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Inter trial phase clustering

Chapter 5

BING 8995

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- average the activity at each time point across trials to form an event-related potential (ERP)
- Average the frequency-band-specific power at each time point across trials
- Phase values cannot be averaged together in the same way that voltage values or power values can be averaged
- Basis for phase based connectivity methods

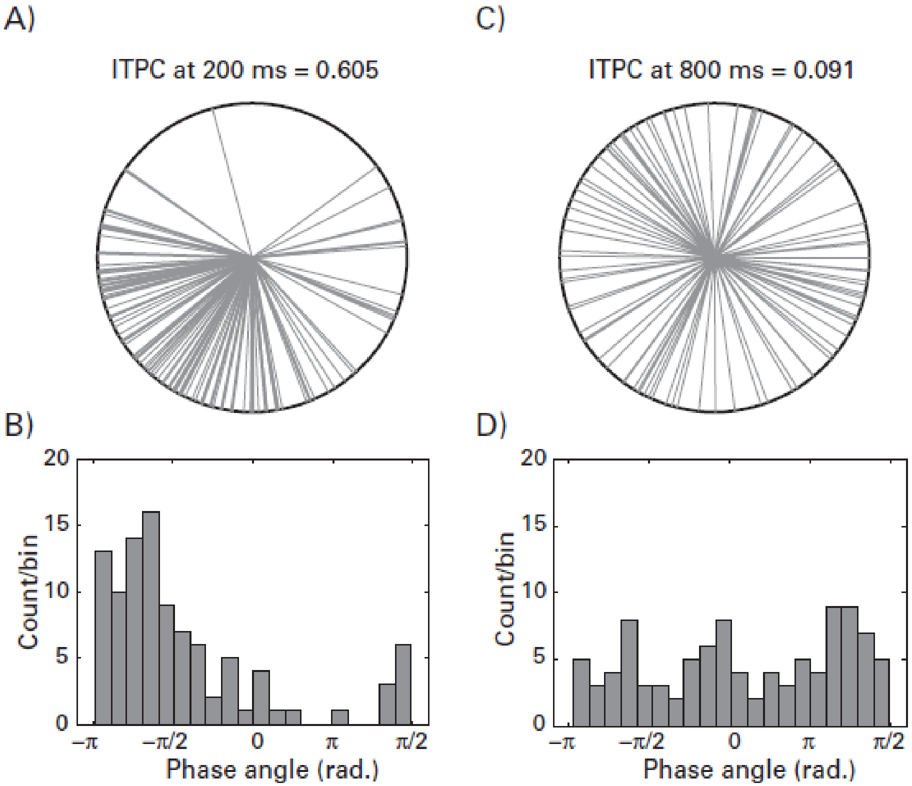

Figure 19.2
Phase-angle distributions at two time-frequency points. Each line in panels A and C corresponds to one trial, and the histograms in panels B and D show counts of trials per phase bin. It is clear that the phase angles are more clustered at 200 ms (panels A and B) compared to 800 ms (panels C and D).

ITPC

- ITPC measures the extent to which a distribution of phase angles at each time-frequency-electrode point across trials is nonuniformly distributed in polar space
- ‘phase-locking value’, ‘phase coherence’
- Measured by computing average vector, and then take the length of that average vector
- Individual vectors have unit length, average vector has a length < 1
- Further apart are the 2 vectors, their average length is smaller
- Length of average vector reflects the closeness of the two unit length vectors
- ITPC is the length
- ITPC = 0 means completely uniformly distributed phase angles
- ITPC = 1 completely identical phase angles
- In Matlab >> abs(mean(exp(1i*k))), k is a vector of phase angles at one time frequency point over trials (it does not average phase angles in radiance, it averages complex vectors whose angles are defined by the phase angles in radians)

$$\mathrm{ITPC}_{tf} = \left| n^{-1} \sum_{r=1}^{n} e^{ik_{tfr}} \right|$$

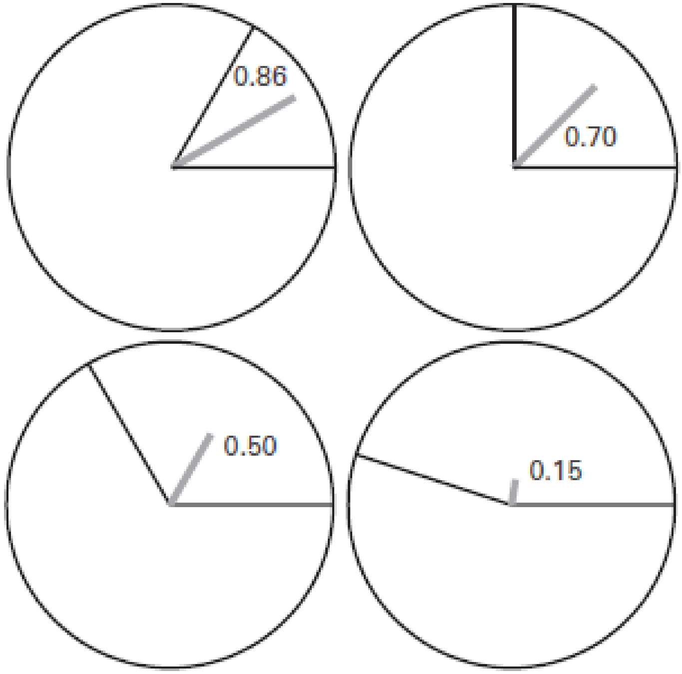

Figure 19.3
Example pairs of unit-length vectors (black lines) and their averages (gray lines). The numbers inside each circle indicate the length of the average vector. This number is the ITPC for those two vectors.

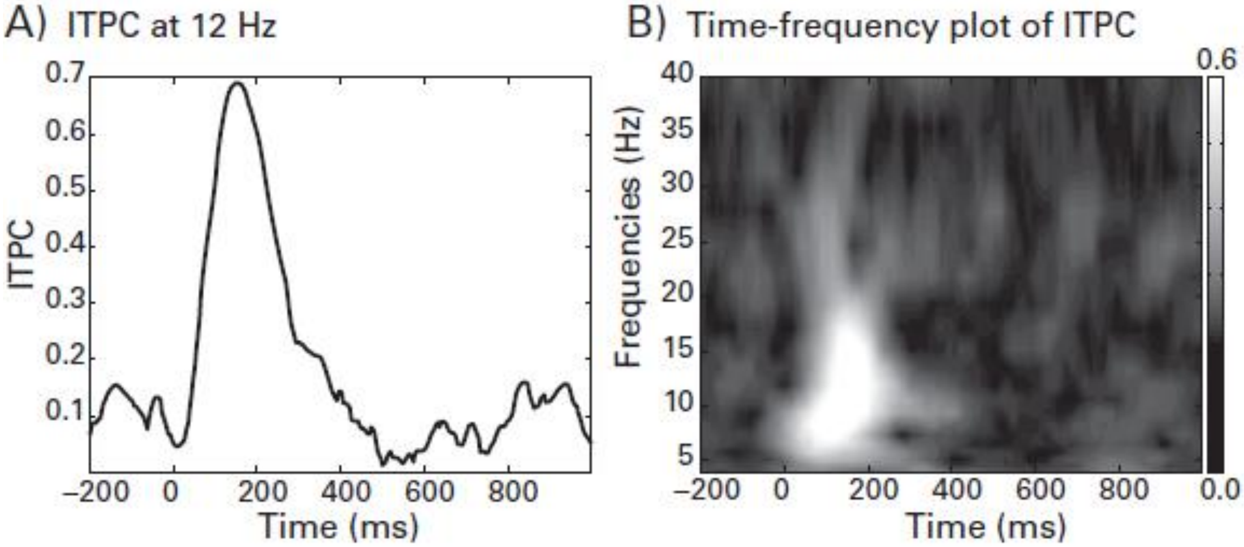

Figure 19.4
ITPC from electrode Pz at 12 Hz (panel A) and over time-frequency space (panel B).

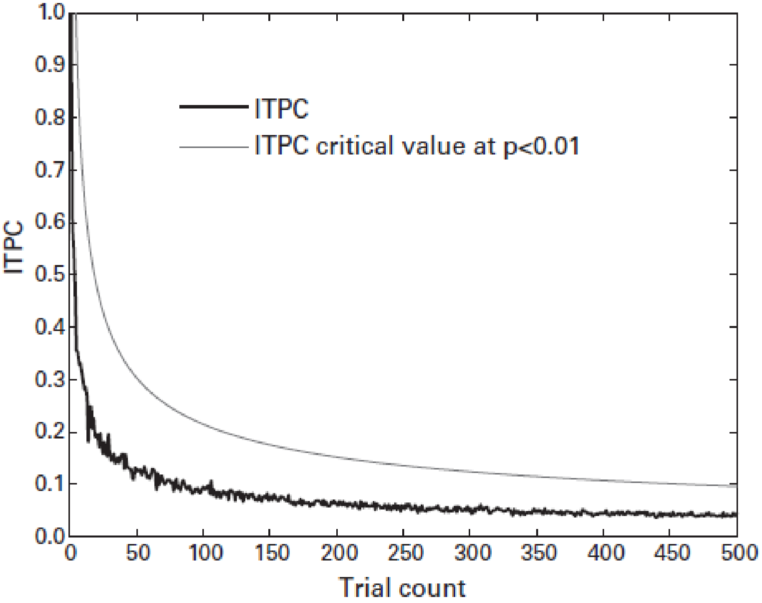

Figure 19.5
ITPC as a function of trial count for simulated random phase angles averaged over 50 simulations. Also shown is the critical ITPC value for each trial count, corresponding to a *p*-value threshold of 0.01.

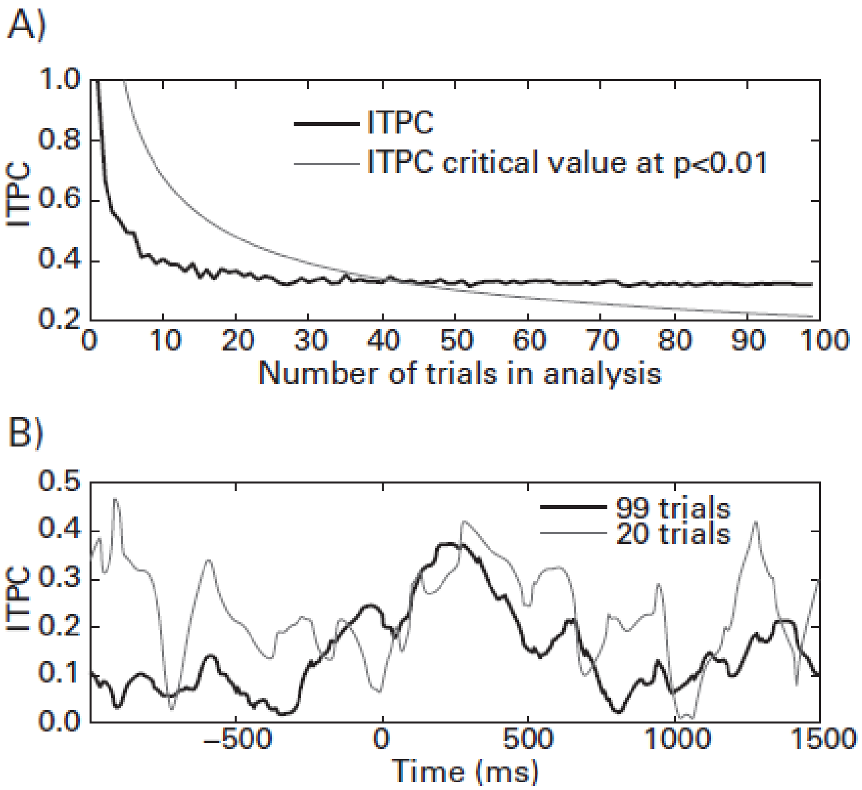

Figure 19.6

Relationship between ITPC and trial count in real data. Panel A shows the same analysis as was shown in figure 19.5 (ITPC as a function of trial count) but for real data instead of randomly generated phase angles. Each point is the average of 50 iterations of random trial selection. Panel B shows the time courses of ITPC for 20 randomly selected trials and all 99 trials. Phase angles were extracted via complex wavelet convolution with a 6-Hz wavelet.

ITPC stabilizes after 20 trials and is significant (above critical value) after 45 trials

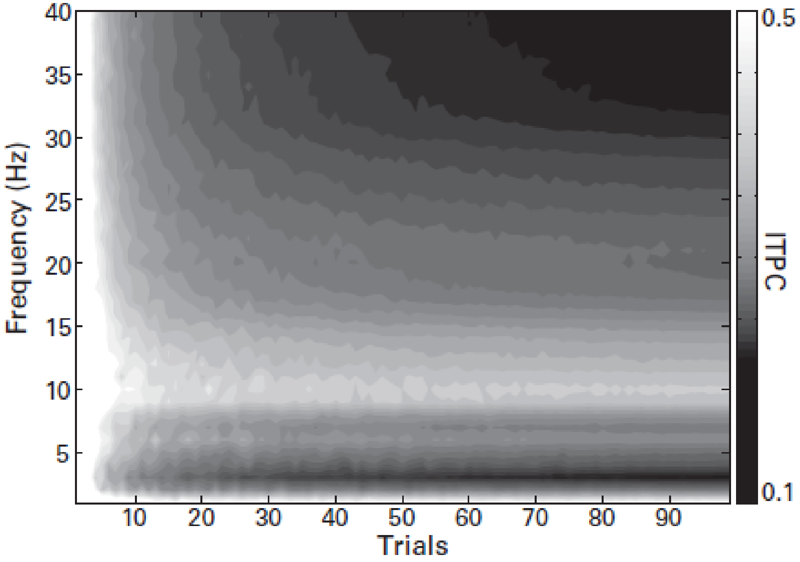

Figure 19.7
ITPC as a function of trial count and frequency. Note that where there is strong ITPC (here, around 10 Hz), trial count seems to have less influence on the strength of ITPC. Results are averaged over 50 iterations of randomly selected trials.

Based on data from one subject, one electrode and one time window

a way to examine in your own data whether you likely have enough trials for a stable estimate of ITPC within each condition

Low trial count can be more deleterious when ITPC is compared between conditions that differ in trial count

if the two conditions have trial counts of 60 and 70, there is less cause for concern about possible spurious results due to trial count differences

Effects of temporal jitter on ITPC and power

- ITPC reflects the precise timing of band-specific activity, it is sensitive to temporal jitter or temporal uncertainty of experiment events

$$ITPC_Z = n * ITPC^2$$

- n is the number of trials. ITPCz is more stable
- For a 60-Hz monitor, if there is uncertainty as to when the stimuli are drawn on the monitor with respect to when the experiment marker is recorded in the EEG acquisition system, this could produce jitters up to 34 ms

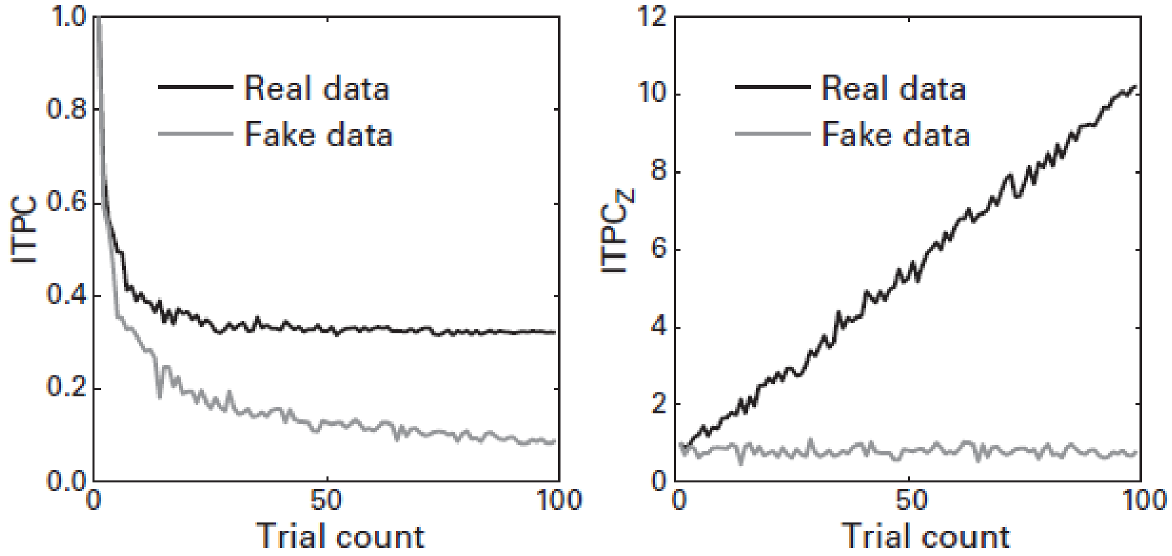

Figure 19.8

Comparison of ITPC and $ITPC_Z$ for randomly generated phase angles (gray lines) and real data (black lines). You can see that $ITPC_Z$ remains flat with increasing trial count for random data, whereas $ITPC_Z$ increases with trial count for real data, even though the "raw" ITPC values remain stable. This reflects increased reliability of $ITPC_Z$ with additional data.

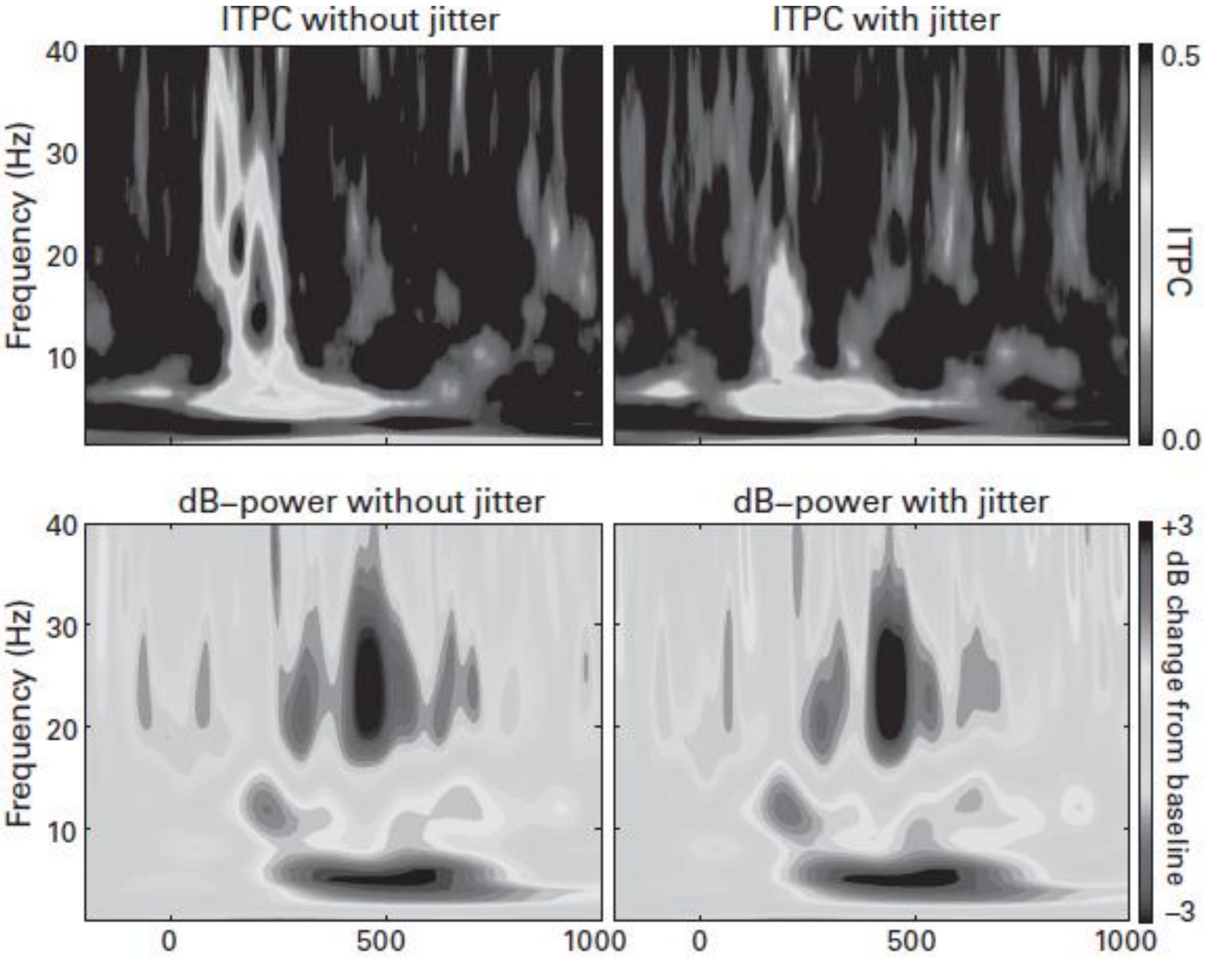

Figure 19.9 (plate 10)

Temporal jitters of less than 40 ms can have deleterious effects on ITPC (top row), particularly at frequencies above 10 Hz. In contrast, temporal jitters have little noticeable effects on power.

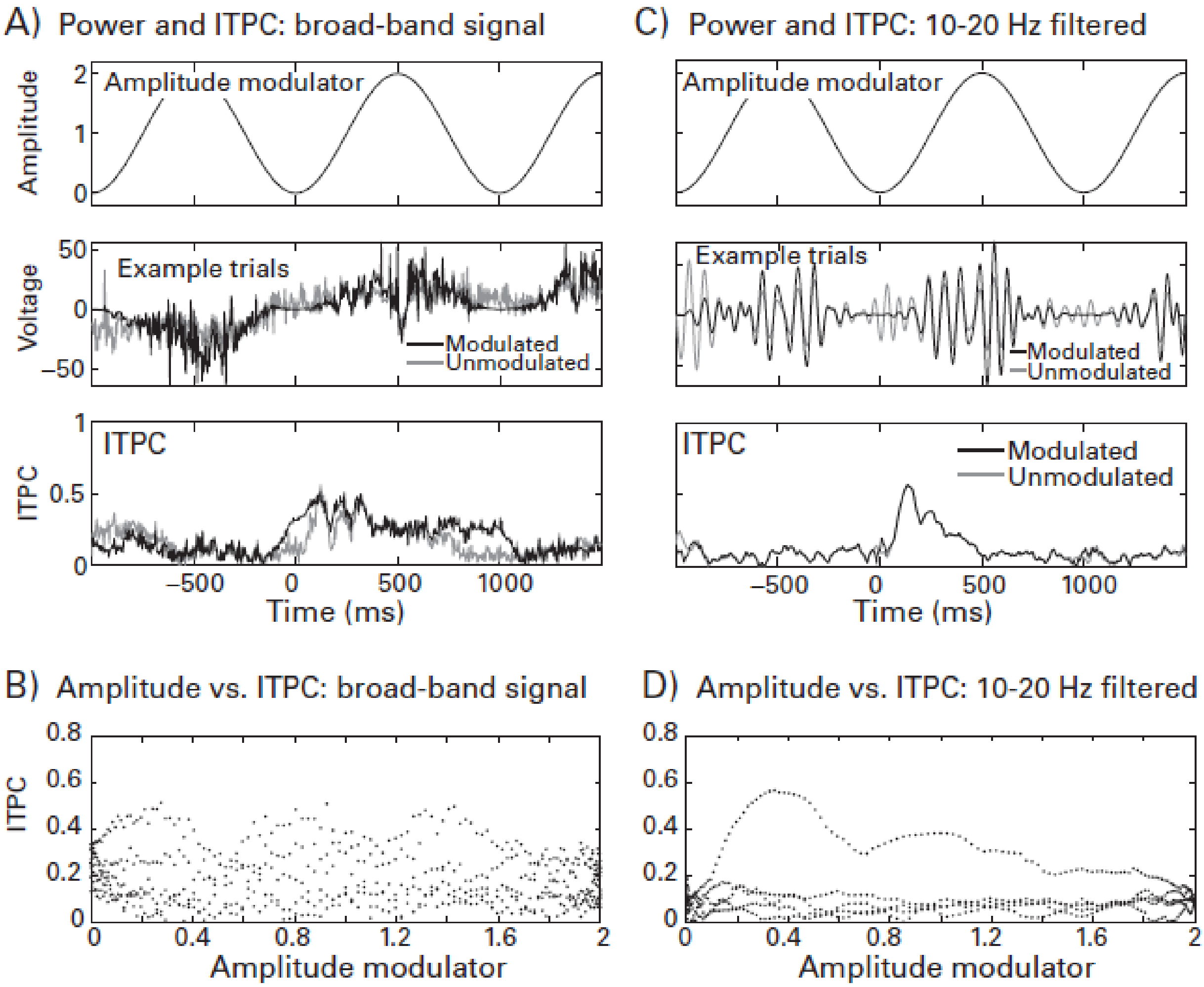

Figure 19.10

The relationship between power and ITPC. Real data were modulated by a 1-Hz sine wave (panels A and C, top row), resulting in significant power decreases and increases over time (panels A and C, middle row). ITPC based on broadband activity was somewhat affected by power being attenuated to zero, whereas ITPC based on band-limited activity was less affected by power (third row; the black and gray lines in panel C are mostly overlapping). Panels B and D show the relationship between ITPC and the modulating power signal.

Power and ITPC

- power and ITPC are not necessarily coupled and that ITPC can be safely interpreted independently of power.
- Nonetheless, the potential relationship between power and ITPC should not be dismissed
- It is a good idea to examine the relationship between ITPC and power in the data before confidently interpreting ITPC and power in different ways.
- This could be done, for example, by showing qualitative differences between power and ITPC over time, frequency, electrodes, or conditions

Spike field coherence

- ITPC is designed for unimodal distributions — that is, phase distributions that have one peak
- There are methods for detecting and quantifying multimodal peaks in phase distributions

Exercise

- 1. Pick three electrodes. Compute time-frequency plots of ITPC and decibel-corrected power for these electrodes, using either complex Morlet wavelet convolution or the filter-Hilbert method. Plot the results side by side for each electrode (power and ITPC in subplots; one figure for each electrode). Are the patterns of results from ITPC and power generally similar or generally different? Do the results look more similar at some electrodes and less similar at other electrodes?

- Total power: take the time frequency decomposition (through any method) of each trial and then average together the time-frequency power from all trials
- Non-phase locked power: time-frequency representation of the data after the phase-locked components of the EEG signal are removed
- ERP of the non-phase-locked activity will be — by definition — zero. For the same reason, the ITPC of non-phase-locked activity will be very close to zero

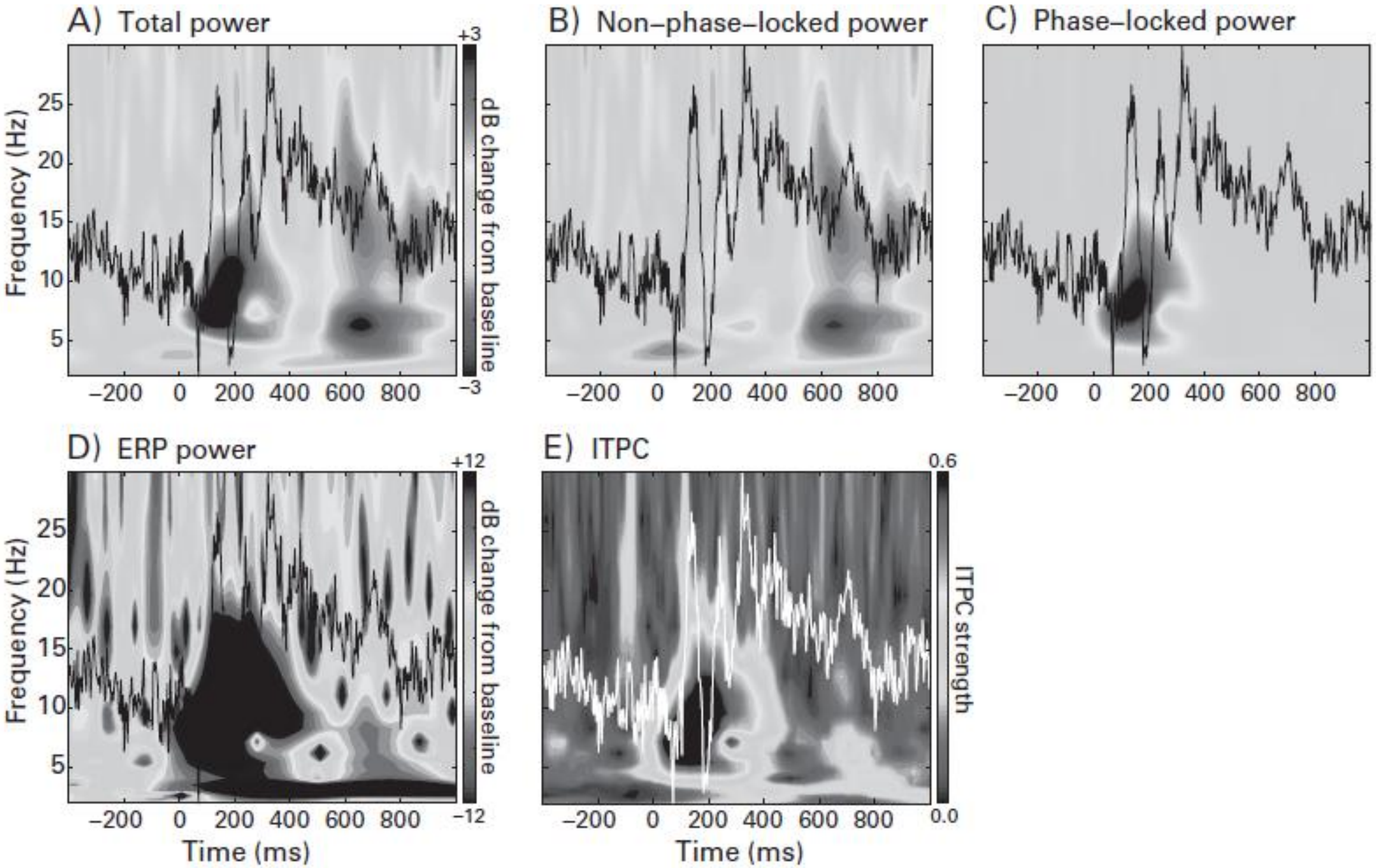

Figure 20.1 (plate 11)

Example results from different methods of computing time-frequency power (panels A–D) and ITPC (panel E) at electrode O1. The ERP is overlaid on the time-frequency plots to facilitate comparison between the ERP and the time-frequency features (the phase-locked ERP is shown in panel B rather than the non-phase-locked ERP because the latter is zero). The ERP is colored white in panel E for increased visibility in the grayscale version of this figure. The color scaling in panels B and C is the same as that in panel A.

Phase locked power (evoked power)

- If total power comprises both phase-locked and non-phase-locked activity, then it is logical that subtracting the non-phase-locked power from the total power yields the phase-locked power.
- ERP time-frequency power may be most useful for attempts to dissociate components of the ERP by their frequency representation rather than by their latency and polarity

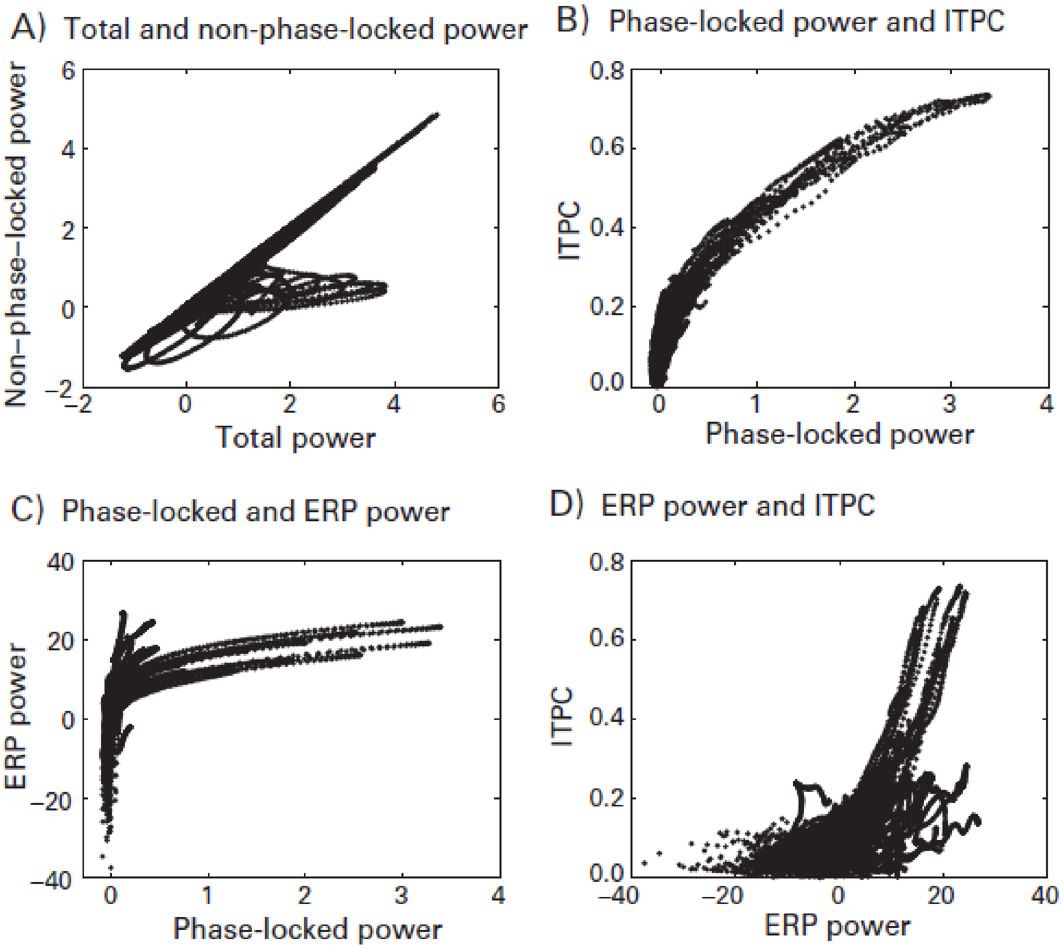

Figure 20.2

Direct comparison of results for the different methods of computing time-frequency power discussed in this chapter. Each dot corresponds to a single time-frequency point. The scale for all axes is dB change from baseline, except for ITPC in panels B and D.

- The slow potential in the ERP, which is visible as a slow fluctuation from around 0 ms until around 800 ms, is captured by the ERP time-frequency response as an increase in delta-band (< 4 Hz) power, but is not readily apparent in the time-frequency power plots in panels A – C
- ITPC is best to use when there are hypotheses regarding the timing of band-specific activity over trials with respect to an experiment event such as stimulus onset or response.
- ITPC is advantageous over the ERP because ERPs often have relatively little frequency-band specificity. On the other hand, the temporal precision of ITPC is lower than that of ERPs

Exercise

- Pick two frequencies and compute total and non-phase-locked power from each electrode over time at these two frequencies. Pick two time windows, one early and one late, of several hundreds of milliseconds each (e.g., 100 – 300 ms and 500 – 800 ms) and show topographical maps of total power, non-phase-locked power, and phase-locked power from the average of all time points within these windows. Are there striking topographical differences among these results? If so, are the differences bigger or smaller in the early or the late time window? Why might this be the case?

Interpreting time frequency power

- Increase in time-frequency power include synchronization at the local neural level
- Synchronization is used to refer to ‘power’
- synchronization among these neurons would lead to synchronous field potential oscillations, which would produce a field potential powerful enough to be detected by scalp electrodes

linking specific brain rhythms in specific brain regions to cognition

- Power increases and decreases are frequency band specific, and different frequency bands seem to have different neurobiological mechanisms
- Gamma, for example, is often interpreted as reflecting spatially local processing, whereas lower frequency bands such as delta and theta are generally interpreted as reflecting coordination of larger-scale networks
- long-range gamma-band synchronization has been reported in humans and nonhuman primates
- Alpha is thought to correlate negatively with cortical activation, suggesting that alpha reflects active and selective inhibition
- Beta-band activity over motor areas is linked with motor responses
- Theta-band activity over prefrontal regions has been implicated in working memory and top-down cognitive control processes

Interpreting Intertrial phase clustering

- ITPC is, mathematically, the clustering of the timing of band-specific activity over trials
- Phase reflects the timing of population activity
- It is a ‘functional configuration’ or ‘functional state’
- at each instance of an event that elicits ITPC, the neural networks contributing to the ITPC return to the same or similar functional configuration, as measured by phase
- Functional configuration maximize information processing, or increase interregional coupling

Limitations

- There are many fewer investigations into the time-frequency dynamics of cognitive processes compared to investigations into the ERP dynamics of cognitive processes
- This limitation should decrease over the coming years as more becomes known about the time-frequency characteristics of different cognitive processes and as theories begin to develop that account for frequency-band-specific dynamics that support cognitive processes

Do time frequency analyses reveal neural oscillations?

- Conceptualizing EEG as containing time-frequency information –yes
- Time-frequency-based analyses do not reveal all of the information in EEG data, but they will help link brain dynamics to behavior dynamics in ways not possible using ERPs
- study involving
- non-phase-locked activity, activity over 20 Hz, prestimulus activity, resting-state activity, or connectivity results likely contains findings that were accessible only through time-frequency-based analysis techniques.
- Time-frequency-based approaches should be used in addition to or instead of ERPs for cognitive electrophysiology
- use terms such as “ band-specific ” or state the center frequencies when describing empirical results (e.g., “ a relative suppression of ~10 Hz power in condition A compared to condition B ” or “ theta-band power was maximal over midfrontal electrodes ”) and to reserve the term “ oscillation ” when interpreting or speculating about the results (e.g., “ oscillations in the alpha band have been implicated in active inhibition of processing ” or “ theta-band oscillations in prefrontal cortex might be used to coordinate large-scale networks ”)