Noise and Data Preprocessing

One of the notable, but surprising, aspects of fMRI for new statistical researchers is that the data are very noisy. By this we mean both that the data are prone to noise from a wide variety of sources, which we shall survey in this chapter, and also that the BOLD signal is but a small portion of the overall measured MR signal. Hence it is crucial, prior to any formal statistical analysis, to clean up as much of the extraneous sources of variation as possible, and to isolate the signal. Fortunately, the noise in fMRI is well understood, and there are standard methods and tools for preprocessing the data, so that new researchers coming into this field do not have to start from the very beginning. This chapter presents the major sources of noise that are of concern in fMRI, and outlines the approaches for preprocessing.

3.1 Sources of Noise

Noise in fMRI data may be roughly characterized into three groups: thermal noise, system noise, and subject- and task-related noise. The first two types of noise are related to the properties of the scanner and are intrinsic to the imaging process. The third type is derived from the inescapable fact that the experimental subjects are human, and as such will breathe and move around while in the scanner. Both of these activities, among others, have the effect of introducing noise into the image.

*Thermal noise* is an intrinsic part of MR imaging. It reflects changes in the strength of the MR signal over the course of an imaging session, caused by thermal motion of the electrons in the sampled tissue and in the electronic components of the scanner. Thermal motion occurs when electrons collide with atoms, for example, in the scanner hardware. As the temperature of the system increases, the rate of collisions goes up, resulting in greater distortion of the signal. In theory, then, it would be possible to eliminate thermal noise by reducing the temperature in the MR system as a whole. As a matter of practice, this approach is not feasible, however, because thermal noise will
always be present, unless the temperature is reduced to absolute zero. Thermal noise also increases with the strength of the main magnetic field (Edelstein et al., 1986). In general, thermal noise is not of much concern. Since it is random, and not related specifically to the experimental task, its effects can usually be mitigated by simply averaging over data points.

As the name implies, system noise is introduced by fluctuations in the functioning of the MR hardware, that is, noise that comes from the system itself. Two common causes of system noise are inhomogeneities in the static magnetic field and instabilities in the gradient fields. Problems with the radiofrequency coils are also a source of system noise. An important form of system noise is drift in the signal, whereby over the course of an experiment, the signal intensity at any given voxel gradually and systematically changes, as shown in Figure 3.1.

Fig. 3.1. Over time, the underlying signal intensity gradually changes. This phenomenon is known as signal drift and is one of the sources of noise in fMRI data.

Thermal and system noise are intrinsic in that even if the object scanned is a so-called inert “phantom,” such as a ball or a cylinder filled with liquid, these types of noise will still be apparent. By far the more interesting forms of noise from a statistical perspective are those arising from the fact that the object in the scanner is not a phantom, but rather a living, breathing, thinking human being, performing an experimental task – subject- and task-related noise.