18 Time-Frequency Power and Baseline Normalizations

Now that you know how to extract estimates of time-varying frequency-band-specific power from EEG data using wavelet convolution, filter-Hilbert, short-window FFT, multitaper, or any other method, it is time to learn what to do with those data and how to link fluctuations in power over time and frequency to task events. If you created two-dimensional (2-D) time-frequency power plots in previous chapters, you may have noticed that the plots were difficult to interpret visually because the magnitude of power changed considerably from the lowest frequency to the highest frequency, perhaps even by several orders of magnitude. The purpose of this chapter is to discuss methods for converting time-frequency power data to a scale that is amenable to qualitative visual inspection and quantitative statistical analysis.

18.1 1/*f* Power Scaling

The reason time-frequency power plots in previous chapters were difficult to interpret is that the color scaling that looked good for one frequency band did not look good for frequency bands that were lower and higher. This is because the frequency spectrum of data tends to show decreasing power at increasing frequencies. This is not specific to EEG data but also characterizes the relationship between power and frequency of many signals, including radio, radiation from the Big Bang, natural images, and many more. This decrease in power as a function of an increase in frequency follows a "1/*f*" shape, which is illustrated in figure 18.1.

The more general form is c/f^x, where c is a constant and x is an exponent (in figure 18.1, $c = 1$ and $x = 1$; you can change c and x to observe the effects on the plot). It is also called a *power law*, because one variable (in this case, EEG time-frequency power) is a power function of another variable (frequency) (note that "power" here refers to raising a number to a power of another number, not the squared magnitude of a complex number). Because

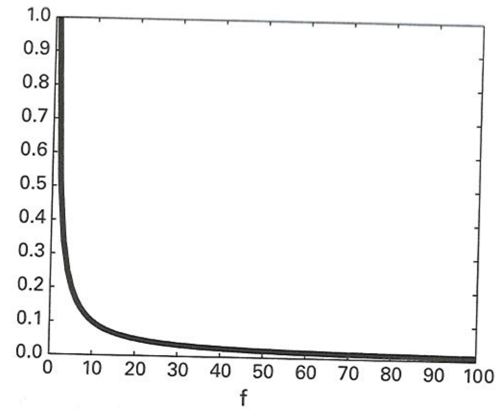

Figure 18.1
A $1/f$ function that characterizes, among other things, EEG power data.

EEG time-frequency power obeys a $1/f$ phenomenon, the power at higher frequencies (e.g., gamma) has a much smaller magnitude than the power at lower frequencies (e.g., delta).

This is why it is difficult to visualize activity from a large range of frequency bands simultaneously. The $1/f$ phenomenon entails five important limitations to interpreting and working with time-frequency power data. Fortunately, as we see later in this chapter, certain baseline normalization methods overcome all of these limitations.

The first limitation is that it is difficult to visualize power across a large range of frequency bands. This was already mentioned and is shown again below. The second limitation is that it is difficult to make quantitative comparisons of power across frequency bands. You might want to determine, for example, whether the power increase in gamma is significantly bigger than the power decrease in alpha. Because the raw power values change in scale as a function of frequency, lower frequencies will usually show a seemingly larger effect than higher frequencies in terms of the overall magnitude. The third limitation is that aggregating effects across subjects can be difficult with raw power values. This is because individual differences in raw power are influenced by skull thickness, sulcal anatomy, cortical surface area recruited, recording environment (e.g., scalp cleanliness and preparation and electrode impedance), and other factors that are independent of the neurocognitive process under investigation (this issue was discussed in section 2.3). The fourth limitation is that task-related changes in power can be difficult to disentangle from background activity (this is also shown below). This is particularly the case for frequencies that generally tend to have higher power or frequencies that tend to have higher power during baseline periods, such as alpha activity over posterior parietal and occipital electrodes. Finally, the fifth limitation is that