CORTICOTHALAMIC SYNCHRONISATION ORGANISED AROUND TASK-RELATED BEHAVIOURAL EVENTS

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QUESTIONS

1. Is there coherence between the central thalamus and visual cortex around the time of saccade, that might reflect a corollary discharge facilitating synchronization across distant regions of the brain?

2. If coherence is present, does its timing and frequency differ for exogenous (or alerting) and endogenous synchronizing signals?

MOTIVATION

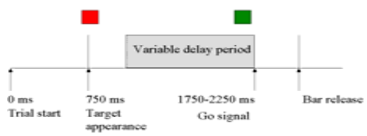
The role of the central thalamus in sustained attention, working memory and motor planning has been demonstrated by previous studies based on electrophysiological recordings (Wyder et.at, 2003, 2004; Schiff et.al,2001), behavioral performance studies following lesions (Mair, 1998, 2001;van der Werf,1999,2003) and functional neuroimaging activation paradigms (Kinomura,1996;Paus,1997). Physiological recordings indicate that a build-up of neuronal firing rates occurs within the central thalamus during short time periods of effortful cognition correlating with increased activation observed in the central thalamus in functional imaging studies. In addition to such sustained increases in neuronal activation, there also is evidence that robust transient signals in response to sensory stimuli and oculomotor control arise within the same neuronal populations (Schlag & Schlag-Rey, 1984ab; Matsumoto, 2001; Minaminoto et.al. 2002; Wyder et.at, 2003, 2004, Purpura et.al, 2003, Tanaka,2006). It has been proposed that these alerting, sensory orienting and eye-movement related signals interact with and shape ongoing envelopes of cerebral persistent activity (Gutkin, 2001; Funahashi, 1993; Brunel & Wang, 2001; Purpura & Schiff, 1997, 2002).

To study the effects or differences elicited by a sensory cue (exogenous) and a pre-motor signal (endogenous) on corticothalamic interactions, we recorded neural activity from the Central thalamus and the Extrastriate Visual Cortex of an awake behaving primate during the performance of a visual attention task.

METHODS

BEHAVIORAL TASK:

Simultaneous recordings of spike and Local field potential (LFP) were made in the central thalamus and extrastriate visual cortex during the performance of a short-term focusing of visual attention task. The behavioral paradigm requires acquisition of a visual target(Red cursor) with a saccadic eye movement, followed by a variable fixation period and a bar release after the cursor turns green.



RECORDINGS:

Spikes: We recorded extracellular potentials simultaneously from the central thalamus and extrastriate visual cortex (V4 and surrounding areas) in the occipital lobe, of a rhesus monkey. Central thalamic sites were identified utilizing 3-dimensional MRI reconstruction and attachments to guide electrodes to central thalamic sites. Action potentials were sorted on-line using two different methods: a multi-window discriminator (Tucker-Davis Technologies) and a neural-network template-matching algorithm implemented on a computer card (MEXv5).
LFP: We recorded local field potentials from high impedance electrodes (~3M,Ω FHC) used for simultaneous single-unit recordings low-pass filtered at 300Hz (Tucker-Davis Technologies). Simultaneous recordings from two electrodes were obtained from central thalamic sites and extrastriate visual regions in 110 separate experiments.
Eye movement: Eye movements were monitored using an infrared camera system (ASL 5000).

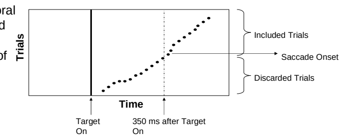
SPECTRAL ANALYSIS:

Multi-Window , Multi- Taper Coherogram: By applying a set of sliding windows and averaging over them we can obtain a multiple window time frequency distribution of coherence for two time-varying signals:Ref: Xu & Haykin,1999;Thomson & Chave,1991;Percival & Walden,1993;Mitra & Pesaran,1999
Statistical Significance: Only tiles meeting the 95% confidence limits set by the Rayleigh Uniform Phase test are included in the analysis.

$$\Gamma_{MW}(t,f)=\frac{\left|\sum_{k=0}^{K-1} X_k(t,f)Y_k(t,f)\right|^2}{\sum_{k=0}^{K-1}\left|X_k(t,f)\right|^2\sum_{k=0}^{K-1}\left|Y_k(t,f)\right|^2}$$

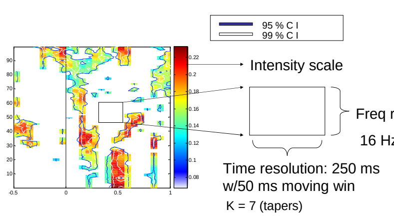
DATA PRE-PROCESSING

We grouped datasets recorded from 110 microelectrode placements with spike activity on both channels using the thalamic firing patterns. The first group (n=30) contained datasets with elevated thalamic firing rates during the variable delay-period prior to a visual go signal prompting a behavioral response (bar release). The second group (n=82) contained datasets with unmodulated thalamic firing rates during the delay-period. LFPs were analyzed separately for direction of saccade (contraversive vs. ipsiversive) and aligned to both the timing of visual target appearance and saccade acquisition of the target. This was to compare coherence patterns elicited by external events to those elicited by endogenous events.
To prevent contamination between exogenous and endogenous events, only datasets containing saccades that occurred after 350 ms of the target on appearance.



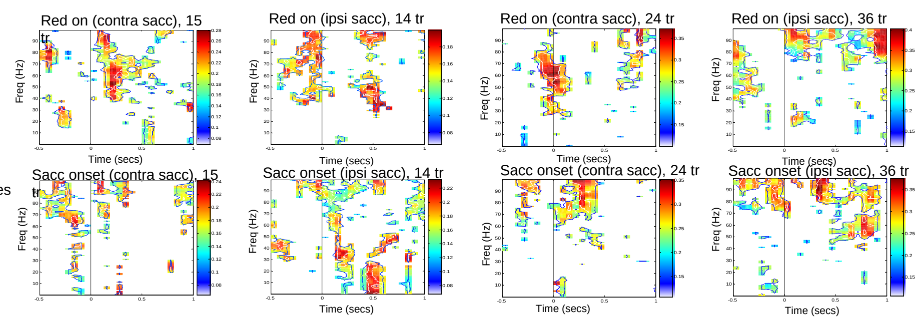
RESULTS

SAMPLE COHEROGRAM



Ref: Xu & Haykin,1999;Thomson & Chave,1991;Percival & Walden,1993;Mitra & Pesaran,1999

SAMPLE DATASET # 1 / SAMPLE DATASET # 2



Individual datasets showed coherence differences around exogenous (Red On) and endogenous (Sacc onset) events. They also showed hemispheric specificity (with respect to contraversive vs. ipsiversive eye movements)

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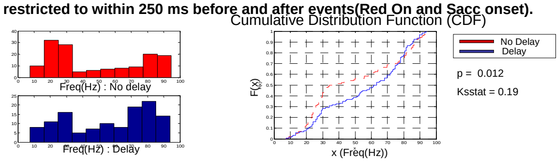
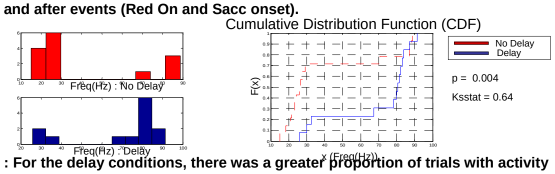
POPULATION ANALYSIS

To determine distributions of frequencies and times of coherence within datasets, we characterize statistically significant coherence tiles as a Region of Interest (ROI) and conduct a group analysis of the ROIs using methods described in Purpura et al. (2003) . We obtained ROIs from individual datasets restricted to +/- 250 ms of time around both target and saccade onset events in each trial. The centroids of the largest ROI of significant coherence from each dataset correspond to a specific frequency and time as shown below.

Frequencies of the largest ROI in each dataset (with 95% significant coherence tiles), in a time restricted to within 250 ms before and after events(Red On and Sacc onset).



Frequencies of the 1st and 2nd largest ROI's (greater than area of 100 pixels) in each dataset (with 99% significant coherence tiles), in a time restricted to within 100 ms before and after events (Red On and Sacc onset).



Result : For the delay conditions, there was a greater proportion of trials with activity in the gamma (20-80 Hz) band.

CONCLUSIONS

1. We identify significant coherence between central thalamus and extrastriate visual cortex regions arising locally in time around behaviorally relevant internal and external events and during brief periods of reallocation of attentional resources (delay period). There are differences between the two events in individual datasets but they are not identified in the group analysis (data not shown).

2. We observe that gamma band(20-80Hz) coherence appears around these events significantly more often in datasets containing delay period activity. Timing showed no statistically significant difference (data not shown).

3. Differences in the timing and frequency content of coherence are observed to be dependent on the direction of saccade in individual datasets but not in a group analysis (data not shown).

4. These results are consistent with previous studies that demonstrate brief correlations of local population activity in a similar frequency range between the central thalamus and distributed cerebral structures during operant condition (Amzica.et.al) and increases in the overall contribution of these frequencies to the EEG power spectrum following direct and indirect stimulation of the central thalamus (Steriade et al. 1991, Schiff et.al 2002).

5. Taken together with the existing experimental literature these findings suggest a common role for neurons within the central thalamus in reshaping the correlation structure of corticothalamic dynamics around ongoing behaviors in wakefulness: i.e, organizing short-time envelopes of coherent activity within the gamma range that may influence assembly processing across a wide spatial range within the forebrain.

6. Future studies will examine the origins of the control of these brief change in coherence which are likely to arise from frontal cortical regions that project to the central thalamus.