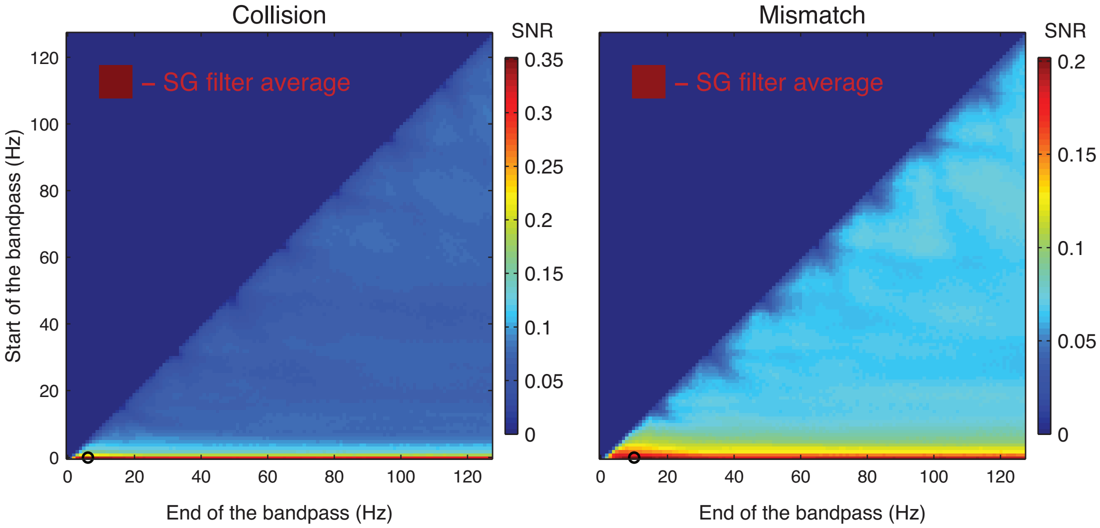
Supplementary material

1. Choice of the filter for the low frequency component of the signal

To investigate the ERNRs in the low frequencies, we low-pass filtered the ECoG signals using a 2nd order symmetric Savitzky-Golay filter of 250ms window length. To show that our choice of filter was suitable for extracting ERNRs contained in the low frequency signal, we compared the strength of ERNRs gained by our filter to the ERNR strength gained by other low and band pass filters. Recordings were filtered with low and band pass 8th order Butterworth filters with low and high cuttoff frequencies taking all possible combinations of values from 0Hz to 127Hz in steps of 1Hz. To measure the ERNR strength, we calculated the SNR of the filtered neural responses to collision and to mismatch events against the baseline activity. Collision and movement mismatch SNR was pooled over subjects and then averaged across channels, for all tested Butterworth filters and for our choice of Savitzky-Golay filter (Supplementary figure 1). For both collision and mismatch SNR, the low pass Butterworth filter had a higher average SNR than any bandpass Butterworth filter. The difference between maximum SNR for Butterworth filter (average collision SNR: 0.34, cutoff frequency of 6Hz; average mismatch SNR: 0.202, cutoff frequency 10Hz) and the SNR for our Savitzky-Golay filter (collision: 0.35; mismatch: 0.199) was not significant ($p<0.05$; Wilcoxon signed-rank test). Therefore, we conclude that our filter was a good choice for extracting the low frequency component of the ERNRs.



Supplementary figure 1. Average collision (left) and movement mismatch (right) SNR for low and band pass filtered signals. SNRs were pooled over subjects and averaged across electrodes and are shown for all possible choices of bottom and top cutoff frequency of the Butterworth filter used to filter the signal. Cutoff frequencies that provided the highest average SNR are shown with black circle. Inset square shows the average SNR gained by using the Savitzky-Golay filter used for defining the low frequency component of the neural response in our study.

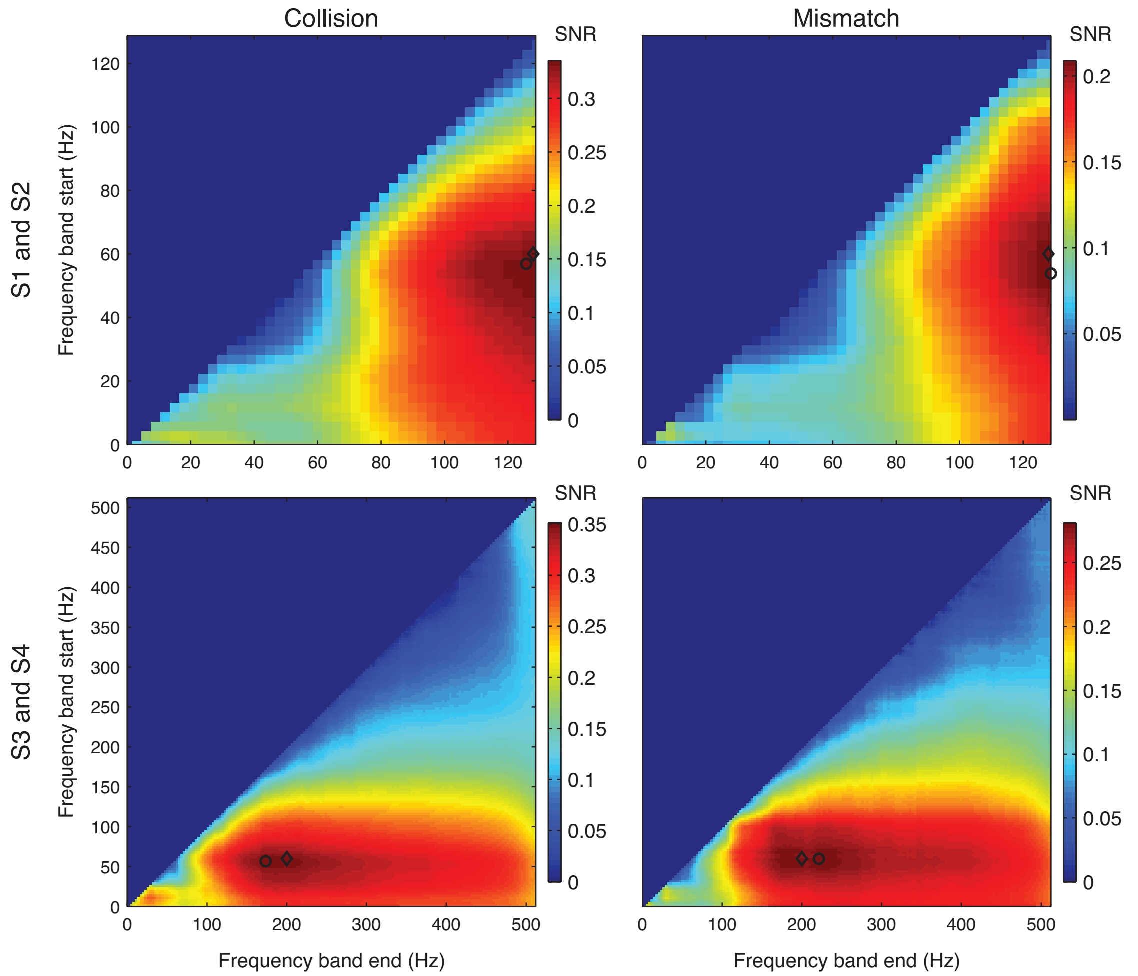
2. Choice of the frequency band for the high frequency component

In addition to the low and band pass filtering in Supplementary section 1 we also investigated the amplitude of different frequency bands with regard to their information about error events. These amplitudes were extracted from the ECoG signals via a time-resolved Fourier transform (see 2.4.2. for details). In contrast to the low and band pass filtered signals, the amplitudes calculated using time-resolved Fourier transform do not contain any phase information, and represent the amplitude envelope of the signal at a certain frequency.

We computed the SNR (event vs. baseline) of the amplitudes in different frequency bands for collision and mismatch events. Collision and movement mismatch SNRs were pooled over subjects and then averaged across channels (Supplementary figure 2). For S1 and S2, where the Nyquist frequency was 128Hz, the average collision SNR peaked at the band starting at 51Hz and ending at 117Hz (average SNR: 0.35), while the average movement mismatch SNR peaked at the band staring at 54Hz and ending at 126Hz (average SNR: 0.172). For S3 and S4, where the Nyquist frequency was 512Hz, the average collision SNR peaked at the band starting at 60Hz and ending at 174Hz (average SNR:0.351), while the average movement mismatch SNR peaked at the band staring at 60Hz and ending at 226Hz (average SNR:0.281). For all subjects and both events, SNR peaks were rather broad and small changes of the upper and lower bounds of the frequency bands did not affect the SNR considerably. Given the lower Nyquist frequency in S1 and S2, it is not surprising that the upper bound of the optimal frequency band in these subjects is lower than in S3 and S4. Indeed the optimal upper bound for S1 and S2 is close to the Nyquist frequency in S1 and S2.

To choose a common band for both events and a band which has the same lower border for all subjects, we decided to use the band 60Hz-200Hz in S3 and S4 and the band 60Hz-128Hz in S1 and S2. For S1 and S2, collision and mismatch SNR was not significantly different between the peak frequency band and the band that we chose to use (band spans from 60Hz to 128Hz; average collision SNR: 0.33; average mismatch SNR: 0.169; $p<0.001$; Wilcoxon signed-rank test). For S3 and S4, collision and mismatch SNR was significantly different between the peak frequency band and the band that we chose to use (band spans from 60Hz to 200Hz; average collision SNR: 0.348; average mismatch SNR: 0.279; $p<0.19$; Wilcoxon signed-rank test), but the differences between the average collision and mismatch SNR for the optimal band and the band we chose is below 1% of the average collision and mismatch SNR for the optimal band.

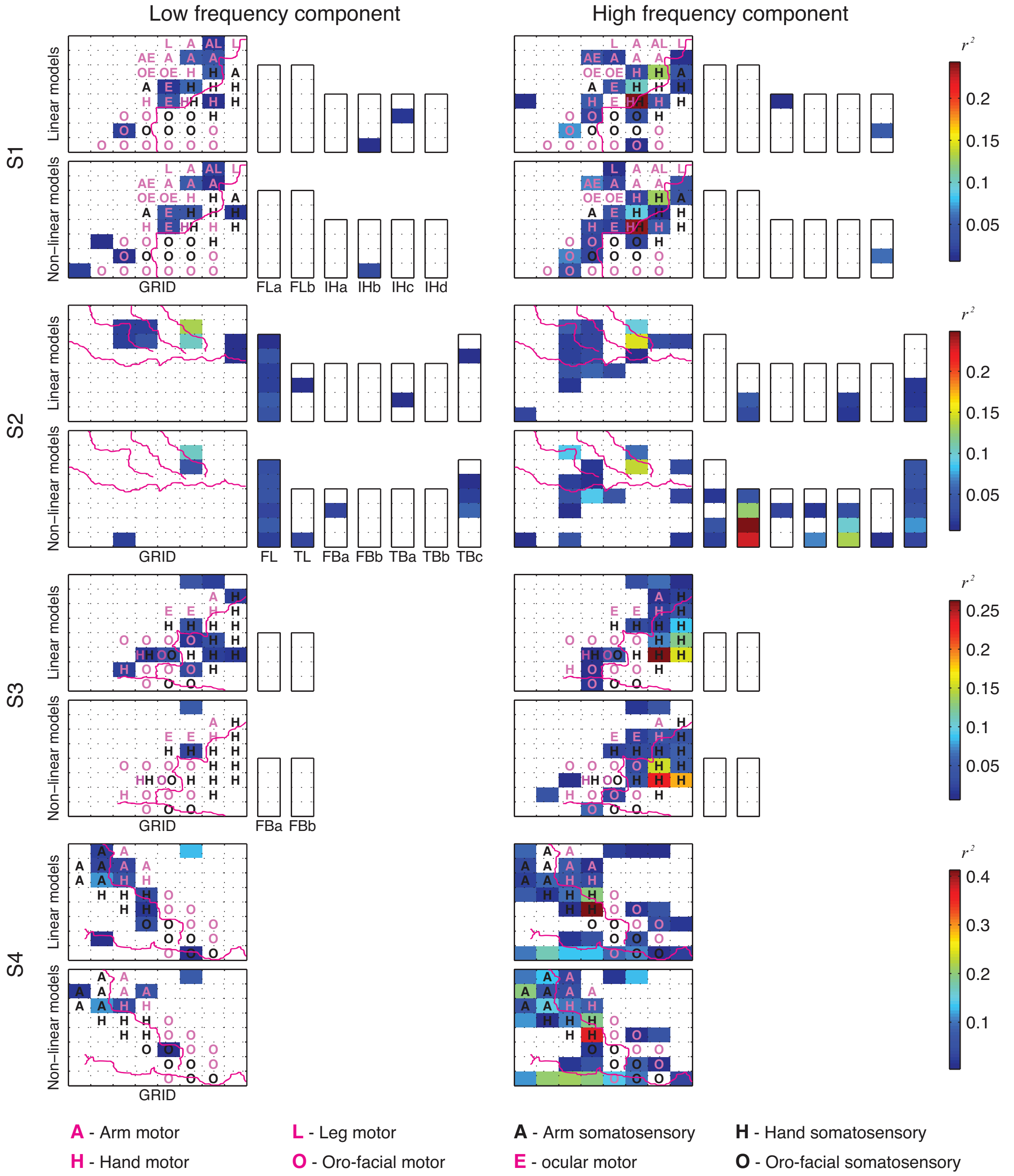
Besides the frequency bands used to define the high frequency component of the signal, our investigation shows that other, intermediate frequency bands (supplementary figure 2, frequency band roughly starting from 10Hz and ending at 30Hz) also contain error-related information, though their response strength is substantially lower and less consistent across subjects and error types.



Supplementary figure 2. Average collision (left) and movement mismatch (right) SNRs for the amplitudes of different frequency bands. SNRs were pooled over subjects and averaged across electrodes and for all possible choices of bottom and top frequencies of the frequency band used to construct the signal. Recordings for S1 and S2 were made at sampling frequency of 256Hz, and recordings for S3 and S4 were made at 1024. Therefore, we averaged SNR for S1 and S2 (top row) independently from the averaging for S3 and S4 (bottom row). Frequency bands were tested until the respective Nyquist frequency (128Hz for S1 and S2; 512Hz for S3 and S4). We marked the band with the highest average SNR (black circle) and the band used in our study for the high frequency component of the neural response (black rhomboid).

3. Amount of variance explained by the MRNRs

We estimated the amount of the movement related component of the neural signals by computing the r^2 values between the predictions made by the models (see section 2.4.3. for details) and the measured signals. Supplementary figure 3 shows the r^2 values of all electrodes. Electrodes with r^2 values below 0.01 were considered as not being movement related and therefore their r^2 value is not shown. For every subject, we found at least one channel/signal component with r^2 value of 0.24 or higher (highest r^2 values: S1: 0.24, S2: 0.25, S3: 0.26, S4: 0.41) which suggests that MRNR were indeed present in the recordings. For S1, S3 and S4, the electrode with the highest r^2 value was marked as hand somatosensory electrode, according to ESM, as was expected from ECoG recordings over the motor and somatosensory cortex for the task involving thumb movements. For S2, ESM was not made and, due to the more ventral location of the grid, we probably did not record over the hand motor and somatosensory areas.



Supplementary figure 3. Spatial distribution of r^2 values for each subject, signal component, model type and electrode in relation to the individual anatomy of the subject (see figure 10 caption for details). Colours of the squares depict the highest r^2 value over number of used data points (N) and length of the movement information (L); white squares represent channels with highest r^2 values below 0.01.