Top-down versus bottom-up influences on gamma-band oscillations as a gain mechanism for attended features and locations

A. Specific Aims:

1. To emphasize exogenous attention systems and determine the effect on gamma-band oscillations. I will test if salient stimuli not the target of a visual search task drive gamma-band oscillations of the electroencephalogram (EEG) differently than a target or neutral, low-saliency stimulus.
2. To emphasize endogenous attention systems and determine the effect on gamma-band oscillations. I will test whether target stimuli outside sustained attention to a specific location drive gamma-band oscillations differently than targets within an attended location or distracter stimuli. I will also test whether salient stimuli irrelevant to an attentionally demanding task correlate with increases in gamma-band activity compared to neutral, low-saliency stimuli. This experiment will also reveal the effect of gamma-band activity related to viewing targets versus non-targets in a demanding sustained attention task.

B. Background and Significance

In everyday perceptual experience, it is necessary to select relevant information from an otherwise overwhelming amount of perceptual input (Desimone and Duncan, 1995). Attentional systems act as the mechanism by which the brain accomplishes this selection (Posner and Petersen, 1990). It has been shown by several methodologies in both human and non-human primate experiments, and in several perceptual modalities, that attending to specific aspects of perceptual input increase the neural activity (i.e., firing rate) and sensitivity of neuronal populations tuned to those properties (Hansen and Hillyard, 1980, Hillyard and Anllo-Vento, 1998, Reynolds, Pasternak and Desimone, 2000, Spitzer, Desimone and Moran, 1988). This effect may reflect the selection and increase in gain of specific populations of neurons in perceptual processing. Computational models of neural circuitry suggest that synchronized oscillatory firing of networks of neurons in the gamma-band frequency range (>30 Hz) may act as a mechanism to increase the gain of information processing from specific neural networks (Salinas and Sejnowski, 2001, Tiesinga et al., 2004). There has been considerable interest in the degree to which selective attention modulates neural activity in the gamma-band frequency range (Fell et al., 2003). In one study, synchronized gamma-band activity of neurons in area V4 of macaque monkeys increased when the monkey attended to a stimulus in the receptive fields of the neurons versus when it attended to an identical stimulus outside the same neurons' receptive fields (Fries et al., 2001). In the human electroencephalogram (EEG), gamma-band power increased over parieto-occipital electrodes while participants shifted attention to a pre-cued visual hemifield (Gruber et al., 1999). Furthermore, increased gamma-band activity has been correlated with attended stimuli in the auditory modality in both odd-ball (i.e., abrupt onset of a novel sound) and sustained attention tasks (Debener et al., 2003, Tiitinen et al., 1993).

Several studies have also related gamma-band activity to binding parts into a coherent object percept (Rodriguez et al., 1999, Tallon-Baudry and Bertrand, 1999, Tallon-Baudry et al., 1996, Tallon-Baudry et al., 1997) suggesting the activity reflects a mechanism of synchronization or coherence between neural populations representing different features. It has been argued this may serve to provide a transient code that binds related features together in perceptual experience (Milner,1974, Singer and Gray, 1995, von der Malsburg and Schneider, 1986). These studies relating gamma-band oscillations to binding could be interpreted as reflecting an attentional process as theories of attention predict (Treisman and Gelade, 1980, Reynolds and Desimone, 1999, Treisman,1996). Furthermore, the above studies were based on visual search tasks that maintain the most "object-like" stimulus as the target of the task; and those were also the stimuli that received the greatest gamma-band response (Tallon-Baudry et al., 1996, Tallon-Baudry et al., 1997, Rodriguez et al., 1999).

Previous studies have shown increases in gamma-band activity related to several attention-related tasks. However, it remains unclear at what point these oscillations come into play during the shifting of allocation of attention and the increase in gain of signal resulting from attending to a given location in space or stimulus feature. A crucial distinction related to this point is the difference between endogenous and exogenous attention. Behavioral studies show distinct differences between the two. Endogenous attention refers to a volitional allocation of attention to a specific location or stimulus feature and is referred to as a top-down process, relying on high-order cognitive functions (Posner,1980). In contrast, exogenous attention refers to an automatic process by which salient stimuli in the environment drive attention to a specific location or feature. This process presumably relies on low-level, reflexive neural mechanisms and is thought of as a bottom-up process (Yantis and Jonides, 1984). Assuming gamma-band activity acts as a gain function to amplify specific sensory neural networks as computational models predict (Salinas and Sejnowski, 2001, Tiesinga et al., 2004), the results of previous attention-related gamma-band studies may be understood as reflecting this process. This would imply this process as a general mechanism of selective attention and thus involved in both exogenous and endogenous forms of attention.

C. Research Design and Methods

Specific Aim 1. To emphasize exogenous attention systems and determine the effect on gamma-band oscillations.

Rationale: I will test if salient stimuli not the target of a visual search task (i.e., a target requires a response) drive gamma-band oscillations of the EEG differently than a target or neutral, low-saliency stimulus.

Experiment 1: Examine the influence of color and orientation salient distracter stimuli on gamma-band oscillations as compared to target and low-saliency non-target stimuli.

Participants will view a visual search task in which they maintain central fixation and view blocks of randomized trials, with each trial consisting of a series of bars arranged in a regular pattern on a computer screen while their EEG is recorded (Fig. 1). Each trial will consist of one of five equally probable stimuli: a neutral stimulus containing all gray vertical bars (Fig. 1A), screens containing a red or green bar at any target location in the pattern of bars (Fig. 1B), and screens containing a bar tilted 45º either to the left or right at any target location presented for 500 msec on a grey screen. The location of the targets and salient, non-target stimuli will be restricted to a band of possible locations around fixation as indicated in Fig. 1B. The bars within this band will be presented at an appropriate radius (i.e., >2º) so as to ensure the stimuli project outside the fovea of the eye. Keeping stimuli in the periphery will allow me to test for hemispheric laterality of attention-related neural activity. Maintaining a fixed radius for all the target and salient non-target stimuli will also increase the power of the experiment by stimulating a defined area of cortex over repeated trials. This will allow for a high signal-to-noise ratio over an adequate number of trials to reliably detect gamma-band oscillations associated with the stimuli. Between trials, the fixation cross will remain on a blank grey screen for a variable inter-stimulus interval (ISI) of 800-1200 msec. At the beginning of each block of trials, participants will be instructed to respond by a button press as quickly and accurately as possible every time a bar with a particular color or orientation appears at any location in the display, depending on the search condition (red, green, left or right). Each participant will view all four conditions with the order counterbalanced across participants.

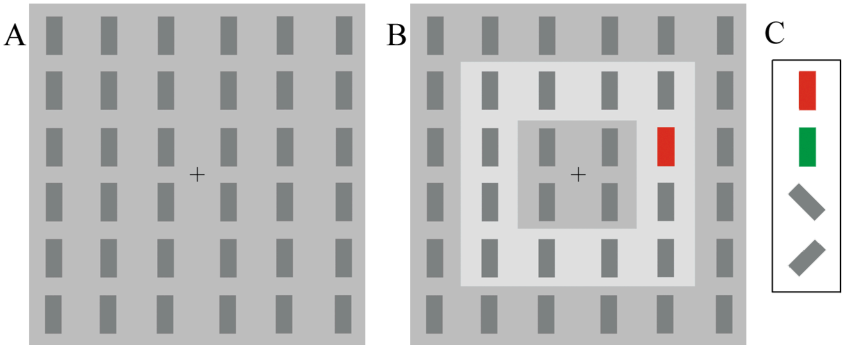

Figure 1. (A) A neutral stimulus (target absent) trial of Expt. 1. (B) A target present trial in Expt. 1 when the target is red. The light-grey band indicates the possible locations for a target. This band will not be presented to participants. (C) The possible target values: red, green, left, right. One of these stimuli will be designated as the target at the beginning of each block of trials. The other stimuli will also be randomly presented within the band in (B) but the participant will be instructed to ignore these stimuli and respond by a button press that no target is present. Thus these stimuli constitute the salient, non-target stimuli of the task.

Interpretation and concerns

To increase the power of the experiment, stimuli will be collapsed into groups of left and right depending on what side of space they appear on. This will also allow me to test for attention-related laterality effects of neural activity (i.e., increased neural activity contralateral to target stimuli reflecting a lateralized attention-related neural event).

In line with results from previous studies showing increases in gamma-band activity related to target stimuli in attention-related tasks (Fries et al., 2001, Gruber et al., 1999, Tiitinen et al., 1993, Debener et al., 2003), I expect to find increased gamma-band oscillatory activity in target present trials compared to neutral distracter trials in Expt. 1. This would suggest that in visual search, detecting a target is related to gamma-band activity.

Salient non-target distracters should stimulate the attentional system of the brain in a bottom-up (exogenous) fashion, as has been shown by similar studies (Luck and Hillyard, 1990, Treisman and Gelade, 1980, Treisman,1982), even though they are not the target of the task. Expt. 1 will show the effects of this bottom-up attention on the power of gamma-band oscillations in cortex. An increase in gamma-band power to salient non-target stimuli as compared to neutral distracter stimuli would imply that a bottom-up process affects gamma-band oscillations in cortex. An increase in gamma-band power to salient non-target stimuli less than the increase to target stimuli would suggest that a top-down mechanism relating to searching for a specific feature affects gamma-band oscillations. A potential caveat in this interpretation is that the gamma-band effect found for salient non-target stimuli is indeed a top-down mechanism because the distracter is similar to the target stimulus. Here, searching for differences between the gamma-band related effects to color versus orientation stimuli would be helpful. It may be that while searching for the color red, green stimuli activate attentional systems allocated to searching for red more than a tilted bar stimulus because the green stimulus is closer in feature to the target stimulus. This experiment will show how important this effect is by comparing across stimulus feature space. As another control, it may be instructive to view the effects of salient non-target stimuli on gamma-band oscillations only in blocks of trials that have not been preceded by blocks with the salient non-target designated as the target. This control would remove the attention-related effects associated with seeing a salient distracter stimulus that was a target in a previous block that may otherwise skew results for salient non-target distracters toward a target-like effect.

All the effects described above rely on properties of the stimuli themselves driving attentional systems in a bottom up fashion. However, top-down influences also play a crucial role in driving attention to specific features and locations. Experiment 2 more directly tests the effects of top-down influences on the gamma-band oscillations related to both exogenous and endogenous attention.

Specific Aim 2: To emphasize endogenous attention systems and determine the effect on gamma-band oscillations.

Rationale: In Expt. 2a I will test whether target stimuli outside sustained attention to a specific location drive gamma-band oscillations differently than targets within an attended location or distracter stimuli. In Expt. 2b I will test whether salient stimuli irrelevant to an attentionally demanding task consisting of a different set of stimuli correlate with increases in gamma-band activity compared to neutral, low-saliency stimuli. This experiment will also test the effect of gamma-band activity related to viewing targets versus non-targets in a demanding sustained attention task.

<u>Experiment 2a: To determine the influence of sustained spatial attention on the effectiveness of target and salient non-target stimuli to influence gamma-band oscillations inside and outside the sustained spatial focus of attention.</u>

Expt. 2a will repeat Expt. 1 with the addition of two possible sustained attention locations. Before each trial, a cue will be presented to the participant at fixation indicating the likely side of space where the target will appear on the next trial. However, a smaller probability of target stimuli will appear on the opposite, non-cued side of space.

Experiment 2b: To determine the effect of sustained spatial and feature-based attention in an attentionally demanding central task on the effectiveness of salient irrelevant, peripheral stimuli to modulate gamma-band oscillations in an exogenous fashion and target stimuli to modulate gamma-band oscillations in an endogenous fashion.

Participants will view a similar set of stimuli as in Expt. 1, however they will be instructed to ignore ongoing colored and tilted bar stimuli. Instead, they will be told to count the number of specific target letters that appear in a stream of several seconds of target and non-target letters flashing at fixation. At the end of a trial, they will press a button indicating how many targets appeared during the trial. This ensures their attention is allocated to the task at fixation throughout the entire trial. A portion of the trials will contain no target letters. While the letters flash at fixation, bar stimuli similar to those in Experiments 1 and 2a will flash in the periphery.

Interpretation and concerns

As in Expt. 1, gamma-band oscillatory activity should generally increase in target present trials compared to neutral distracter stimuli in Expt. 2. The effect will be different in Expt. 2 in that it will be influenced by the top-down manipulations of each task, and in Expt. 2b, it will be spread in time. In Expt. 2b, target present trials will vary in the number of targets present in a given trial, and the targets will occur at different time intervals. This will effectively smear the more punctuated attentional event that occurs in Expt. 1 and Expt. 2a, and thus the gamma-band activity associated with that event. Regardless, it should be possible to detect a change in gamma-band activity collapsed over a longer time interval in target present compared to target absent trials in Expt. 2b.

Experiment 2a adds an additional component to Expt. 1 in that attention will be allocated to a region of space in a top-down manner, as has been described previously (Eriksen and Yeh, 1985, Posner and Petersen, 1990) and shown electrophysiologically (Eimer,1999). This emphasizes the top-down effects associated with allocating attention in space. Expt. 2a focuses on this effect specifically and offers a clean comparison with Expt. 1 since the stimuli and task are the same. The only difference is that attention to space is manipulated by the cues at fixation. If targets appearing on the cued side of space show increased gamma-band activity compared to targets on the non-cued side of space, it would suggest that the top-down influence of sustained attention to a location modulates gamma-band activity. This effect may also be present for salient non-target distracter stimuli, demonstrating a top-down influence on exogenously evoked gamma-band oscillations. If target present trials correlate with increased gamma-band activity, but the cues fail to modulate this increase, it may be that the top-down influences either do not affect the gamma-band activity, suggesting a purely bottom-up modulation of gamma-band activity, or that the top-down influence was not strong enough to modulate the gamma-band response.

Experiment 2b addresses this discrepancy by implementing an attentionally demanding task at fixation coupled with colored and tilted bar stimuli that are irrelevant to the task. This emphasizes the top down influence of attending to a specific region of space and the importance of attending to a particular feature and location (i.e., a specific letter shape at fixation) on suppressing attention to unrelated features and locations (i.e., bar and tilted stimuli in the periphery). In other words, if salient distracter stimuli irrelevant to the task are still able to influence gamma-band oscillations, then the bottom-up influence on gamma-band oscillations may be a strong one. How attentionally demanding the central task is will likely influence this effect. For this reason, it may be instructive to vary the difficulty of the central task by, for example, increasing the rate and/or number of letter presentation. Allocating attentional resources to the center of space, limiting their effectiveness on the periphery, may have a great impact on the gamma-band responses found to peripheral salient non-target stimuli. Expt. 2b will thus test the effectiveness of top-down attentional influences on overcoming bottom-up related gamma-band responses to salient non-target stimuli. If bottom-up processes strongly influence gamma-band activity regardless of sustained attention to a different location and stimulus feature, then increases in gamma-band activity should be similar to those found in Expt. 1 to salient non-target stimuli. The most direct way to test this will be to limit analysis of gamma-band changes related to salient irrelevant distracters to target absent trials of the central task. This will eliminate any contribution to gamma-band activity from targets in the central task. However, it may still be worthwhile to do the same analyses for target present trials since the increase in attention allocated to targets and away from the periphery in target present trials may more effectively suppress attention related changes in gamma-band activity related to salient peripheral distracters compared to neutral peripheral distracters than target absent trials. The baseline level of gamma-band activity related to targets in the target present trials should be the same on average for instances of salient irrelevant distracters and neutral distracters, making it possible to search for influences on gamma-band activity stemming from the salient distracter stimuli. Furthermore, it will be possible to isolate periods of time in the continuous EEG when a target was present at fixation and there was a salient or neutral distracter in the periphery. This would presumably be the case when the most attention is allocated to the center of space, and away from the periphery. In this case, the top-down influence of spatial attention should dominate the influence on gamma-band activity. This may be enough to wash out the bottom-up effect related to salient over neutral distracters.

If top-down influences are sufficient to overcome some or all of these bottom-up effect even in target absent trials, then a reduced or absent increase in gamma-band oscillations will be found for salient distracters. If this lack of effect is found for salient distracters in this task, it will be helpful to compare the results with Expts. 1 and 2a which rely more heavily exogenous attention. Further information may be gained from testing naïve participants on a passive viewing task, in which they are simply instructed to maintain fixation while stimuli from Expt. 1 are presented. A simple task between blocks of several trials could be used to encourage participants to pay attention to the ongoing irrelevant stimuli. This experiment would take top-down influences out of the picture and make it possible to attribute any changes in gamma-band activity to different types of salient or neutral stimuli.

Experiments 1 and 2 will both test the main hypothesis of the proposal that both endogenous and exogenous forms of attention modulate gamma-band oscillations. However, each experiment emphasizes different influences on attentional resources. Comparing the results of each experiment will give a sense of the relative contributions of both endogenous (top-down) and exogenous (bottom-up) attention to gamma-band oscillations in cortex.

D. General Methods

Participants

At least 12 right-handed human adults will participate in each experiment and will either receive course credit or monetary compensation. An effort will be made to include equal numbers of males and females.

Electrophysiological recordings

Each participant will be run individually in a sound-attenuated room. Participants will sit in front of a video monitor at a consistent viewing distance to standardize stimulus size across participants. The EEG will be recorded at a sampling rate of 1,024 Hz from 64 electrode sites using a modified 10-20 system montage (Nuwer et al., 1998). This sampling rate is more than sufficient to measure spectral perturbations in the 100 Hz range and below. Horizontal electrooculographic (EOG) signals will be recorded using electrodes at the left and right external canthi, and vertical EOG signals will be recorded from an electrode below the left eye. All scalp electrodes, as well as the electrode below the left eye, will be referenced offline to the tip of the nose. The data will be segmented into epochs from 200 ms before the stimulus event to 1000 ms after the event. Epochs including eye movements or eye blinks, as well as incorrect and missed trials will be removed from the analysis using a semi-automatic data inspection algorithm. Epochs of raw EEG will be baseline corrected to the period from 0 to 100 ms before the stimulus. These data will then be exported to EEGLAB for spectral analysis.

Spectral Analysis

To measure the spectral power at each frequency band and time point, the data will be processed using the timef function of EEGLAB (Matlab Toolbox; (Delorme and Makeig, 2004)). Epoched EEG trials that were not rejected by the methods described above will be convolved with Gaussian-windowed sinusoidal wavelets of two-cycle duration. At each frequency band, the mean spectral energy of the pre-stimulus (from –200 to –50 ms) baseline will be subtracted from the pre- and post-stimulus TF energy. The absolute power measure will be converted to decibels (dB; 10 * log (microV^2)). This procedure describes power values as relative to the corresponding baseline level of each frequency band. The resulting time × frequency (TF) maps will be averaged across trials for each subject to form the event-related spectral perturbation (ERSP; (Makeig,1993). The resulting individual subject maps will then averaged across subjects to create grand average ERSP maps. Inter-trial coherence (ITC) will be computed for all electrodes for all target types, using the ‘phase-coher’ option (see (Delorme and Makeig, 2004) for method). This measures how phase-locked oscillations are to stimulus onset and will be useful in characterizing gamma-band oscillations as either “evoked” or “induced” (Tallon-Baudry and Bertrand, 1999).

Since the precise time and frequency of gamma-band bursts is not known *a prior,* I will implement a procedure to statistically locate bursts of spectral activity and create a region of interest (ROI) for comparisons across conditions. I will base the parameters for analyses of spectral bursts on those used in similar experiments (Tallon-Baudry et al., 1996, Tallon-Baudry et al., 1997). Statistical analyses will be restricted to the 20 – 100 Hz frequency range with a 1 Hz resolution. Furthermore, because we are interested in the stimulus-driven attentional responses (not to response properties themselves), we will limit analyses to the duration after stimulus onset, from 0 – 500 ms. As in Tallon-Baudry et al., 1996 and Tallon-Baudry et al., 1997, a 100 ms × 15 Hz averaging window will be passed over the average (over trials) TF map of each condition for each subject in 14 ms and 3 Hz steps from 20-100 Hz and 0-500 ms (stimulus duration). All points in each window will be averaged and then plotted in a new TF map. Thus, the resulting TF map for each condition is smoothed over time and frequency. A region of interest (ROI) will be defined by significant differences found between conditions in the smoothed maps. Appropriate comparisons will be made between conditions depending on the hypothesis. A permutation t-test procedure will be used for the statistical test (adapted from (Blair and Karniski, 1993)). The test makes no assumptions about the correlation between different time-frequency points in the multivariate analysis of the TF map and corrects for multiple comparisons. This procedure will be repeated for each electrode.

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