separate figures for each frequency. The
me within a frequency, but the color scal
seline normalization and should also be

phical distributions of power with com
differences more prominent in some fre
be causing these differences?

19 Intertrial Phase Clustering

In chapter 13 you learned that the analytic signal resulting from convolution between an EEG time series and a complex wavelet, or resulting from the filter-Hilbert method, can be conceptualized as a vector in a complex polar plane with a magnitude (length of the vector) and a phase angle (the angle in radians relative to the positive real axis). These phase angles provide information about the timing of frequency-band-specific activity and are the main focus of this chapter.

If you want to compute the consistency of time-domain EEG traces over trials, you simply average the activity at each time point across trials to form an event-related potential (ERP). Computing the consistency of time-frequency power over trials is the same as for ERPs: average the frequency-band-specific power at each time point across trials. However, computing the consistency of time-frequency phase values over trials is not so simple because phase values cannot be averaged together in the same way that voltage values or power values can be averaged. Learning how to average phase values and compute the consistency of phase values over trials is useful not only for examining the timing of frequency-band-specific activity but also forms the basis of several phase-based connectivity methods.

19.1 Why Phase Values Cannot Be Averaged

It would seem easy simply to average together the phase angle time series across trials, the way you would average single-trial EEG traces to form an ERP. Unfortunately, however, this is inappropriate. Phase angles are circular, which means that, for example, 0.05 and 6.2332 might seem far apart from each other when considered as numbers on a number line, but are actually very close to each other when considered as radians. Indeed, averaging these two numbers together gives a result close to π, which is in the opposite side of polar space from angles 0.05 and 6.2332 radians. Thus, it is not appropriate to average radian values together as if they were normal numbers (figure 19.1).

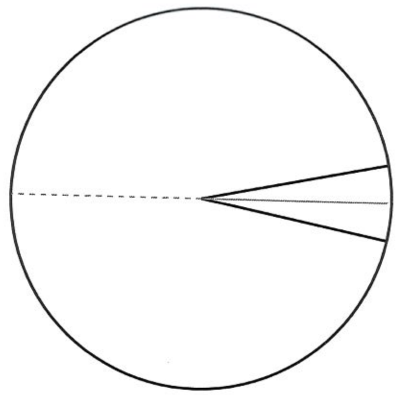

Figure 19.1
Two vectors (black lines) have similar angles; the average vector (solid gray line) reflects their proximity, but a vector formed by averaging their angles in radians (dashed gray line) does not reflect the two vectors. This is an illustration of why averaging phase angle radian values is inappropriate.

Remember that phase angles can be represented as vectors with unit length on a circle, and that Euler's formula (e^{ik}) provides a convenient mathematical description of those vectors in a complex plane. Thus, a population of phase angles can be represented as a population of vectors on a circle. For example, figure 19.2A,C shows phase angles from all trials at 200 ms and at 800 ms post–stimulus onset. Each vector (shown as a gray line) was formed by taking the phase angle from one trial and setting the vector length to 1 (rather than the vector length reflecting the similarity between the time series and the wavelet). The histograms on the bottom row show these same phase angle distributions in a different and perhaps more familiar way. You can see that at 200 ms, the vectors are clustered around one region of the circle, whereas at 800 ms they are more scattered. Another way to describe these distributions of phase angles is that the distribution of phase angles over trials is less uniform at 200 ms compared to the distribution at 800 ms. The extent to which these vectors are clustered (or nonuniformly distributed) is the measure of phase clustering across trials. This should make sense conceptually: if the timing of an oscillatory process is the same or similar at each repetition of a stimulus or other experiment event, their phase angles should take on similar values across trials.

19.2 Intertrial Phase Clustering

The measure of phase angle clustering illustrated conceptually in figure 19.2 is called intertrial phase clustering (ITPC). ITPC measures the extent to which a distribution of phase