follow up reports apply this method, and discuss the Xi parameter, e.g.:
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>> Amador, A. A., Valdés Sosa, P. A., Pascual Marqui, R. D., Garcia, L. G., Lirio, R. B., & Bayard, J. B. (1989). On the structure of EEG development. *Electroencephalography and Clinical Neurophysiology*, *73*(1), 10–19. https://doi.org/10.1016/0013-4694(89)90015-1

Nakata, M., & Mukawa, K. (1989). Fourier analysis of broad spectral EEG from a fluctuation point of view. *The Pavlovian Journal of Biological Science*, *24*(3), 90–97.
https://doi.org/10.1007/BF02701923

> Fit 1/f & Lorentzian functions to LFP power spectra, across broad frequency ranges (up to ~3 kHz). Report different patterns of aperiodic activity between cortical and sub-cortical regions.

Pritchard, W. S. (1992). The Brain in Fractal Time: 1/F-Like Power Spectrum Scaling of the Human Electroencephalogram. *International Journal of Neuroscience*, *66*(1–2), 119–129.
https://doi.org/10.3109/00207459208999796

> Examines 1/f scaling of EEG power spectra, reporting it in eyes-open and eyes-closed conditions, as well as differences across channels. Discusses fractals & chaos.

Nakata, M., Mukawa, J., & Fromm, G. H. (1993). Evaluation of human consciousness level by means of "automated fluctuation analysis" of high frequency electroencephalogram fitted by double

Lorentzians. *Integrative Physiological and Behavioral Science*, *28*(4), 343–352.
https://doi.org/10.1007/BF02690931

> Analyze EEG recordings across a broad frequency range, fitting Lorentzians (1/k with a knee) and note differences in model form and fit parameters between wake and sleep.

Inouye, T., Matsumoto, Y., Shinosaki, K., Iyama, A., & Toi, S. (1994). Increases in the power spectral slope of background electroencephalogram just prior to asymmetric spike and wave complexes in epileptic patients. *Neuroscience Letters*, *173*, 197–200. https://doi.org/10.1016/0304-3940(94)90182-1

> An early analysis of aperiodic neural activity in a clinical context, this report measures aperiodic activity in epileptic patients and shows it systematically relates to epileptiform activity.

Barrie, J. M., Freeman, W. J., & Lenhart, M. D. (1996). Spatiotemporal analysis of prepyriform, visual, auditory, and somesthetic surface EEGs in trained rabbits. *Journal of Neurophysiology*, *76*(1), 520–539. https://doi.org/10.1152/jn.1996.76.1.520

> Examines recordings from cortical ECoG grids in rabbits, fitting 1/f parameters to power spectra and comparing pre / post stimulus. Report a stimulus-related change in aperiodic parameters.

Menon, V., Freeman, W. J., Cutillo, B. A., Desmond, J. E., Ward, M. F., Bressler, S. L., Laxer, K. D., Barbaro, N., & Gevins, A. S. (1996). Spatio-temporal correlations in human gamma band electrocorticograms. *Electroencephalography and Clinical Neurophysiology*, *98*(2), 89–102. https://doi.org/10.1016/0013-4694(95)00206-5

> Examines human ECoG data during a somatosensory discrimination task, applying multiple analyses, and notes the 1/f form of the power spectra and how this relates to task dynamics.

Novikov, E., Novikov, A., Shannahoff-Khalsa, D., Schwartz, B., & Wright, J. (1997). Scale-similar activity in the brain. *Physical Review E*, *56*(3), R2387–R2389. https://doi.org/10.1103/PhysRevE.56.R2387

> Fits the aperiodic exponent in power spectra from 2 MEG subjects. Motivates and discusses the approach and findings in relation to scale-similar activity.

Chang, H.-J., Freeman, W. J., & Burke, B. C. (1998). Optimization of olfactory model in software to give 1/f power spectra reveals numerical instabilities in solutions governed by aperiodic (chaotic) attractors. *Neural Networks*, *11*(3), 449–466. https://doi.org/10.1016/S0893-6080(97)00116-0

> Describes a model of the olfactory system, which is optimized to match the 1/f property of empirical recordings. Report that the model settles into a strange attractor.

Chen, Z., Tretyakov, A., Takayasu, H., & Nakasato, N. (1998). Spectral Analysis of Multichannel Meg Data. *Fractals*, *06*(04), 395–400. https://doi.org/10.1142/S0218348X98000432

Fits aperiodic exponent to power spectra from one MEG subject. Motivates the analysis in relation to fractal properties. Notes that alpha activity appears to be independent of 1/f activity.

Pereda, E., Gamundi, A., Rial, R., & González, J. (1998). Non-linear behaviour of human EEG: Fractal exponent versus correlation dimension in awake and sleep stages. *Neuroscience Letters*, *250*(2), 91–94. https://doi.org/10.1016/S0304-3940(98)00435-2

Computes the aperiodic exponent (and other measures) in EEG data, reporting a fractal structure in EEG data (exponent values from 1-3), and changes in the exponent between wake & sleep.

González, J., Gamundi, A., Rial, R., Nicolau, M. C., De Vera, L., & Pereda, E. (1999). Nonlinear, fractal, and spectral analysis of the EEG of lizard, *Gallotia galloti. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *277*(1), R86–R93. https://doi.org/10.1152/ajpregu.1999.277.1.R86

Examine EEG from lizards, to test for the presence of fractal / nonlinear structure. Report an aperiodic exponent of ~2 in the lizard brain, that flattens with increased temperature.

Freeman, W. J., Rogers, L. J., Holmes, M. D., & Silbergeld, D. L. (2000). Spatial spectral analysis of human electrocorticograms including the alpha and gamma bands. *Journal of Neuroscience Methods*, *95*(2), 111–121. https://doi.org/10.1016/S0165-0270(99)00160-0

Examines scaling properties in intracranial human recordings, including reporting on the aperiodic exponent, in both awake and anesthetized patients.

Freeman, W. J., & Barrie, J. M. (2000). Analysis of Spatial Patterns of Phase in Neocortical Gamma EEGs in Rabbit. *Journal of Neurophysiology*, *84*(3), 1266–1278. https://doi.org/10.1152/jn.2000.84.3.1266

Examines scaling properties in animal model recordings, including reporting on the aperiodic exponent, noting 1/f properties across the cortex.

Caplan, J. B., Madsen, J. R., Raghavachari, S., & Kahana, M. J. (2001). Distinct patterns of brain oscillations underlie two basic parameters of human maze learning. *Journal of Neurophysiology*, *86*(1), 368–380. https://doi.org/10.1152/jn.2001.86.1.368

With the goal of measuring oscillations, proposes a method that fits a 1/f function to neural power spectrum in order to derive a threshold value to use for peak detection.

Note – later reports further expand upon the method (BOSC - better oscillation detector):

Whitten, T. A., Hughes, A. M., Dickson, C. T., & Caplan, J. B. (2011). A better oscillation detection method robustly extracts EEG rhythms across brain state changes: The human alpha rhythm as a test case. *NeuroImage*, *54*(2), 860–874. https://doi.org/10.1016/j.neuroimage.2010.08.064

Hughes, A. M., Whitten, T. A., Caplan, J. B., & Dickson, C. T. (2012). BOSC: A better oscillation detection method, extracts both sustained and transient rhythms from rat

hippocampal recordings. *Hippocampus*, *22*(6), 1417–1428. https://doi.org/10.1002/hipo.20979

Freeman, W. J., Holmes, M. D., Burke, B. C., & Vanhatalo, S. (2003). Spatial spectra of scalp EEG and EMG from awake humans. *Clinical Neurophysiology*, *114*(6), 1053–1068. https://doi.org/10.1016/S1388-2457(03)00045-2

Examines scaling properties in EEG and EMG, including reporting aperiodic exponent values for EEG, which is reported to vary across scalp location (steeper frontal compared to occipital).

Polonnikov, R. I., Wasserman, E. L., & Kartashev, N. K. (2003). Regular Developmental Changes in EEG Multifractal Characteristics. *International Journal of Neuroscience*, *113*(11), 1615–1639. https://doi.org/10.1080/00207450390240086

Look at age-related changes of the aperiodic exponent in EEG data, and find that the aperiodic exponent decreases, in both healthy and clinical (cerebral palsy) patients.

Popivanov, D., Janyan, A., Andonova, E., & Stamenov, M. (2003). *Common Dynamic Properties of Biosignals During Cognition: Self-Similarity and Chaotic Dynamics of Both Response Times and EEG During Movement Imagery.*

Examine nonlinear properties of behavioral and EEG measures during imagined movement, including aperiodic exponent. Discuss results in relation to chaos theory.

Bédard, C., Kröger, H., & Destexhe, A. (2006). Does the 1 / f Frequency Scaling of Brain Signals Reflect Self-Organized Critical States? *Physical Review Letters*, *97*(11). https://doi.org/10.1103/PhysRevLett.97.118102

Examine 1/f activity in neural recordings in relation to self-organized criticality. Report 1/f properties in intracortical recordings, but argue they are not consistent with critical states.

Freeman, W. J., Holmes, M. D., West, G. A., & Vanhatalo, S. (2006). Fine spatiotemporal structure of phase in human intracranial EEG. *Clinical Neurophysiology*, *117*(6), 1228–1243. https://doi.org/10.1016/j.clinph.2006.03.012

Examines spatial phase patterns ('phase cones') and also discusses 1/f power spectra and reports a difference in the aperiodic exponent between wake and sleep in human ECoG recordings.

Phothisonothai, M., & Nakagawa, M. (2007). Fractal-Based EEG Data Analysis of Body Parts Movement Imagery Tasks. *The Journal of Physiological Sciences*, *57*(4), 217–226. https://doi.org/10.2170/physiolsci.RP006307

Analyze multiple fractal measures, including the aperiodic exponent, in EEG data during imagined movement, and report that these methods characterize the data.

Shimono, M., Owaki, T., Amano, K., Kitajo, K., & Takeda, T. (2007). Functional modulation of power-law distribution in visual perception. *Physical Review E*, *75*(5), 051902. https://doi.org/10.1103/PhysRevE.75.051902

    Investigate aperiodic exponent in MEG data during a visual detection task, and report that aperiodic exponent differs between correct and incorrect trials.

Freeman, W. J., O'Nuallain, S., & Rodriguez, J. (2008). Simulating cortical background activity at rest with filtered noise. *Journal of Integrative Neuroscience*, *7*(03), 337–344. https://doi.org/10.1142/S0219635208001885

    Explore simulations in which the cumulative summation of random events gives rise to 1/f power spectra and explores this framework as it compares to empirical human ECoG data.

Krakovská, A., & Štolc, S. (2008). Spectral decay vs. Correlation dimension of EEG. *Neurocomputing*, *71*(13–15), 2978–2985. https://doi.org/10.1016/j.neucom.2007.06.007

    Examines the relationship between aperiodic exponent and correlation dimension in awake EEG data, finding that the two measures are highly correlated.

Šušmáková, K., & Krakovská, A. (2008). Discrimination ability of individual measures used in sleep stages classification. *Artificial Intelligence in Medicine*, *44*(3), 261–277. https://doi.org/10.1016/j.artmed.2008.07.005

    Applies multiple methods, including the aperiodic exponent, to sleep EEG data, and compare across sleep stages. Report that the aperiodic exponent differentiates between wake and sleep.

Aoki, R., Wake, H., Sasaki, H., & Agata, K. (2009). Recording and spectrum analysis of the planarian electroencephalogram. *Neuroscience*, *159*(2), 908–914. https://doi.org/10.1016/j.neuroscience.2008.11.011

    Examines neural recordings in planarian (flatworms) to investigate EEG patterns in a 'primitive' brain. Report that the power spectrum follows a 1/f pattern after 1 Hz.

Bédard, C., & Destexhe, A. (2009). Macroscopic Models of Local Field Potentials and the Apparent 1/f Noise in Brain Activity. *Biophysical Journal*, *96*(7), 2589–2603. https://doi.org/10.1016/j.bpj.2008.12.3951

    Explore a model of LFP generation investigating possible causes of 1/f scaling of power spectra and argue that ionic diffusion is responsible for frequency-dependent electrical conductivity.

Freeman, W. J., & Zhai, J. (2009). Simulated power spectral density (PSD) of background electrocorticogram (ECoG). *Cognitive Neurodynamics*, *3*(1), 97–103. https://doi.org/10.1007/s11571-008-9064-y

    Describes a model of 'background' in LFP activity, that generates 1/f data & relates the 'scale-free' activity to population firing. Compare the model to human ECoG recordings.

Miller, K. J., Sorensen, L. B., Ojemann, J. G., & den Nijs, M. (2009). Power-Law Scaling in the Brain Surface Electric Potential. *PLoS Computational Biology*, *5*(12), e1000609. https://doi.org/10.1371/journal.pcbi.1000609

> Report powerlaw scaling in human ECoG recordings, consistent across subjects in the analyzed range of 80-500 Hz. Examines neural models that may explain these patterns.

Miller, K. J., Zanos, S., Fetz, E. E., den Nijs, M., & Ojemann, J. G. (2009). Decoupling the Cortical Power Spectrum Reveals Real-Time Representation of Individual Finger Movements in Humans. *Journal of Neuroscience*, *29*(10), 3132–3137. https://doi.org/10.1523/JNEUROSCI.5506-08.2009

> Apply a PCA based method to separate low-frequency rhythms & broadband activity. Apply the method to a human ECoG motor task & report movement-specific broadband spectral motifs.

Milstein, J., Mormann, F., Fried, I., & Koch, C. (2009). Neuronal Shot Noise and Brownian 1/f2 Behavior in the Local Field Potential. *PLoS ONE*, *4*(2), e4338. https://doi.org/10.1371/journal.pone.0004338

> Explore a model of LFP generation akin to shot noise, in which the summation of many events gives rise to 1/f power spectra. Also analyze and compare to data from human micro-electrodes.

Dehghani, N., Bédard, C., Cash, S. S., Halgren, E., & Destexhe, A. (2010). Comparative power spectral analysis of simultaneous elecroencephalographic and magnetoencephalographic recordings in humans suggests non-resistive extracellular media. *Journal of Computational Neuroscience*, *29*(3), 405–421. https://doi.org/10.1007/s10827-010-0263-2

> Compare the frequency scaling of simultaneous EEG & MEG recordings, to evaluate if results are consistent with a resistive medium. Find spatial variation of the aperiodic exponent (in both) and differences between modalities, which is interpreted as relating to a non-resistive media.

He, B. J., Zempel, J. M., Snyder, A. Z., & Raichle, M. E. (2010). The Temporal Structures and Functional Significance of Scale-free Brain Activity. *Neuron*, *66*(3), 353–369. https://doi.org/10.1016/j.neuron.2010.04.020

> Examine powerlaw properties in neural power spectra of human ECoG. Also analyze and discusses nested frequencies, and variations of powerlaw properties with task modulation.

Baranauskas, G., Maggiolini, E., Vato, A., Angotzi, G., Bonfanti, A., Zambra, G., Spinelli, A., & Fadiga, L. (2012). Origins of 1/f^2 scaling in the power spectrum of intracortical local field potential. *Journal of Neurophysiology*, *107*(3), 984–994. https://doi.org/10.1152/jn.00470.2011

> Examine a model of 1/f in LFP based on steplike transitions between up and down states in neural activity. Also analyze and compare to recordings from anesthetized rats.

Valencia, M., López-Azcárate, J., Nicolás, M. J., Alegre, M., & Artieda, J. (2012). Dopaminergic modulation of the spectral characteristics in the rat brain oscillatory activity. *Chaos, Solitons & Fractals*, *45*(5), 619–628. https://doi.org/10.1016/j.chaos.2011.12.019

> Examines the effect of dopaminergic drugs on the aperiodic exponent in rats, reporting that antagonists & agonists cause rotations around a fulcrum of 20 Hz. Discuss self-organized criticality.

Fransson, P., Metsäranta, M., Blennow, M., Åden, U., Lagercrantz, H., & Vanhatalo, S. (2013). Early Development of Spatial Patterns of Power-Law Frequency Scaling in fMRI Resting-State and EEG Data in the Newborn Brain. *Cerebral Cortex*, *23*(3), 638–646. https://doi.org/10.1093/cercor/bhs047

> Examines powerlaw scaling in both EEG and fMRI in newborns and adults and analyzing spatial patterns. Report variation across spatial locations in EEG (and fMRI) powerlaw properties.

Janjarasjitt, S., & Loparo, K. A. (2013). Comparison of complexity measures using two complex system analysis methods applied to the epileptic ECoG. *Journal of the Korean Physical Society*, *63*(8), 1659–1665. https://doi.org/10.3938/jkps.63.1659

> Examines aperiodic exponent (and other measures) in human ECoG data from epilepsy patients, and reports that changes in aperiodic exponent relate to seizure activity.

> Note: there are additional related reports from Janjarasjitt & colleagues, including conference papers prior to this report, and subsequent further work on aperiodic activity in epilepsy.

Mareš, J., Vyšata, O., Procházka, A., & Vališ, M. (2013). Age-dependent complex noise fluctuations in the brain. *Physiological Measurement*, *34*(10), 1269–1279. https://doi.org/10.1088/0967-3334/34/10/1269

> Examines a large EEG dataset (n=17722) and reports a systematic decrease in exponent with increasing age. Discusses results in relation to self-organized criticality.

Miller, K. J., Honey, C. J., Hermes, D., Rao, R. P., den Nijs, M., & Ojemann, J. G. (2014). Broadband changes in the cortical surface potential track activation of functionally diverse neuronal populations. *NeuroImage*, *85*, 711–720. https://doi.org/10.1016/j.neuroimage.2013.08.070

> Examines broadband changes in human ECoG data. Report changes in broadband activity (offset) during task activity. Also discusses the aperiodic exponent.

Vyšata, O., Procházka, A., Mareš, J., Rusina, R., Pazdera, L., Vališ, M., & Kukal, J. (2014). Change in the Characteristics of EEG Color Noise in Alzheimer's Disease. *Clinical EEG and Neuroscience*, *45*(3), 147–151. https://doi.org/10.1177/1550059413491558

> Compare aperiodic exponent in EEG recordings between control and Alzheimer's patients. Report clinically-related differences in prefrontal areas.

Podvalny, E., Noy, N., Harel, M., Bickel, S., Chechik, G., Schroeder, C. E., Mehta, A. D., Tsodyks, M., & Malach, R. (2015). A unifying principle underlying the extracellular field potential spectral

responses in the human cortex. *Journal of Neurophysiology, 114*(1), 505–519.
https://doi.org/10.1152/jn.00943.2014

> Examines the aperiodic exponent in human ECoG data during a visual task. Report that the aperiodic exponent changes with stimulus presentation and relate this to neuronal activation.

Aperiodic History: Annotated Bibliography
Additional Related Papers on Methodological Aspects

This annotated bibliography lists additional papers related to the analysis of aperiodic activity in neural field recordings, specifically those that do not explicitly employ spectral measures of aperiodic activity.

Jasper, H. H. (1948). Charting the Sea of Brain Waves. *Science*, *108*(2805), 343–347. https://doi.org/10.1126/science.108.2805.343

> Discusses the analysis of EEG recordings and notes the 'Fourier fallacy' – that of assuming that measured frequencies in a frequency domain representation necessarily actually occur in the data.

Imahori, E., & Suhara, K. (1949). On the Statistical Method in the Brain-Wave Study. Part I. *Psychiatry and Clinical Neurosciences*, *3*(2), 137–155. https://doi.org/10.1111/j.1440-1819.1949.tb02697.x

> Propose an auto-correlation method for analyzing EEG. Describe a rhythmic component and an 'aperiodic motion or heavily damped undulation'. Suggest overall that 'brain rhythms' are not sinusoidal and may instead be damped oscillations and/or 'non-periodic motions'.

Brazier, M. A. B., & Barlow, J. S. (1956). Some applications of correlation analysis to clinical problems in electroencephalography. *Electroencephalography and Clinical Neurophysiology*, *8*(2), 325–331. https://doi.org/10.1016/0013-4694(56)90124-9

> Discusses autocorrelation analyses of EEG data, including how to analyze and interpret such measures, and the implication of EEG signals reflecting both periodic & aperiodic components.

Matoušek, M., Volavka, J., Roubicek, J., & Chamrád, V. (1969). The autocorrelation and frequency analysis of the EEG compared with GSR at different levels of activation. *Brain Research*, *15*(2), 507–514. https://doi.org/10.1016/0006-8993(69)90171-1

> Apply auto-correlation analyses to EEG data to investigate periodic vs. aperiodic components. Report 'mental stress' leads to decreased periodic and increased aperiodic activity.

Wennberg, A., & Zetterberg, L. H. (1971). Application of a Computer-Based Model for EEG Analysis. *Electroencephalography and Clinical Neurophysiology*, *31*(5), 457–468. https://doi.org/10.1016/0013-4694(71)90167-2

> Applies an auto-regressive model to EEG data to parameterize different 'types' of activity, including those with power across all frequencies ('Type I') & rhythmic components ('Type II').

Bullock, T. H., Mcclune, M. C., & Enright, J. T. (2003). Are the electroencephalograms mainly rhythmic? Assessment of periodicity in wide-band time series. *Neuroscience*, *121*(1), 233–252. https://doi.org/10.1016/S0306-4522(03)00208-2

> Examine and test the idea that EEG is largely made up of oscillations with a new method, and argue against this idea, suggesting that most of the power spectrum is non-rhythmic.