**Title:** Inter-Individual differences in visually induced gamma band amplitude are driven primarily by macroscopic differences in brain/head anatomy rather than differences in strength of functional response.

**Abstract:** The visually induced gamma band (40-90Hz) response varies within a healthy population in both amplitude and peak frequency. Due to the wide range of literature linking gamma amplitude and peak frequency to behavior, cognition/perception, and mental disorders, in recent years several studies have sought to establish the basis of amplitude and peak frequency in the healthy brain using both structural and functional MRI, achieving mixed results. To further address this, we compared gamma amplitude and peak frequency in two groups of healthy humans (n=24, n=9) with MRI-derived structural measures such as distance from electrode to active cortex, dipole cancellation over active cortex, intrinsic curvature of active cortex, and functional measures such as extent of functional activation, and percent change. We find that of these measures, gamma amplitude is best explained by distance from electrode to active cortex and intrinsic curvature of active cortex, while gamma peak frequency is best explained by extent of functional activation. We propose that inter-individual differences in non-invasively measured gamma amplitude are due to differences in macroscopic anatomy (distance and curvature), while gamma peak frequency is more related to differences in functional response (percent change and extent of activation).

**Introduction:**

Electroencephalography (EEG) measures fluctuations in electrical potential on the surface of the scalp (nunes) which often occur in narrowly defined frequency ranges, leading to the classification of these fluctuations as brain rhythms (Buzsaki). Despite the nearly 100 year history of EEG (berger), much remains to be understood about the biophysical and anatomical basis for brain rhythms observed from the surface of the scalp (nature ref).

Two of the most commonly studied brain rhythms are the gamma band rhythm (high frequency, 40-90Hz) (ref, finding gamma) and the alpha band rhythm (8-13Hz) (ref, Berger, others). In particular, the visually induced gamma band response has recently been shown to co-vary strongly with a number of perceptual phenomena (refs), neurological disorders (refs), and is also thought to underlie changes in the blood oxygen level dependent functional magnetic resonance imaging (BOLD FMRI) signal (refs) although see (Butler, Muthu) for opposing evidence. As such, understanding the anatomical basis for inter-individual differences in healthy human visually induced gamma band response is of considerable interest.

The visually induced gamma band response is commonly described using two metrics 1) amplitude and 2) peak frequency. Amplitude represents the strength of the signal in a given frequency range, and is typically defined as the difference in Fourier coefficient from task to rest at each frequency. Peak frequency is defined simply as the frequency at which amplitude is highest. Amplitude and peak frequency are thought to provide different indices of neural activity due to the fact that they are dissociable in both experimental (ref, jia) and modeling (ref) work, although a complete understanding of the neuronal generators giving rise to gamma power and peak frequency is still lacking (ref).

While much remains to be understood about how gamma amplitude and peak frequency arise from neuronal circuits, empirically these metrics are known to co-vary with a number of cognitive disorders, such as schizophrenia and autism. For example, schizophrenia has been shown in multiple studies to result in reduced gamma amplitude over a number of experimental paradigms (review, Tan). Interestingly, while gamma amplitude is also reduced in autism (review, Simon) there is evidence for increased peak frequency with increasing levels of autistic traits (Dickinson) which may provide a neurophysiological correlate for some of the enhanced visuospatial abilities observed in autism (Caron et al, 2006). In any case, evidence from twin studies points toward a strong genetic basis for inter-individual differences in the gamma rhythm (van-Pelt), suggesting an anatomical origin for the differences in gamma rhythms in autism and schizophrenia. This is further supported by the fact that gamma rhythms are stable within individuals across both hours and days (Muthu), which also suggests that differences in gamma across subjects are not due to behavioral variables such as attention (Womelsdorf and Fries, 2007).

A number of studies have directly investigated the anatomical basis for healthy human variability in visually induced gamma amplitude and peak frequency. The original investigation into peak frequency reported a positive correlation between magnetic resonance spectroscopy (MRS) GABA concentration in occipital cortex and gamma peak frequency (ref, muthu). The authors suggested that increased GABA concentrations reflect increased inhibition in V1, driving the peak frequency higher according to some modeling work (Brunel and Wang). However, a replication attempt using similar but not identical methodology with a much larger group of subjects found no such relationship (ref cousijn, ref muthu2) between gamma peak frequency and MRS-measured GABA concentration in occipital cortex, and experimental work (albeit in the hippocampus) show increased GABA concentrations having the opposite effect on gamma peak frequency (Traub, Whittington). More recently, the original positive MRS GABA vs peak frequency correlation was replicated (ref, PET) but using completely different methodology (GABA receptor density using positron emission tomography (PET)).

Another correlate of visually induced gamma peak frequency which has been proposed is the surface area of retinotopically defined primary visual cortex (V1), which has been shown to also correlate positively with gamma peak frequency (ref, Schwarzkopf). This was explained using the theory of coupled oscillators (Breakspear). While this finding was not replicated on a different group of subjects, (Muthu et al), the study by (Muthu et al) did not base their measure of surface area on functionally defined regions of interest. A replication attempt by the same authors as the original paper (Schwarzkopf 2) yielded the same positive correlation, again suggesting that methodology may be an important factor.

With respect to gamma amplitude, to our knowledge only one study has shown a significant anatomical correlate (ref, PET) where a negative correlation between inter-individual GABA receptor density and gamma band amplitude was reported. All other studies found no relationship between any of the anatomical measures and gamma amplitude including cortical surface area (Schwarzkopf), GABA concentration (Muthu, Cousijn), occipital volume, or thickness (Muthu). It should be noted that in (Muthu) a significant positive correlation between gamma amplitude and the event-related field was found, which the authors attributed to signal to noise differences in subjects due to distance from cortex to MEG sensors.

In summary, with respect to the anatomical correlates of gamma amplitude and peak frequency, there is a lack of consensus in the literature regarding peak frequency, and as only one study has reported a significant relationship between gamma amplitude and anatomy (Ref), a lack of information regarding gamma amplitude. We therefore set out to investigate the anatomical correlates of both gamma amplitude and peak frequency using measures derived from a combination of structural and functional MRI. Cortical curvature (both intrinsic and extrinsic, Freesurfer, Van Essen), cortical cancellation (Irimia), distance from cortex to electrode (Butler), and the extent or size of a functional response to visual stimulation were all compared with inter-individual differences in gamma amplitude and peak frequency. Many of these metrics, in particular those dealing with cortical curvature have never been compared with the gamma rhythm, and in examining these new metrics we hope to both establish the anatomical basis for inter-individual differences in gamma amplitude, and reconcile the varying reports on the correlates of peak frequency.

**Methods:**

**Subjects:** The data was acquired as part of a larger study at the institute involving two separate acquisition protocols. The MRI/FMRI and EEG subjects from the large group (n=24) were acquired during separate EEG and FMRI scanning sessions, while the subjects from the small group (n=9) were acquired during a simultaneous EEG-FMRI recording session. Of the 24 subjects participating in the large group study, 3 were also present in the small group study, for a total of 30 different subjects (13 female, no psychiatric or neurologic symptoms at the time of scanning or in the past, normal or corrected to normal vision). Informed consent was obtained according to the guidelines of the Internal Review Board of the Centre Hospitalier Universitaire de Sherbrooke.

**Stimulus construction and presentation:** All stimuli were generated using Psychophysics Toolbox (ref) and presented on a gray background with luminance equal to the mean luminance of the stimulus. For the large group, all stimuli were variations of a drifting sinusoidal grating, which had the following parameters: spatial frequency 3cycles/degree, temporal frequency 6 cycles/s, drifting from right to left within a 7 degree circular aperture in the center of the subject’s visual field. Six separate stimuli (Figure 1A) were used to induce a wide range of gamma responses 1) unperturbed (described above), 2) 5% contrast, 3) 33% contrast, 4) plaid, 5) 10% randomized, 6) 60% randomized. Details on stimulus construction are available in a previous publication (ref, Butler). For the small group, three separate stimuli were used 1) unperturbed, 2) 10% randomized 3) 100% randomized, and stimulus construction was identical to the that of the large group, with the exception that stimuli were presented using a full field aperture rather than a 7 degree circular aperture. Within the scanner, stimuli were projected from an MRI-compatible monitor (800x600 pixels, frame rate 75Hz) to a mirror positioned above the subject’s face attached to the head coil. For the large group, 45 trials/stimulus type were presented (270 trials per subject), with a 2 second presentation duration, and 14 second inter-stimulus interval (ISI). For the small group, 32 trials/stimulus type were presented (96 trials per subject), with a 5-second stimulus duration and ISI of 3-5 seconds (randomly jittered). Outside the scanner, EEG was recorded for the large group only, stimuli were presented on a CRT monitor (800x600 pixels, frame rate = 85Hz), at a rate of 1 stimulus every 5 seconds, (2 second presentation duration, 3 second ISI), each of the 6 stimulus types was presented 135 times (810 trials per subject).

**MRI acquisition and preprocessing:**

**Acquisition:** Whole brain FMRI volumes were acquired on a 3T MRI scanner (Ingenia, Philips Healthcare) using a 32 channel head coil for reception. The FMRI sequence parameters differed slightly from large group to small group. Large group (n=24) sequence parameters: TR/TE = 2000/30ms, flip angle=70deg, FOV=224x224x136.5mm, voxel size = 3.5mm isotropic, no multiband. Small group (n=9) sequence parameters: TR/TE = 693/30, flip angle=50deg, FOV=240X240X123.75mm, voxel size=3.75mm isotropic, multiband factor 3. An anatomical T1-weighted 3D gradient-echo image (TR/TE=7.9/3.5ms, flip angle = 8deg, FOV=240x240x150mm, voxel size = 1mm isotropic) was acquired following FMRI acquisition sessions for both groups.

**EEG recording and preprocessing:**

**Large group (n=24) recording:** Scalp signals were acquired on a 64 channel EEG actiCap system (Brain Products) at 500Hz referenced from electrode Fz according to the 10-20 system. The cap was positioned by the experimenter according to the following anatomical landmarks: electrode Oz directly superior to the inion, and the midpoint between electrodes Cz and reference on the apex of the head. **Preprocessing:** Poorly connected electrodes were isolated using visual inspection of the raw electrode time series, and interpolated using spherical interpolation (ref, EEGLAB). To maximize the signal to noise ratio (SNR) of the EEG gamma band response, temporal independent component analysis (ICA) (ref, EEGLAB) was performed on each subject separately after applying a 1-120Hz bandpass filter and epoching from -1:3 seconds relative to stimulus onset of each trial. ICA components were then visually inspected for each subject, and a small subset (2-5 components per subject) were selected based on the presence of a narrow band gamma response and/or weight maps with dipolar-like topography constrained to the posterior electrodes (figure sup.). Signal from these gamma band components was projected back to channel level using the inverse weight matrix, to yield artifact free channel level EEG signals in each subject.

**Small group (n=9) recording:** Scalp signals were acquired on a 63 channel MR-compatible EEG cap (Brain Products) sampling at 5000Hz referenced from electrode Fz according to the 10-20 system. Impedances were reduced to values below 20kOhm at each electrode prior to placing the subject in the MR scanner, and monitored throughout the recording. The cap was positioned according to the same anatomical landmarks as in the large group, by the same experimenter, and electrodes were precisely localized using an ultra-short echo time sequence (ref, Butler) which is capable of directly imaging the plastic materials of the EEG cap. **Preprocessing:** MRI artifacts (FMRI gradient artifact and ballistocardiogram artifacts) were removed using the sliding window average artifact subtraction approach (ref) as implemented in BrainVision Analyzer software. ICA denoising was then performed on MRI-artifact cleaned data in an identical fashion as for the large group.

**Analysis:**

**Gamma amplitude:** After ICA denoising and back projection to channel level signal, EEG gamma amplitude was defined at each channel separately for each subject and stimulus type: the Fast Fourier Transform (FFT) was computed for both baseline (-1000ms to 0ms) and task (0ms to 2000ms for large group, 0ms to 5000ms for small group). Baseline FFT amplitude was then subtracted from task FFT amplitude at each frequency band separately, yielding a spectrum of Fourier coefficient differences from task to rest. Gamma amplitude was then defined at each electrode as the mean difference between task and rest from 40-90Hz. A single gamma amplitude value was obtained in each subject by averaging amplitude over all posterior electrodes (P, PO, and O) and stimulus types.

**Gamma peak frequency:** Gamma peak frequency was defined at the ICA component level rather than the channel level. In order to isolate a single, robust gamma peak frequency in each subject only the unperturbed and 10% randomized grating stimuli were used, as both induced a single, strong gamma peak in the 40-90Hz range for all subjects who were gamma responders (defined below). This was in contrast to the plaid or 60% randomized stimuli, which resulted in a double peak or a strong blurring of the gamma peak respectively, and not suitable for gamma peak frequency estimation. Event-related spectral perturbation (ERSP) was computed on ICA component time series in partially overlapping 250ms Hanning windows (ref, EEGLAB) at 200 separate time points yielding ERSP for each ICA gamma component. For each subject, the ERSP was then averaged across ICA components (2-5 per subject), stimulus types (unperturbed and 10% randomized) and stimulus duration (500-2000ms large group, 500-5000ms small group). The initial 500ms was not included in peak frequency estimation, to avoid stimulus onset effects and include only the peak during the sustained narrow-band gamma response. The gamma peak frequency for each subject was then defined as the frequency band between 40-90Hz with the highest amplitude. **Removal of “non-responders” when computing gamma peak frequency:** Although subjects with a complete absence of gamma power in response to the stimulus are of interest when investigating gamma amplitude, it is impossible to define a peak frequency subjects with no discernible gamma peak. A “gamma responder” was hence defined as a subject with a stimulus induced db increase greater than 0.5 at any frequency in the gamma range.

**FMRI regions of interest:** An FMRI region of interest (ROI) was defined in each subject separately by convolving a stimulus design time series with a hemodynamic response function (HRF) (ref, SFPM) and correlating the HRF-convolved time series with the FMRI signal in each voxel. The whole brain correlation map was then thresholded to yield binary ROIs in each subject. In the large group, this threshold was r>0.5, and in the small group, r>0.25. The threshold was lower in the small than the large group due to the slightly different stimulus presentation paradigm (a shorter rest period, and a pseudo-random ISI between stimulus presentations in the small group), which resulted in overall weaker correlations for the small group.

**Distance from active cortex to electrode:** distance was defined at each electrode as the Euclidean distance from the center of mass of each subject’s FMRI ROI to the electrode location. To obtain a single distance measure in each subject, distance values across all posterior electrodes (P, PO, and O) were averaged, giving the mean distance from posterior electrodes to the center of functional activation. In the small group, distances were accurate to within 1mm (Butler et al) as the electrode locations were measured directly using the UTE MRI sequence. In the large group, locations were obtained by the following procedure: UTE localized coordinates from each subject in the small group were mapped to an anatomical template (MNI152) based on a 12 DOF affine transform from each subject’s T1. Small group coordinates were then averaged across all subjects, the create an electrode coordinate template in the MNI152. The electrode coordinate template was then mapped to each subject in the large group, again using a 12 DOF affine transform based on the T1.

**Metrics of cortical morphometry (intrinsic curvature, mean curvature, cancellation index):** Intrinsic curvature and mean curvature were obtained using Freesurfer (ref). As Freesurfer defines these values based on cortical parcellations, we isolated the Freesurfer defined cortical parcel with the largest overlap with our FMRI ROI, which happened to be the lateral occipital cortex (surprisingly, 60% of lateral occipital voxels were contained within the FMRI ROI, while only 35% of calcarine sulcus voxels). Intrinsic curvature (curvInd) and mean curvature (meancurv) of lateral occipital cortex were then extracted from freesurfer output using text file processing, and averaged across hemispheres in each subject. The cancellation index (I0) (ref, Irimia) was defined as 1-mean(sum(normal vectors)). The normal vectors used to calculate I0 were obtained by intersecting the Freesurfer white matter surface normals with each subject’s FMRI ROI mask. As I0 increases systematically with the number of normal vectors used in the calculation (ref), we arbitrarily restricted the number of normals in each subject to the 2000 normals in the region of strongest functional activation (ie, the 2000 normals in voxels with the highest correlation to the stimulus).

**Extent of functional activation and percent change:** The extent of functional activation was defined simply as the number of voxels remaining after applying a correlation threshold to the FMRI correlation map (see above). Percent change (%change) was defined as the mean BOLD signal

**Results:**

*Visually induced narrow band gamma was observed in 80% of healthy humans.* Single subject gamma responses are shown (Figure 1A, Figure 1B). For visualization purposes, each subject’s response to unperturbed and 10%random stimuli were pooled and the average displayed in these plots. Based on the criteria defined in (Methods, gamma peak frequency), 24/30 or 80% of subjects can be defined as “gamma responders”.

*Inter-subject gamma amplitude is consistent across stimulus types.* To justify pooling of gamma amplitude in response to different stimulus types before correlating with anatomy, we examined the inter-subject correlation of gamma amplitude across stimulus types. We find that, despite the wide range of gamma amplitude response across stimulus types (Figure 1C), there was strong correlation of inter-subject gamma amplitude across stimulus types (Figure 1D, p<0.0001). That is to say, subjects with a high amplitude gamma response to one stimulus type were also high amplitude responders to all other stimuli.

*Inter-subject gamma amplitude and distance from cortex to electrode are inversely correlated.* There was a significant inverse relationship between distance from electrode to active cortex in the large group (Figure 2A, rho=-0.48, p=0.016) and a strong trend towards significance for the small group (Figure 2A, rho=-0.59, p=0.091).

*Gamma amplitude is inversely related to intrinsic curvature, but no significant relationship between amplitude and mean curvature or cortical cancellation.* There was a significant inverse relationship between intrinsic curvature and gamma amplitude in the large group (Figure 2B, rho=-0.49, p=0.015), and a similar trend that did not reach significance in the small group (Figure 2B, rho=-0.26, p=0.493). There was no significant relationship between extrinsic (mean) curvature and gamma amplitude in either large (rho=-0.22, p=0.304) or small (rho=-0.2, p=0.598) groups. Similarly, there was no significant relationship between the cortical cancellation index (I0) and gamma amplitude in either large (Figure 2C, rho=-0.18, p=0.387) or small (Figure 2C, rho=-0.14, p=0.711) groups.

*Intrinsic curvature and distance are positively correlated.* There was a significant positive correlation between intrinsic curvature and distance from cortex to electrode for large group (r=0.47, p=0.02) and a clear trend in the small group (r=0.6, p=0.088).

*Gamma peak frequency but not amplitude is positively correlated to extent of functional activation.* When removing “non-responders” from the large group, there was a strong significant correlation between peak frequency and the extent of functional activation (Figure 2D, rho=0.70, p=0.001), however this was not present in the smaller group (Figure 2D, rho=0.07, p=0.863). When including all subjects in the large group, the correlation was weaker but still significant (r=0.47, p=0.022). There was no correlation between peak frequency and any of the structural measures (distance (large group p=0.86, small group p=0.98), intrinsic curvature (large group p=0.47, small group p=0.37), mean curvature (large group p=0.74, mall group p=0.70), or cancellation (large group p=0.39, small group p=0.79)). Surprisingly, there was no correlation between gamma amplitude and extent of functional activation (large group p=0.87, small group p=0.78).

*FMRI %change is not correlated to gamma amplitude.* There was no correlation between %change and gamma amplitude for large group (rho=0.26, p=0.21) or small group (rho=0.14, p=0.71). There was a trend towards a positive correlation between %change and peak frequency in the large group (rho=0.34, p=0.09) but not in the small group (rho=-0.2, p=0.59).

*Correlations are reproducible across both groups.* When comparing correlation tables (Figure 2E, 2F) across large and small groups there was a significant positive correlation (rho=0.41, p=0.031) between the two correlation matrices, indicating that the results noted above should generalize to other subject groups.

**Discussion:**

The anatomical basis for inter-individual differences in the healthy human visually induced gamma band response has been investigated. In contrast to previous studies (many refs), we focused mainly on anatomical variables likely to affect gamma amplitude rather than gamma peak frequency, although peak frequency was investigated as well. The gamma rhythm is a complex neurophysiological phenomenon (jia, modeling refs) that is still not fully understood, but we hypothesized that inter-individual differences in non-invasively measured healthy human gamma responses may be explained in large part by differences in macroscopic brain anatomy.

The most robust result noted here is the inverse relationship between gamma amplitude and mean distance from center of functional activation to electrode. This result was noted in both subject groups, and makes sense from a purely physical standpoint, as the electric field arising from a dipole is known to fall off as 1/r^2 (ref). Clearly, inter-individual variation in gamma rhythm amplitude is no exception to this fundamental law of nature. Unfortunately, due to limited imaging methods we were unable to investigate the effects of different tissue layers on distance (ie, is the distance correlation driven by thicker skull, meninges, or scalp), but this provides an interesting question for future research. While this is the first study empirically demonstrating a relationship between distance and gamma band amplitude, it was hinted at in earlier work by (Muthu et al) where a positive association was found between inter-subject event-related field and gamma amplitude, and this co-variance was attributed to distance from MEG sensor to cortex.

We also investigated the relationship between different indices of cortical curvature and gamma amplitude. Only one of these indices (Intrinsic curvature) correlated significantly with gamma amplitude, and in only one of the subject groups (large group). However, it is worthwhile to note that all correlations between curvature and amplitude were negative, and the null result for mean curvature and cortical cancellation could be due to the small sample sizes used here. This result has implications for the source localization community, which has long assumed that the orientation of cortical dipoles strongly influence the resulting scalp potential. We find that the cortical cancellation index has the weakest relationship to gamma amplitude of all curvature metrics, instead, it appears as if more local curvature metrics (Van Essen) have a larger effect on the gamma rhythm.

Gamma peak frequency was also investigated. Peak frequency was unrelated to any of the structural parameters (distance, curvature) in either group, but in the large group we noted a strong positive correlation between peak frequency and extent of functional activation, and a trend towards positive correlation between peak frequency and %change. This result is interesting for two reasons 1) it shows that peak frequency is independent of macroscopic anatomical features, and can hence serve as a useful biomarker in studies of neurodegeneration, cognitive disorders (ref, autism), or perceptual processing and 2) helps to reconcile previously reported results on peak frequency. To date, there are two main hypotheses relating to the basis of gamma peak frequency across a healthy population 1) peak frequency is driven by differences in GABA concentration (Muthu, others) and 2) peak frequency is driven by differences in surface area of visual cortex (Schwarzkopf). We believe that the result reported here (peak frequency correlates positively with extent of functional activation) supports the surface area hypothesis for several reasons. First, studies reporting null results between peak frequency and surface area (Muthu, Muthu review) did not use FMRI to delineate subject specific cortical regions of interest, and we show here that the size of an FMRI cluster alone strongly predicts peak frequency, without considering any anatomical variables. Second, studies that do use FMRI to delineate subject specific visual areas replicate the association between peak frequency and surface area (Schwarzkopf, 2). Third, methodological differences between studies investigating the relationship between GABA and peak frequency point strongly to partial volume effects (PVE) as the underlying cause. The MRS voxel in the study reporting the null result between peak frequency and GABA concentration (Cousijn) was 1/3 of the size of the voxel in the study reporting positive association (Muthu), and hence, less likely to suffer from PVE contamination. If the surface area of visual cortex is what drives gamma peak frequency, differences in surface area across subjects are likely to have a strong effect on MRS-measured GABA concentrations. Fourth, the study reporting positive correlations between PET-derived measures of GABA receptor density (Kujala) used a large smoothing kernel (15x15x21mm FWHM) when processing PET images, which is again likely to cause strong PVE effects and drive the correlation.

**Possible confounds:** We used FMRI to restrict our structural estimates such as cancellation and distance, based on this one might argue that our structural correlations of gamma amplitude are due to differences in functional activation across subjects. We believe this not to be the case for the following reasons First, there was no correlation between functional MRI and gamma amplitude when considering only FMRI derived parameters such as #active voxels and %change. Second, our measure of distance was based on the center of mass of functional activation, which is a single point that changes minimally when altering the correlation threshold. Third, while our measure of cortical cancellation was indeed based on surface normals within an FMRI-derived mask, we restricted the mask to be the same size in all subjects (n voxels). Fourth, our measure of intrinsic and mean curvature were based on the same anatomically defined Freesurfer region (lateral occipital cortex) across all subjects.

Another confound which may explain the null result for peak frequency in the small group is that the stimulus employed was not masked by a 7degree circular aperture as in the large group, but instead was full field. Increasing the stimulus aperture of a grating decreases peak frequency (ref), which is reflected in our data where peak frequency in the small group varied between 50-60Hz, and in the large group, 50-90Hz. The use of a full field stimulus in the small group may have resulted in a “saturation effect” on peak frequency, driving each subject’s peak frequency down and negating any inter-individual variability.

**Conclusion:** subjects with flatter cortices that are closer to the surface of the scalp will tend to exhibit higher amplitude visually induced gamma band responses. This finding confirms that the gamma rhythm is no exception to the basic scalp potential equation proposed many years ago (Nunes et al), and while the neurophysiological underpinnings of gamma are undoubtedly complex, inter-subject variability in non-invasively measured gamma amplitude appears to be more closely related to macroscopic brain/head anatomy.

**References:**