Supplementary Methods

1 Examination of Bandwidth and Data Length on Performance

1.1 Introduction

The proposed time-frequency optimized beamformer makes use of data segmented into a lattice of time windows and frequency bands before generating a covariance estimate for each time-frequency segment. Consequently, window lengths and bandwidths must be designed to ensure each segment contains sufficient data to calculate a stable and well-conditioned covariance estimate. This is of significant importance, as the quality of the covariance estimate has a dramatic impact on beamformer performance (Robinson, 2006; Brookes et al., 2007). While this topic is a complex one, here we present a series of analyses to illustrate the effect of bandwidth, time window length, and numbers of trials on performance for a given simulated dataset.

1.2 Data Generation

A single 19 Hz sine wave source was synthesized and placed at $(25, 30, 100)$ mm. The contrast between the active period and control period was set to 10 dB. As with the simulations in the main article, a human subject's head model was used to generate the simulated MEG recordings; in this case, real "brain noise" was added such that the SNR of the active period was 0.5 (-3 dB). The active and control periods each consisted of 1750 ms and 50 trials. The "true" covariance for this simulation is known to be $\boldsymbol{R} = \boldsymbol{l}(\boldsymbol{r})\boldsymbol{l}^T(\boldsymbol{r})$, where $\boldsymbol{r} = (25, 30, 100)\ mm$.

1.3 Results

The method proposed in Section 2.4 was applied to reconstruct the simulated source, varying different parameters. First, the bandwidth and time window lengths (using all 50 trials) were varied. The reliability of the resulting covariance estimates were quantified by calculating their condition numbers (Figure 1(a)) as well as their correlations with the true covariance (Figure 1(b)).

As can be seen in the figures, extremely short windows or narrow bandwidths result in ill-conditioned matrices that may result in unreliable inversion. However, only 200 ms of data were necessary to reduce the condition number to below 10^5 for the 12–30 Hz band. All band choices converge to a condition number of approximately 10^4 given large enough time windows.

The correlation between the covariance estimate and the true covariance was highest for the narrowest bands. This correlation did not vary significantly with time window length. We can therefore infer that filtering alone increases the SNR such that the covariance estimate is improved given narrowband oscillatory sources. In this situation, the reliability of the inverse of the covariance estimate (quantified by the condition number) appears to be the deciding factor in beamformer performance.

Next, the contrast of the localized source between the resulting active and control beamformer images was examined (Figure 1(c)) along with the full-width at half-maximum (FWHM) as a measure of blur (Figure 1(d)). Here, the compromise between bandwidth and time window length becomes readily apparent. The ultimate parameter choice, then, must be driven by experimental hypotheses. It must be considered that real sources are unlikely to stay active for several hundreds of milliseconds at a time, making extremely narrow bandwidths impractical. Conversely, a source at a given location may generate a power increase in one band simultaneously with a power decrease in another band (as with common beta ERD-gamma ERS observations); performance would suffer if both events were contained by a single wide frequency band. Given these considerations, we felt that 12–30 Hz was a reasonable compromise between band separation and time resolution.

We then proceeded to determine how performance varies with numbers of trials (Figures 2(a) and 2(b)). We found that total data length (time window length multiplied by number of trials) directly determined performance; e.g., using twice as many trials with half the window length produced similar results. Therefore, experiments should be designed with the duration of expected activations in mind, increasing the number of trials acquired as necessary.

1.4 Conclusions

Although the behavior observed here is empirically similar for other line frequencies and source locations, the exact shape of the curves will depend on several factors that preclude complete generalization of the results. The SNR and stationarity of the data are other significant variables that can impact performance. The optimal window length will likely shift as a function of center frequency as well; for example, a 200 ms window would poorly characterize an alpha band source, while it would capture several cycles of a possibly transient gamma band oscillation. Keeping these additional variables in mind, the performance tradeoffs demonstrated here can provide a guide for potential users in designing optimal parameters for their own experiments and data.

References

Brookes, M. J., Vrba, J., Robinson, S. E., Stevenson, C. M., Peters, A. M., Barnes, G. R., Hillebrand, A., Morris, P. G., 2007. Optimising experimental design for MEG beamformer imaging. NeuroImage.

Robinson, S. E., August 2006. Beamforming: How much data do you really need? Talk given at the Recent Advances in Biomagnetic Signal Processing and Source Localization, Biomag 2006 Workshop, Vancouver, BC, Canada.

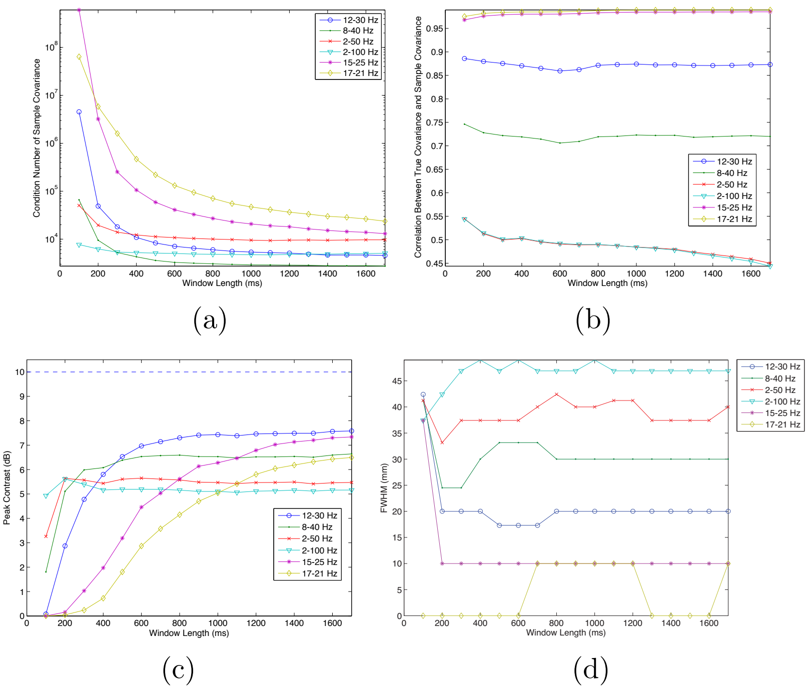

Fig. 1. (a) Condition number of the sample covariance matrix as a function of time window length and bandwidth. (b) Correlation coefficient of the sample covariance matrix with the true covariance matrix, as a function of time window length and bandwidth. (c) Peak source image contrast observed with various time window lengths and bandwidths. (True contrast was 10 dB.) (d) The full-width at half–maximum (FWHM) of the resolved peak, indicating degree of blur, for various time window lengths and bandwidths.

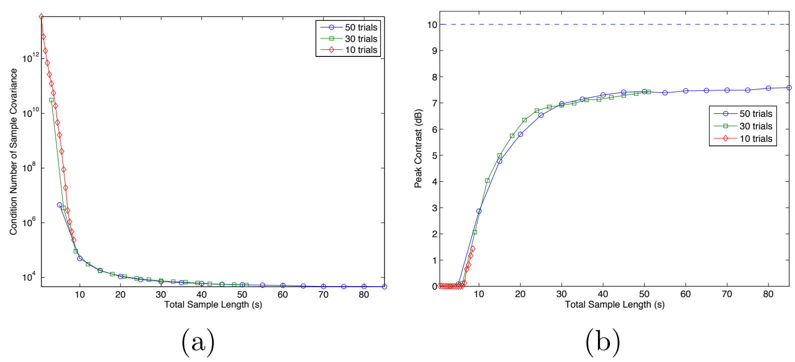

Fig. 2. (a) Condition number of the sample covariance matrix as a function of total sample length (window length × trials), given 10, 30, or 50 trials. (b) Peak source image contrast as a function of total sample length, given 10, 30, or 50 trials. True contrast was 10 dB.