Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

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Consortium members

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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BEVEZETÉS A FUNKCIONÁLIS NEUROBIOLÓGIÁBA

INTRODUCTION TO FUNCTIONAL NEUROBIOLOGY

By Imre Kalló

Contributed by: Tamás Freund, Zsolt Liposits, Zoltán Nusser, László Acsády, Szabolcs Káli, József Haller, Zsófia Maglóczky, Nórbert Hájos, Emilia Madarász, György Karmos, Miklós Palkovits, Anita Kamondi, Lóránd Erőss, Róbert Gábriel, Zoltán Kisvárday, Zoltán Vidnyánszky

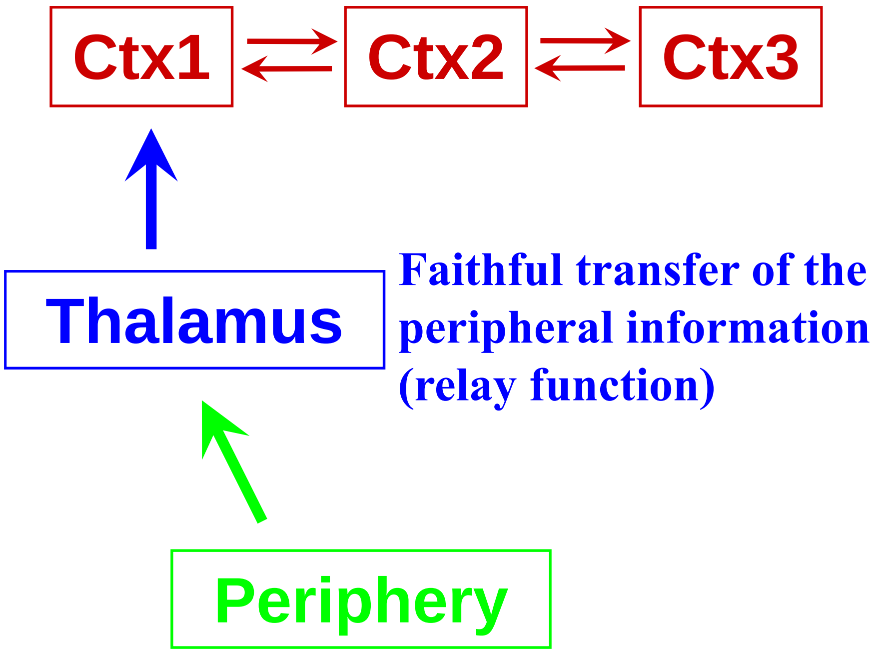
Thalamus

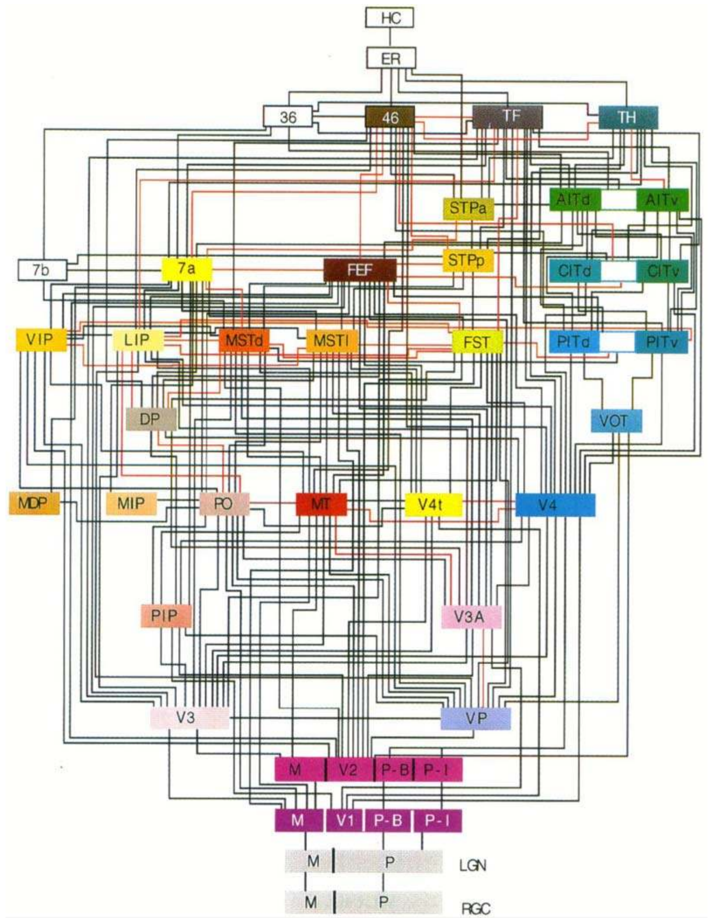
Imre Kalló & László Acsády

Pázmány Péter Catholic University, Faculty of Information Technology

I. Thalamic nuclei relaying peripheral signals to the cerebral cortex. Input from the cortex and the reticular nucleus of the thalamus.
II. Thalamo-cortical rhythms. Tonic and burst activity pattern of relay cells.
III. Thalamic nuclei, activity of which reflect higher cognitive processes.
IV. The extrareticular inhibition.

Corticocentral world concept

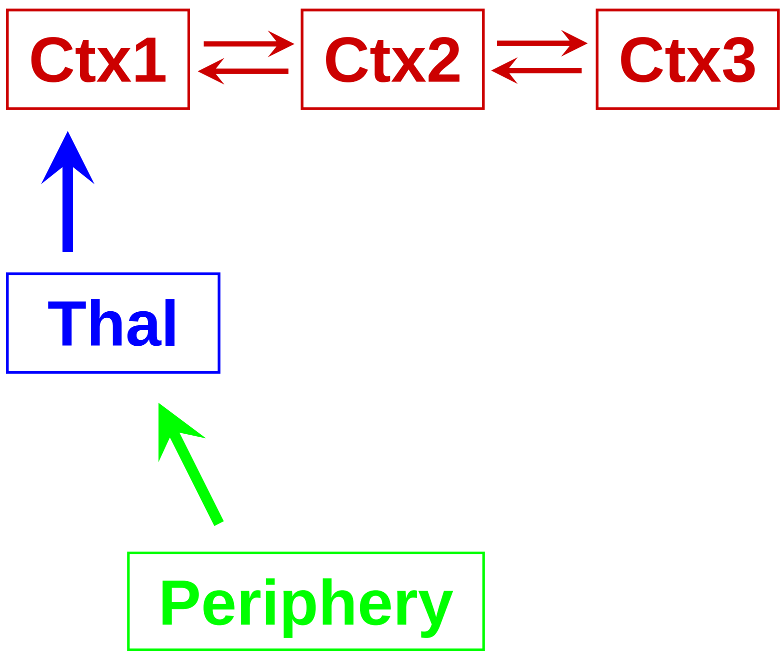




D. van Essen

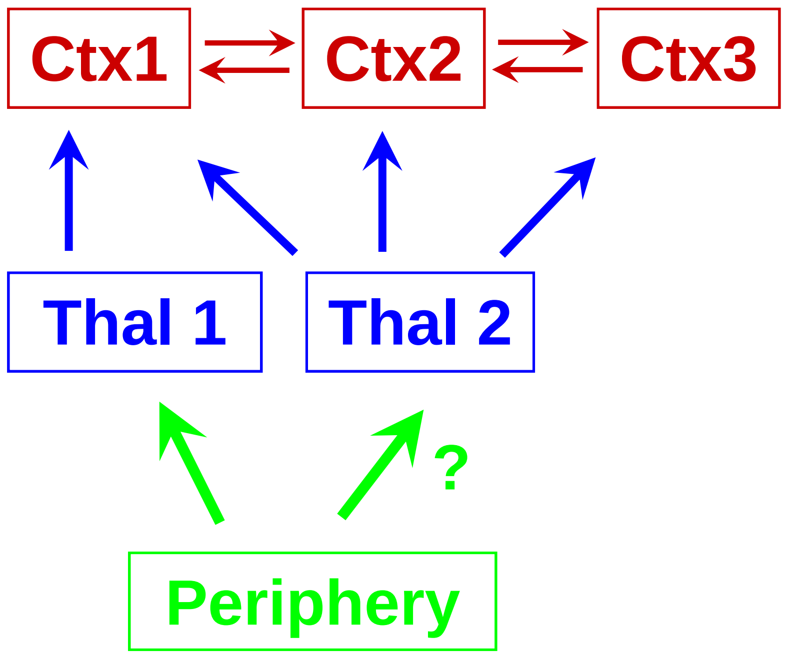
Corticocentral world concept

The higher order neuronal function is based on cortico-cortical connections



Thalamocortical world concept

Thalamic input is required to all (studied so far) cortical functions



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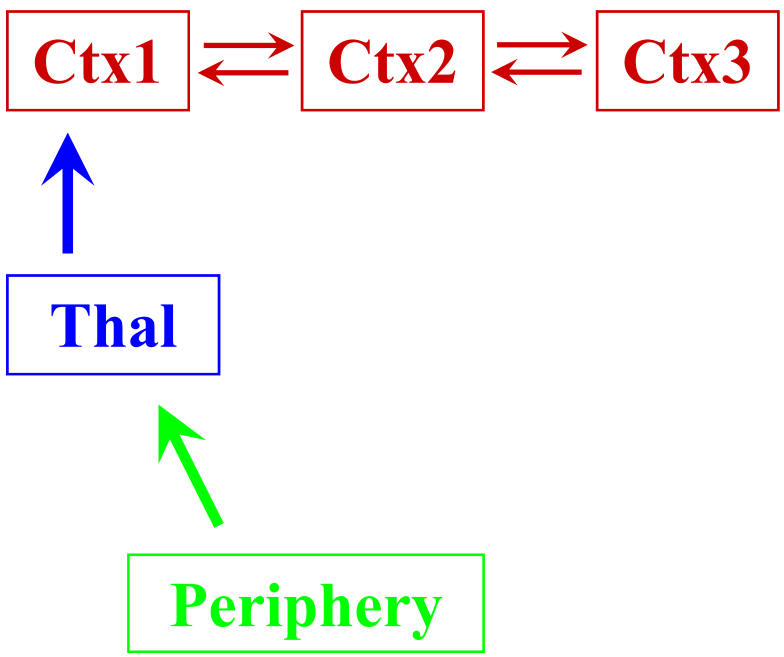

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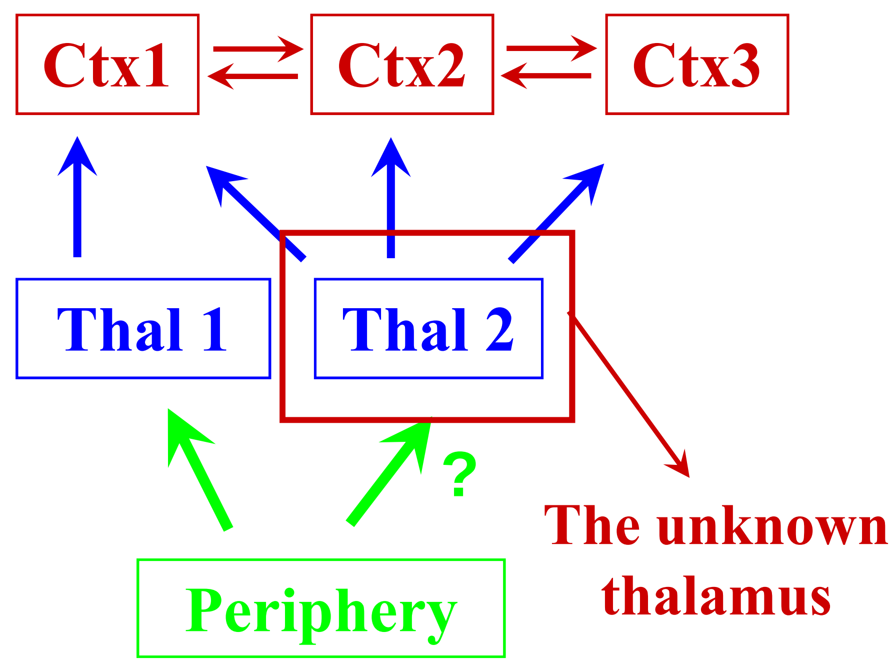
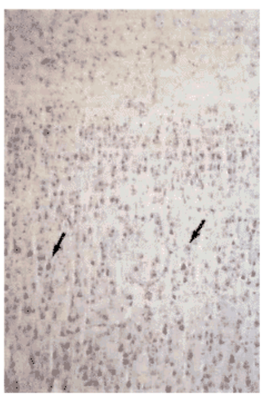


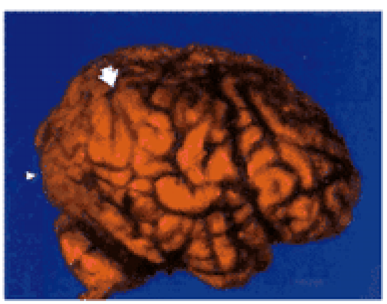
The case of Karel Ann Quinlan

- There was a transitional circulatory-respiratory arrest at her age 21 year.
- After resuscitation her autonomic functions returned, but never gained her consciousness back. She remained in persistent autonomic state.
- She died ten years later.

What was lesioned in the nervous system of Karen Ann Quinlan ?

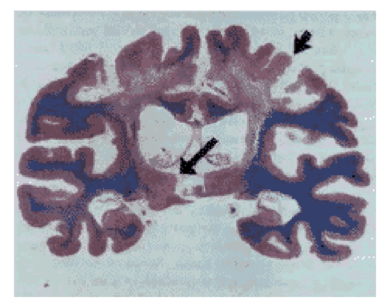


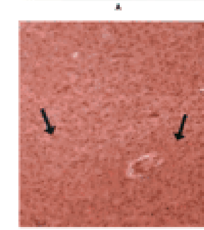
Negligible lesion in the cerebral cortex



Kinney et al., 1994

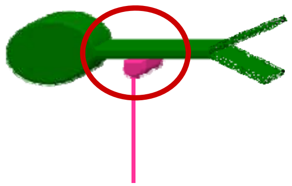
Serious defect in the thalamus





Kinney et al., 1994

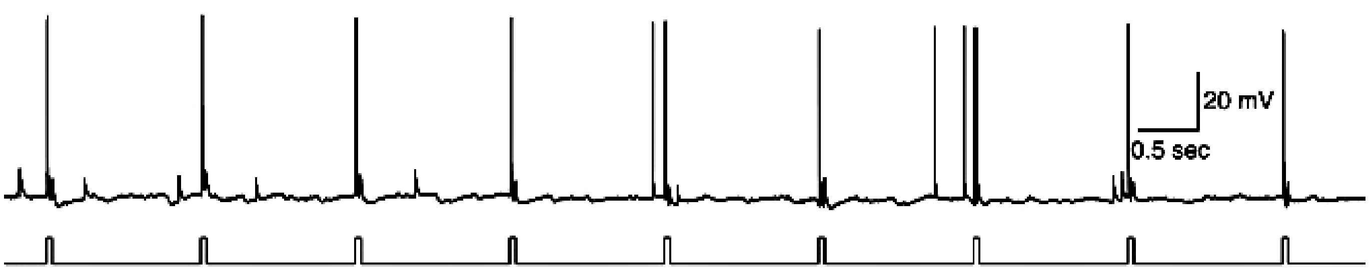
Basic concepts of thalamic organisation



The „driver" concept

Driving input

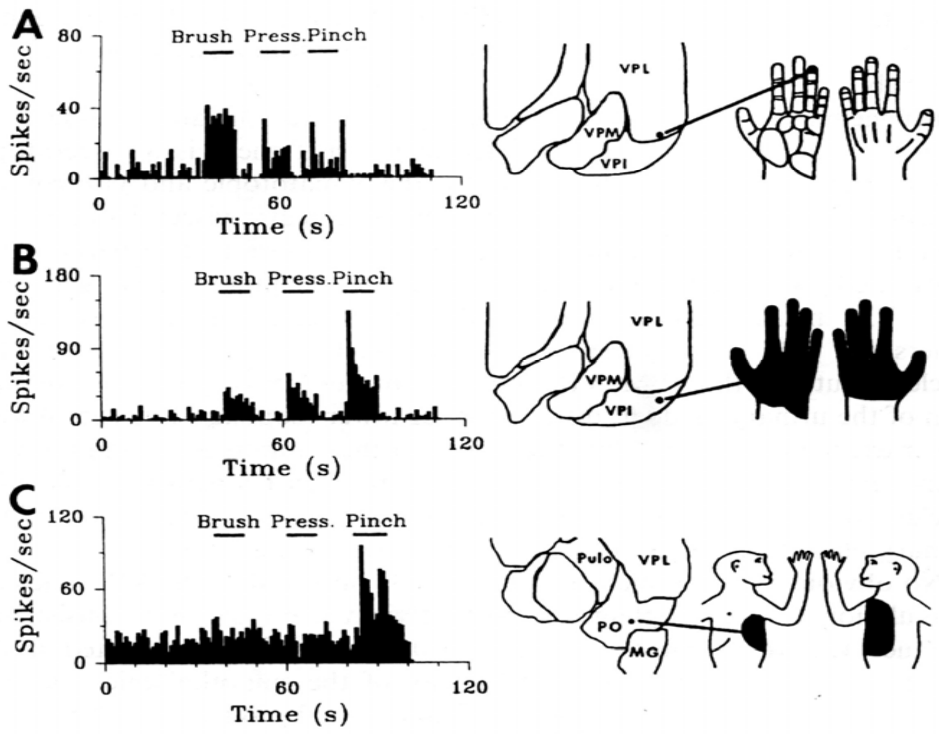
Actvity response of a VPM relay cell to whisker stimulation



Lavallée et al. 2005 JNsci

The relay function

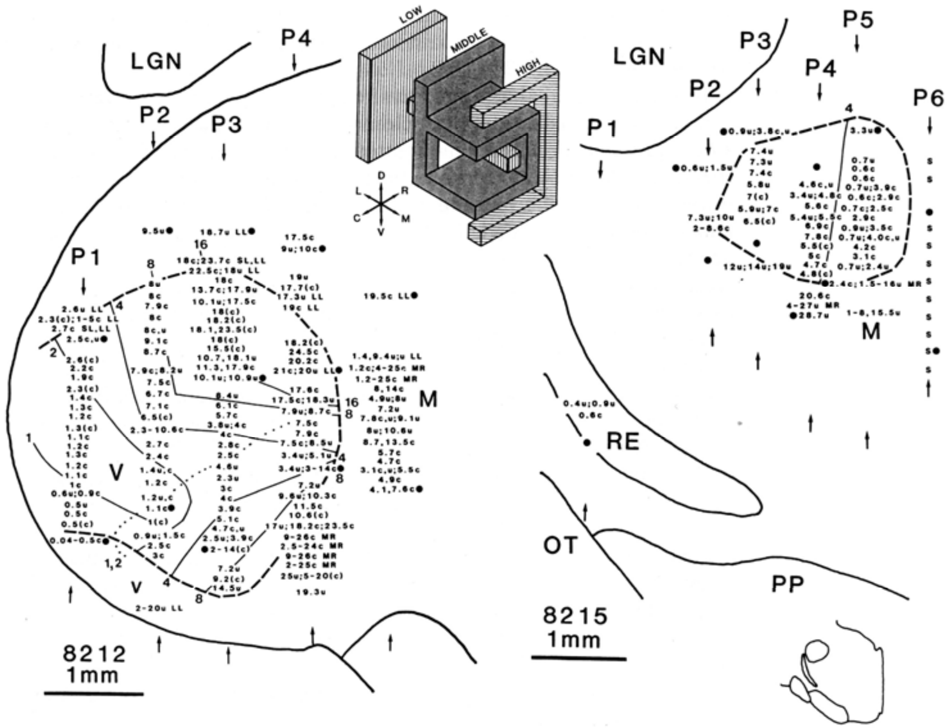
Topographic organization and specificity of modalities



Different types of somatosensory responses recorded in the monkey thalamus

The relay function

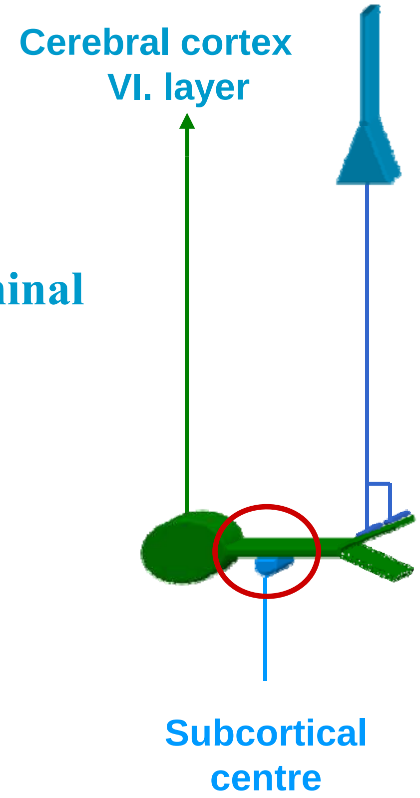
Topographic organization and specificity of modalities



Imig and Morel 1985

Tonotopic representation in the cat thalamus

The source of „modulators”

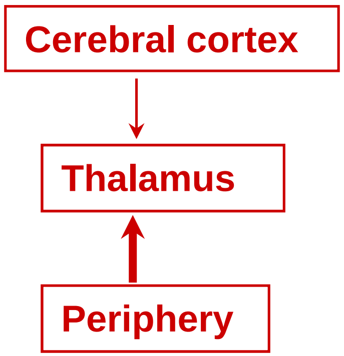


vGLUT1 – cerebral input

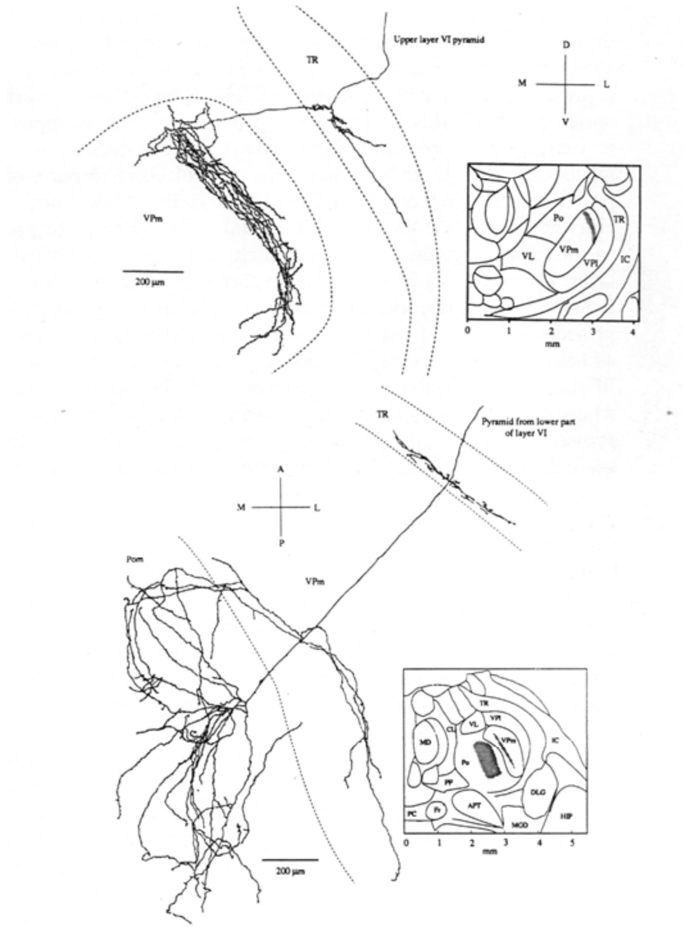
Modulator – small axon terminal
Target - distal dendrite
One bouton one synapse

vGLUT2 – subcortical input

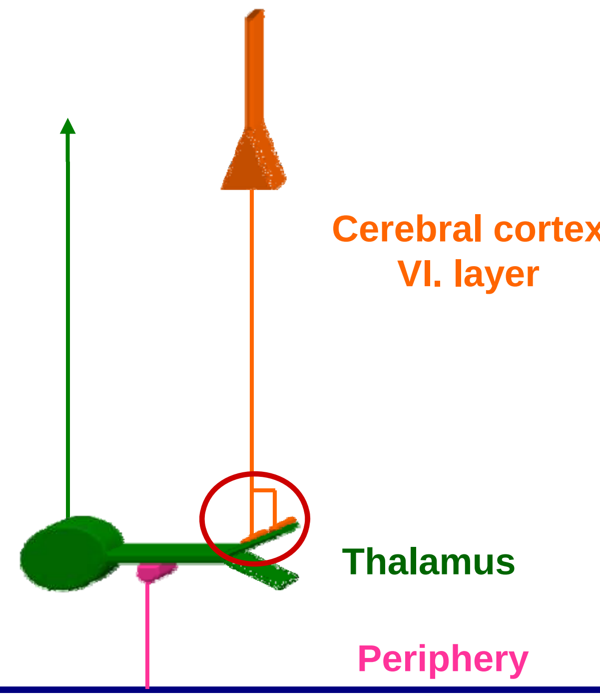
Driver – large axon terminal
Target - proximal dendrite
One bouton many synapse



The cortical feed-back

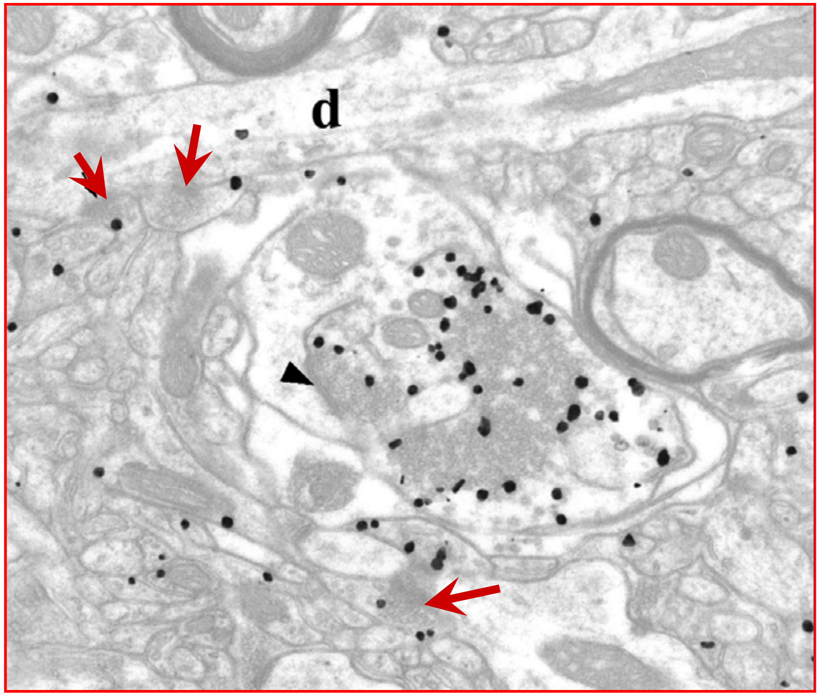


All thalamic regions receive an order of magnitude more input from the VI. layer of the cortical area, which they innervate, than from the periphery.

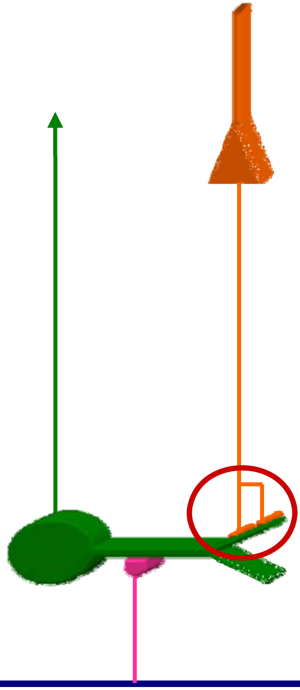


The cortical feed-back

The VI. layer afferent:



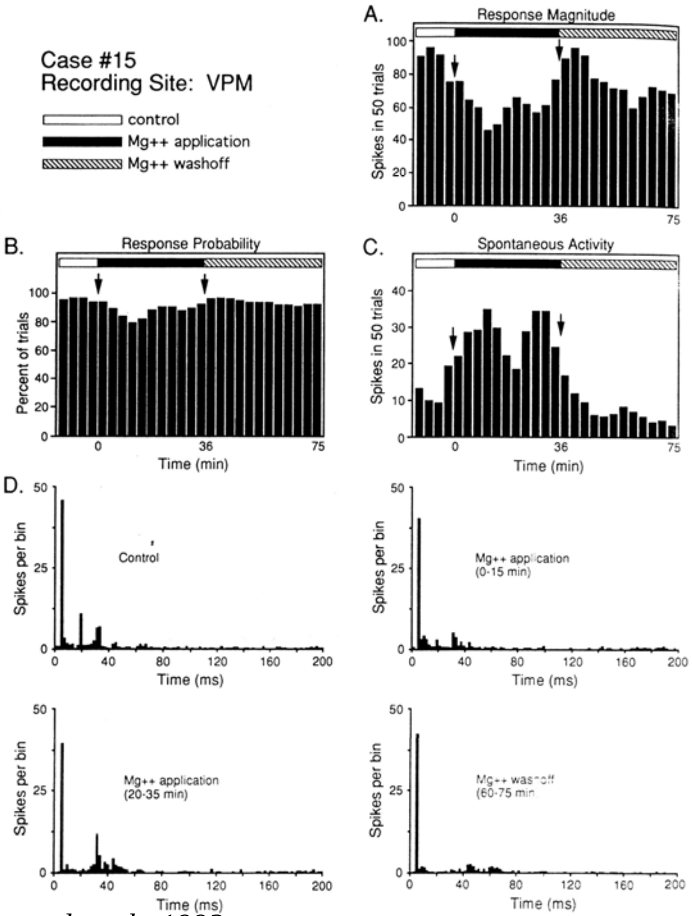
- Small
- It establishes a single synapse
- On the distal dendrite



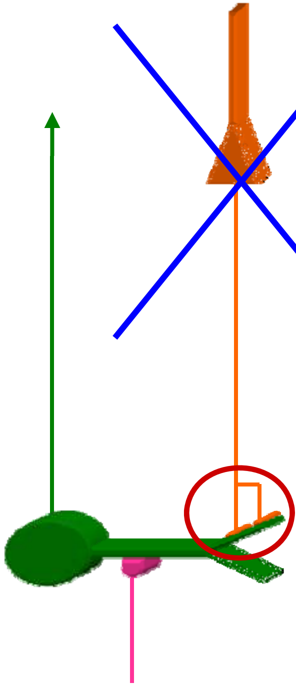
The „modulator" cortical afferent

The cortical feed-back

VPM - Inactivation of the cerebral cortex hardly influences the transfer of the peripheral stimulus

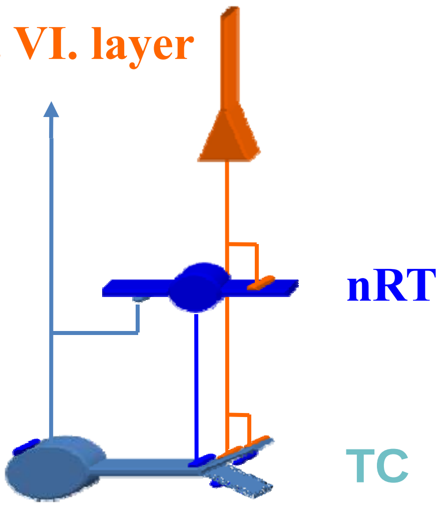


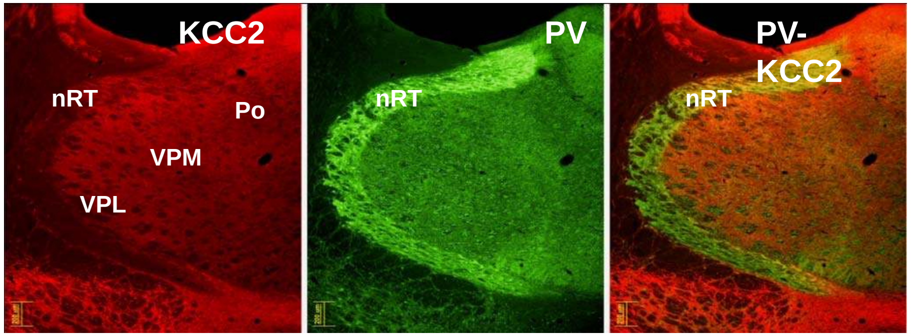
Diamond et al., 1992



Whisker stimulation-evoked response in the rat somatosensory thalamus, when the cerebral cortex was inactivated.

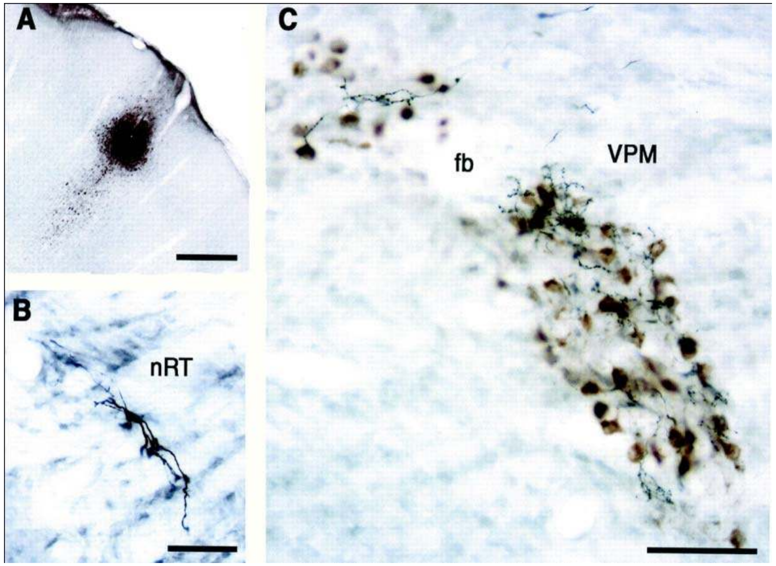
The thalamic inhibition: Nucleus reticularis thalami - nRT





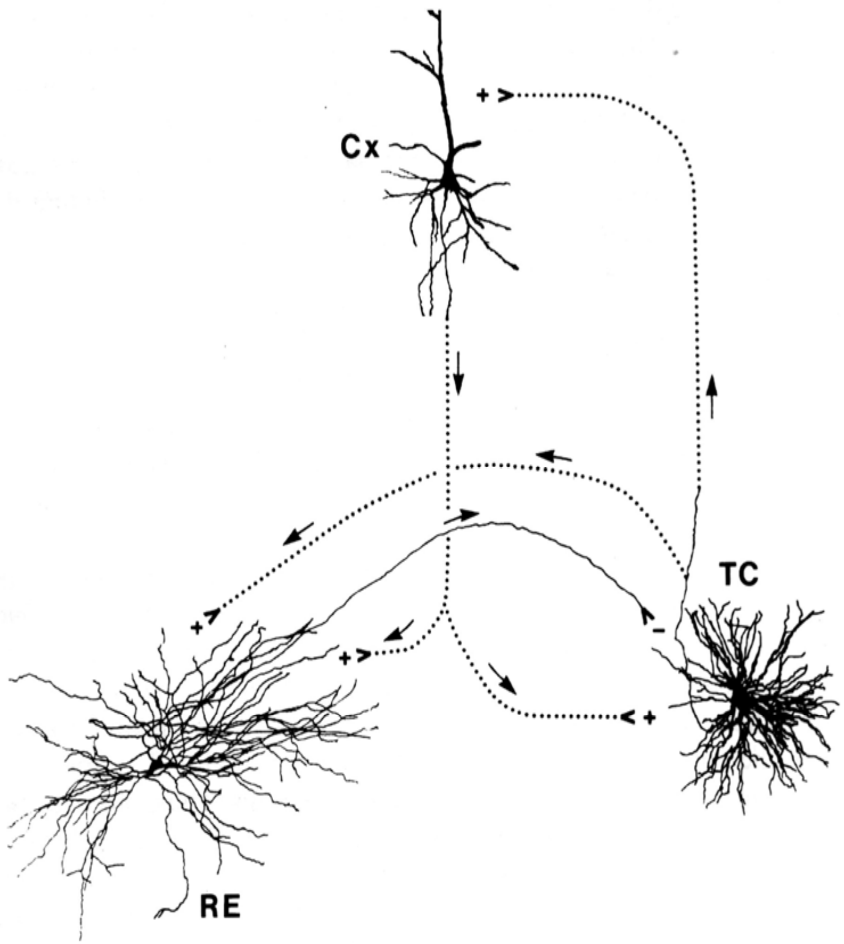
The nRT ensures a precise topographic inhibition in all thalamic nuclei.

Both the corticothalamic cells in the VI. layer, and the thalamocortical cells provide axon collaterals to the nRT.

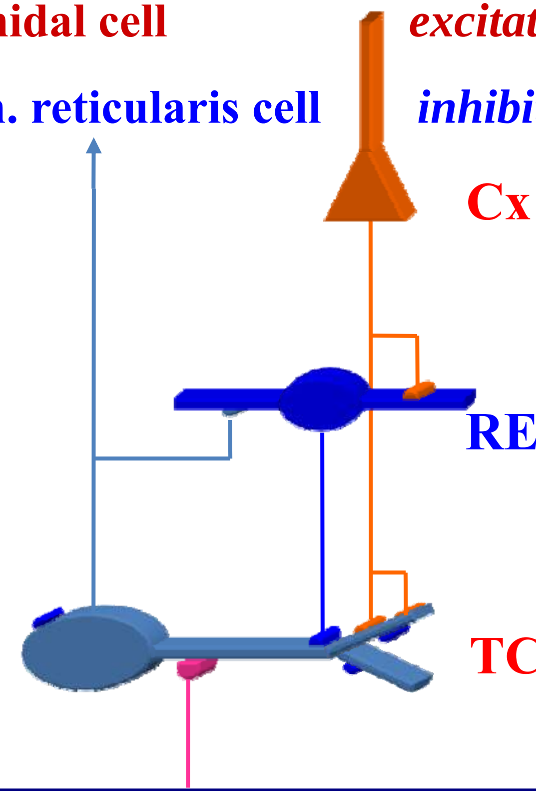


Desilets-Roy et al., 2002

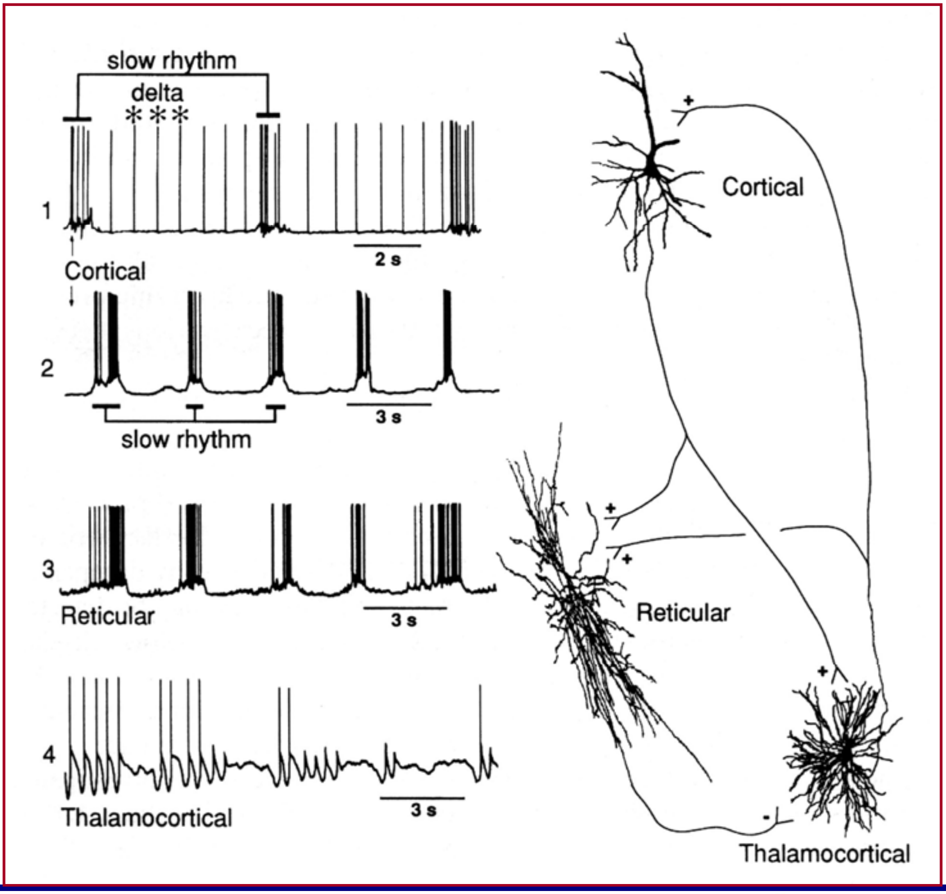
Three members of the thalamocortical circuit



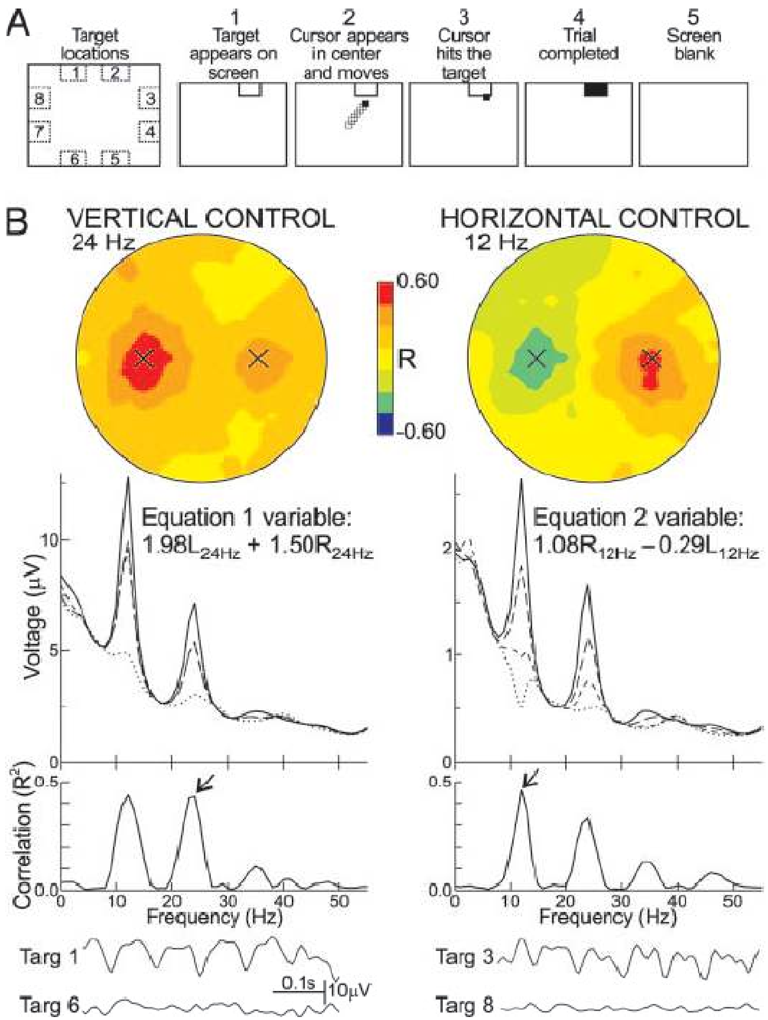
- **TC – thalamo-cortical relay cell** ***excitatory***
- **Cx - VI. layer cortical corticothalamic pyramidal cell** ***excitatory***
- **RE - n. reticularis cell** ***inhibitory***



Thalamocortical rhythms

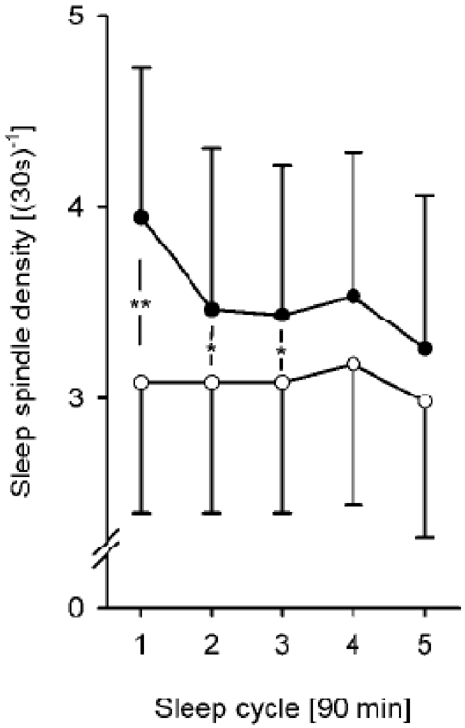


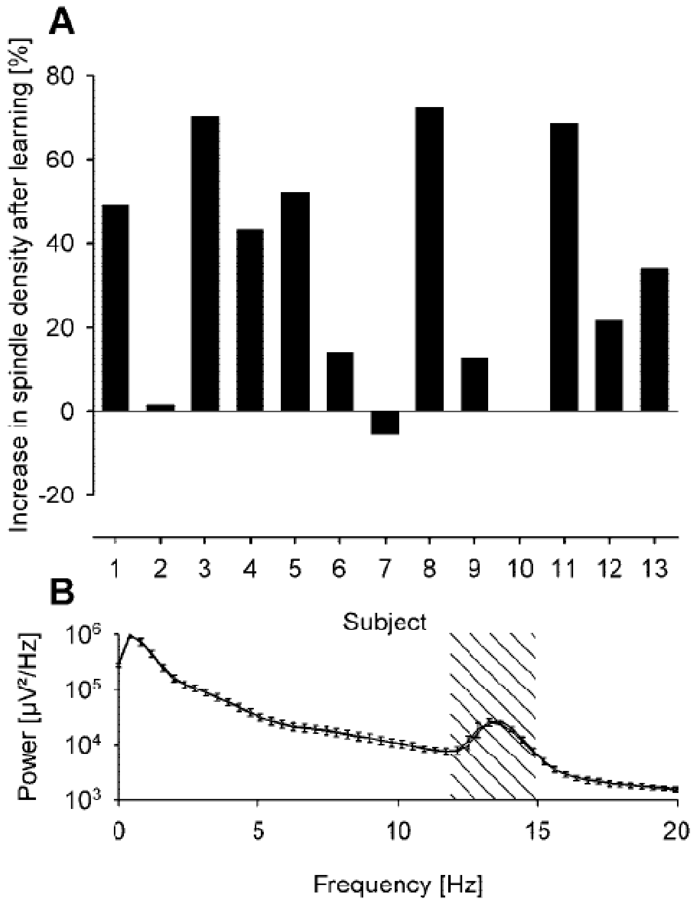
Brain-computer interface: movement of cursor with the aid of α (μ) waves



Wolpaw and McFarland 2004

Slow wave sleep, sleep spindles and learning

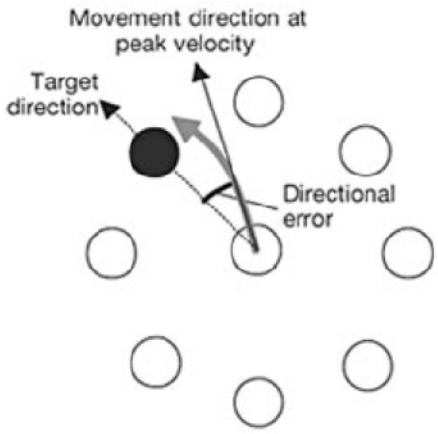


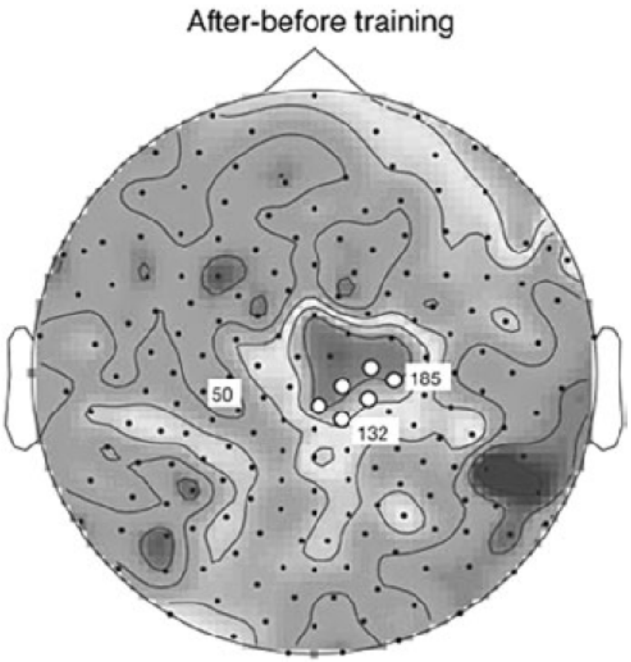


Declarative memory task - controls received a task unrelated to learing

The density of sleep spindles was in correlation with the success of recall before and after sleep

Learning – Specific increase of delta wave performance in the affected cortical field



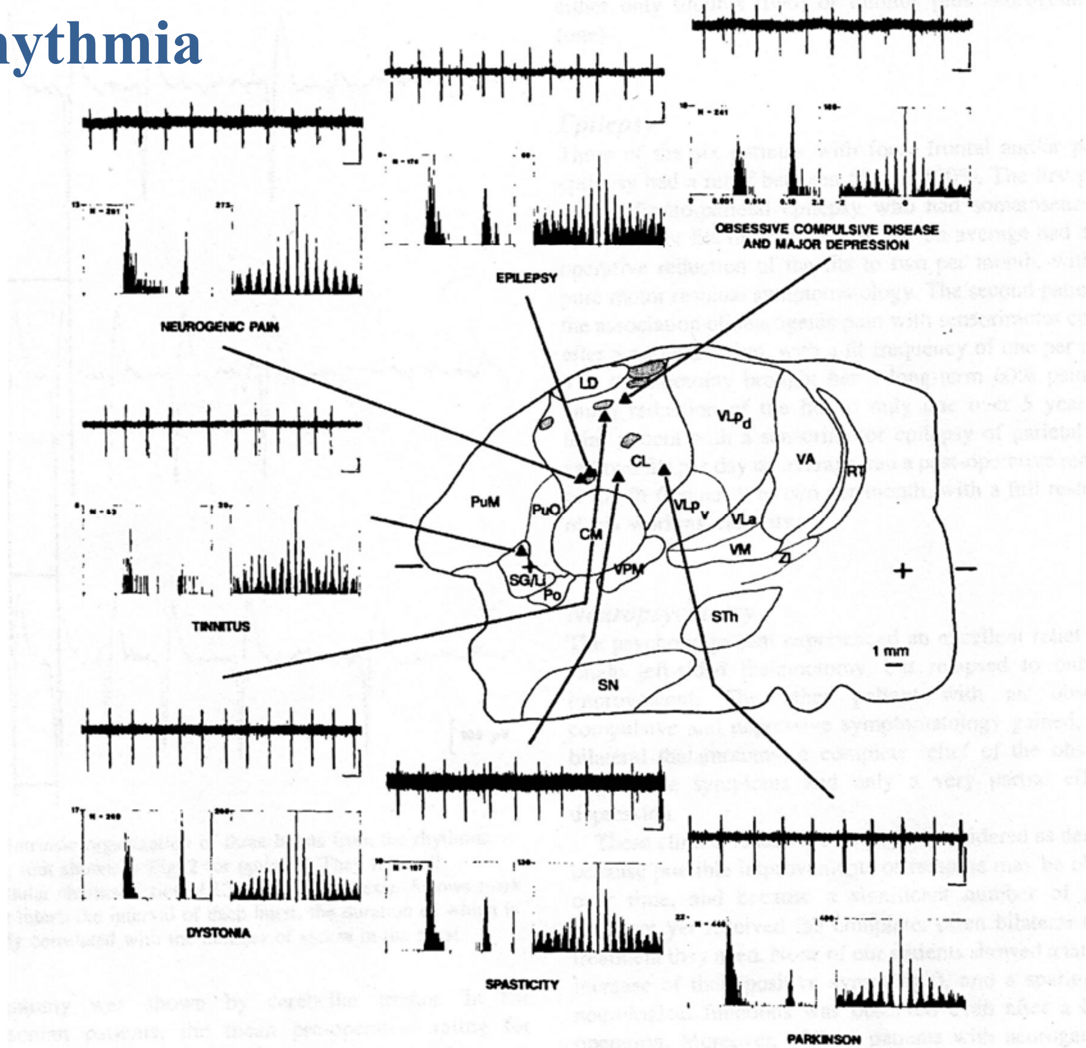


Huber et al. 2004

Thalamocortical dysrhythmia

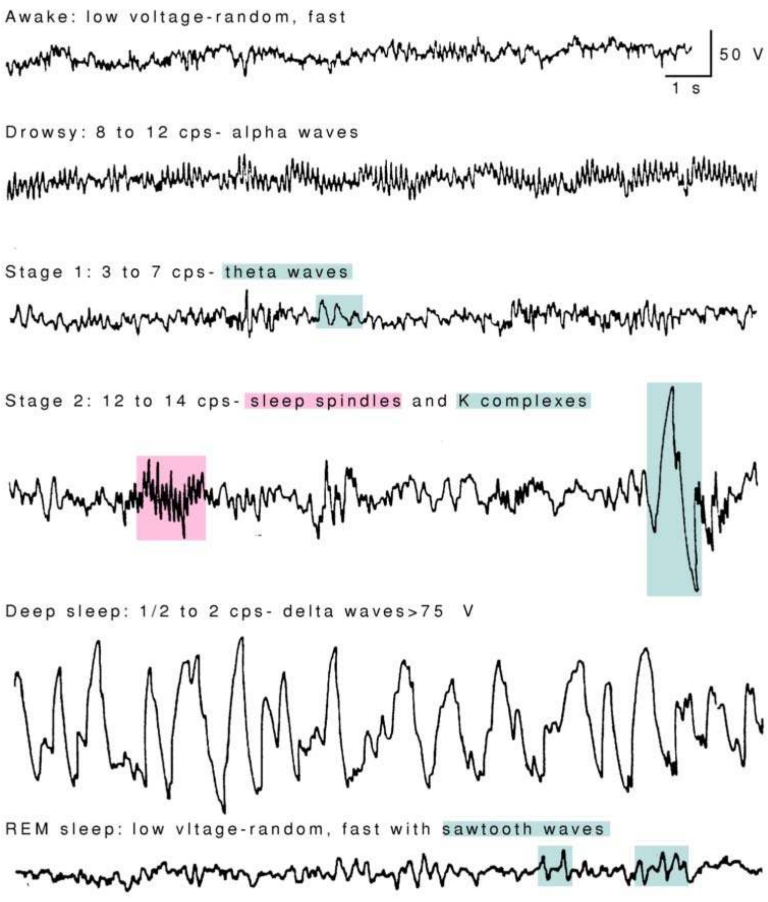
Common pathophysiologic alterations can be found in the background of different neurological and neuropsychiatric symptoms.

3-4Hz rhythmic relay cell activity and slow EEG oscillation in awake state .



Jeanmonod 1996

EEG activity in the different phases of the sleep-wake cycle

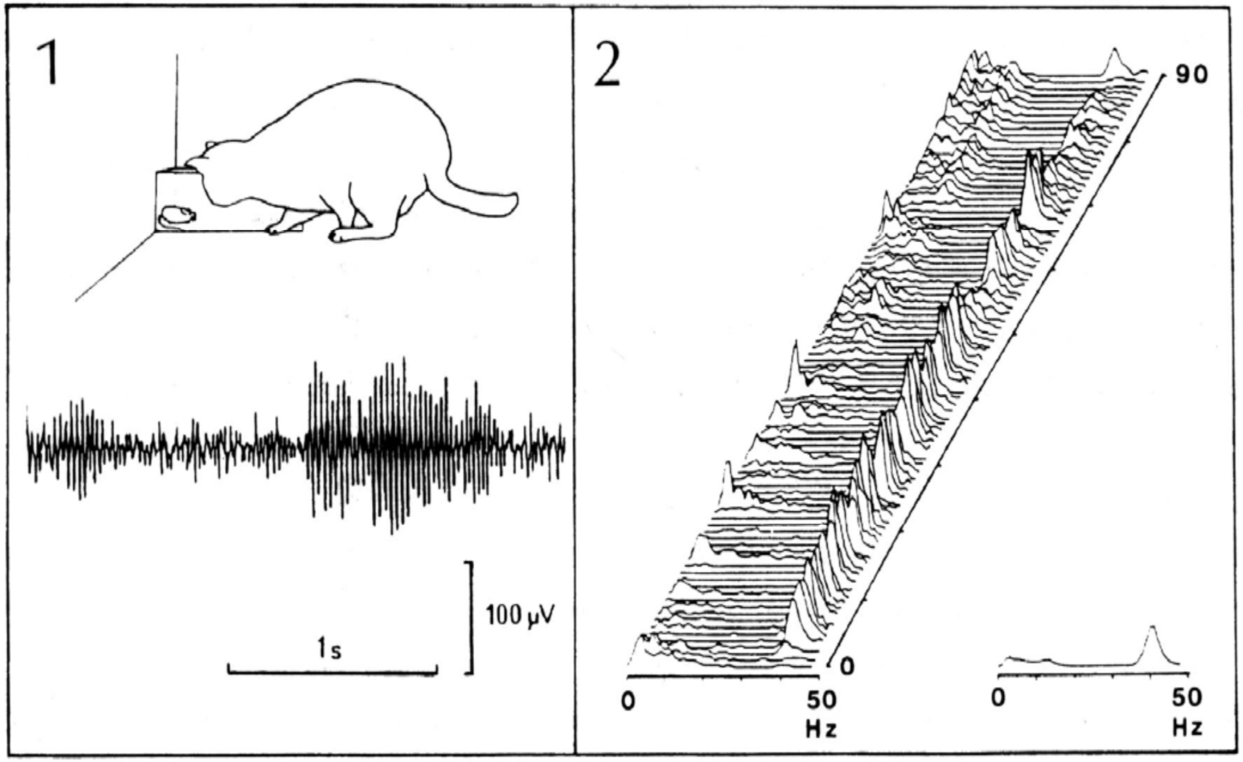


Awake: high frequency small amplitude activity

Non-REM sleep: low frequency high amplitude activity

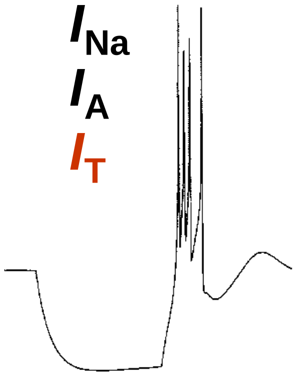
REM sleep: the same as in awake state

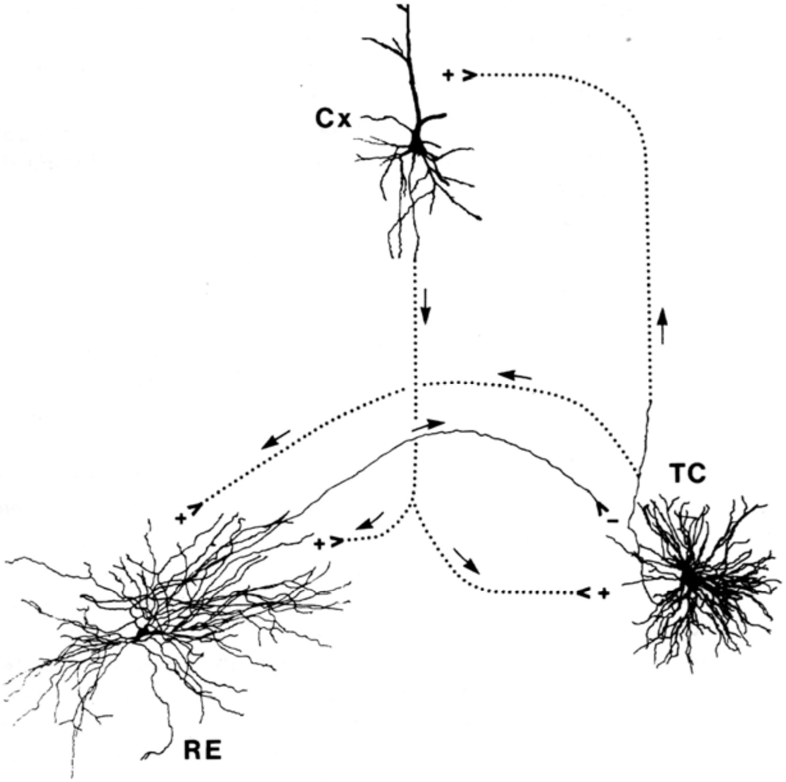
Fast rhythmic EEG activity in the cat parietal cortex during focused attention



Rougel-Buser and Buser 1994

Mechanisms of formation of thalamocortical rhythms





During different rhythms, activity is determined by the internal characteristics AND synaptic connections of the cells.

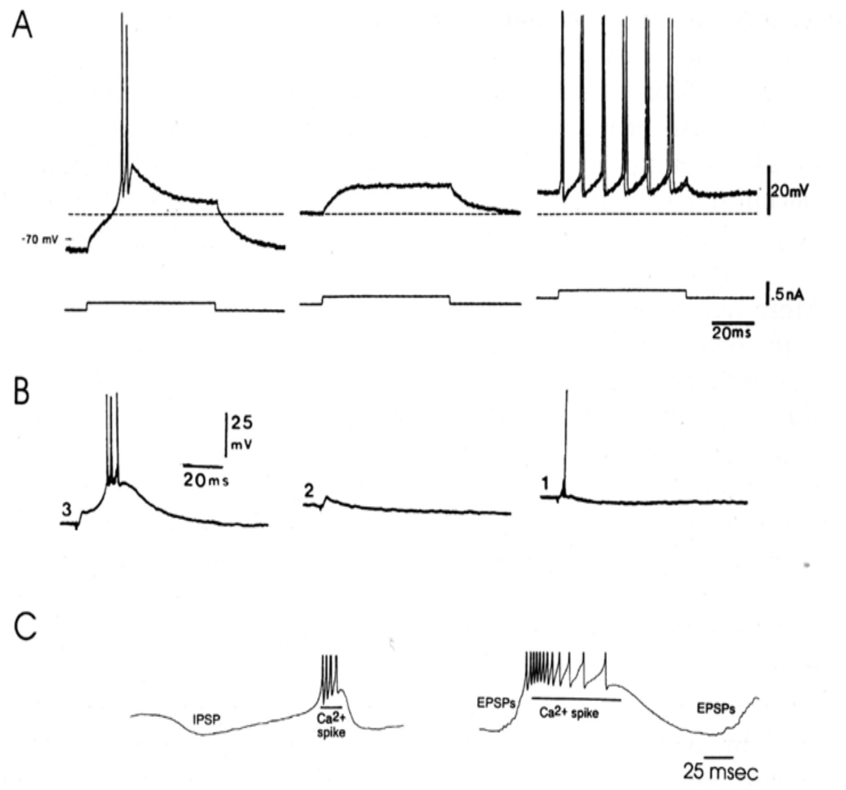
The system shows stable (resonant) characteristics in several different states.

Two different types of firing mode of the relay cells Burst vs single spike

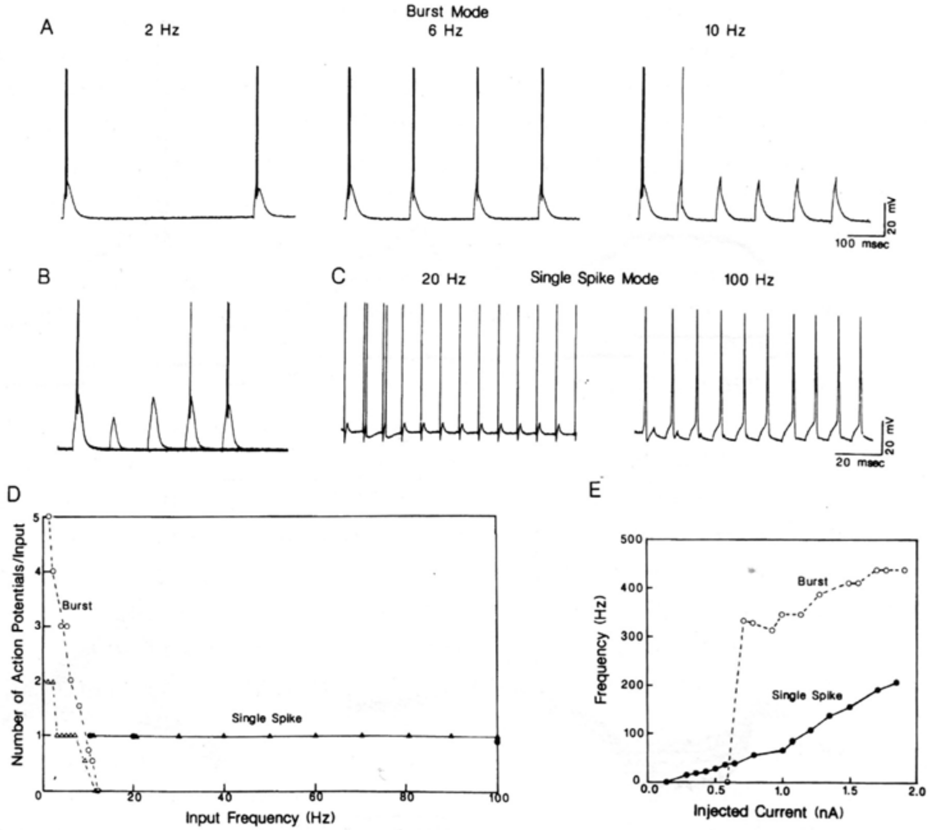
A) Different types of action potentials triggered by different current injections at various membrane potentials

B) The same phenomena induced by stimulating the excitatory afferents

C) burst activity following IPSPs



Reliability of signal transfer in tonic and burst mode of the firing activity of thalamocortical cells



McCormick and Feeser, 1990

Awake - „tonic mode” the activity of relay cells precisely mediates the afferent signal towards the cerebral cortex

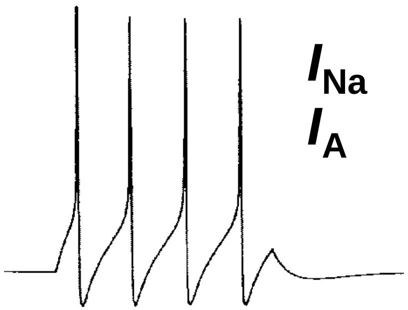
Sleeping - „burst mode” the activity of relay cells does not follow the frequency of the afferent signal

During sleep, by means of the burst activity, the thalamus cuts off the cerebral cortex from the external world.

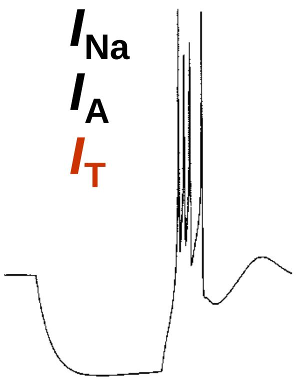
The two types of firing pattern of the thalamocortical cells

The T-type calcium channel

Tonic firing



Burst firing



- **<u>Tonic:</u> depolarised membrane potential, single Na+/K+ action potentials (I_{Na}, I_A)**
- **<u>Burst:</u> hyperpolarised membrane potential, Ca^{2+} mediated depolarization „riding" Na+/K+ action potential train**

<u>I_T – low threshold calcium-channel two activation gates</u>

- it is inactive at resting potential – it can not open – there is no Ca^{2+} -influx

- it becomes de-inactivated in response to hyperpolarization (it turns into an activable state – there is no Ca^{2+} - influx)

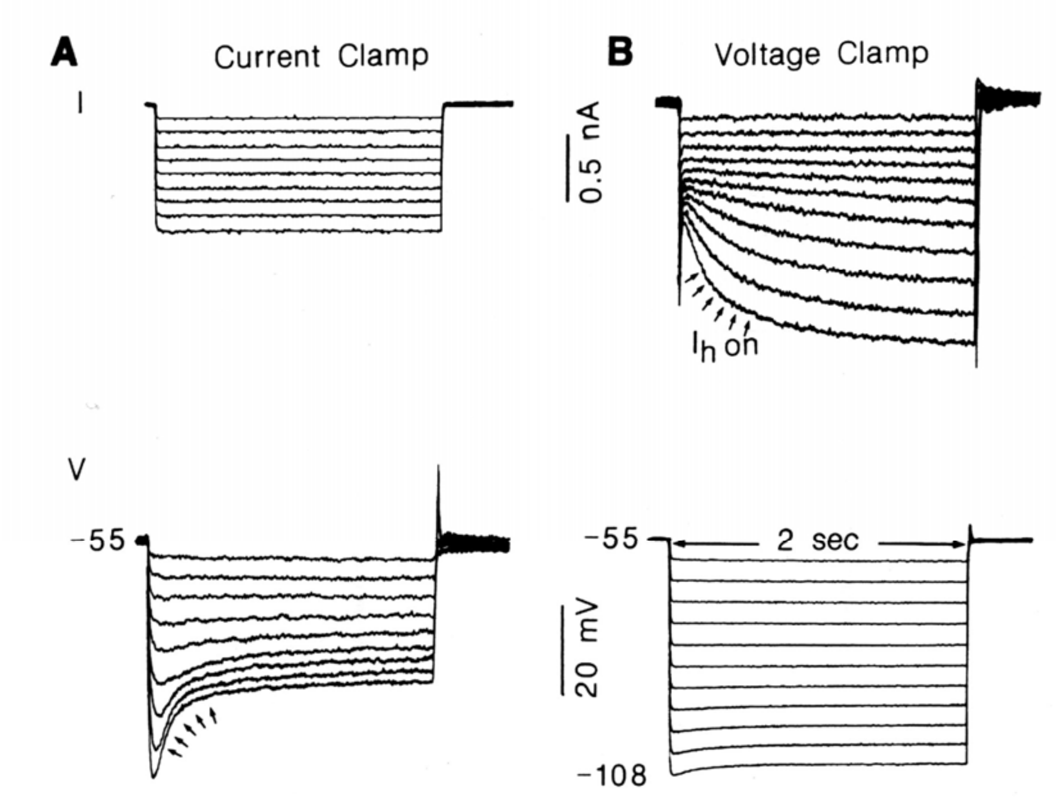
- in response to a subsequent depolarization it becomes activated - huge Ca^{2+} influx – it causes depolarization, which may induce a Na/K action potential train (burst)

The two types of firing pattern of the thalamocortical cells
The H current

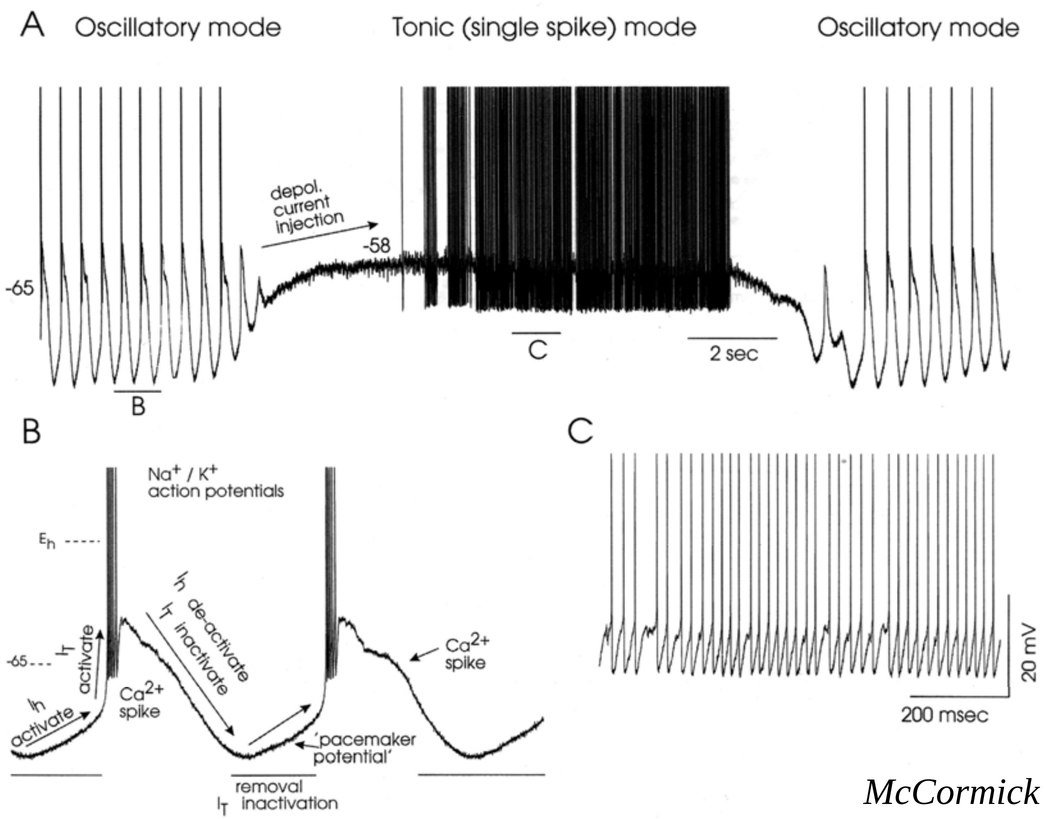
Mixed kationic current opened by membrane hyperpolarization .

It acts against hyperpolarization by depolarising the cell.

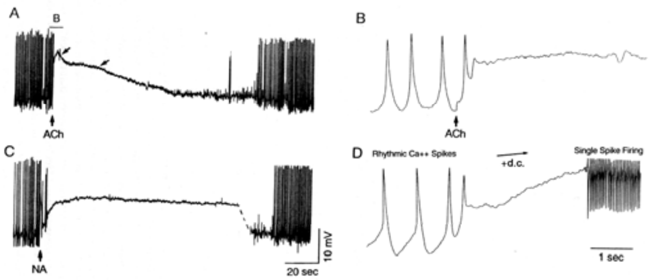
„Pacemaker current”



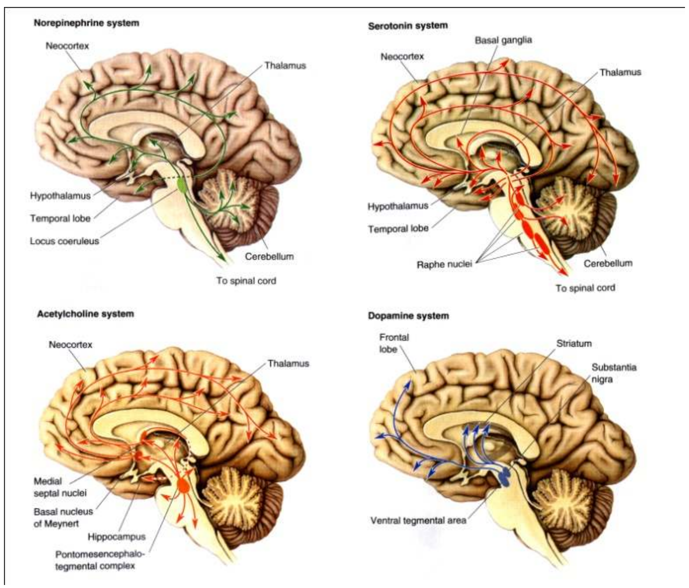
The interaction of the two currents at hyperpolarised membrane potential leads to oscillation, rhythmic burst activity



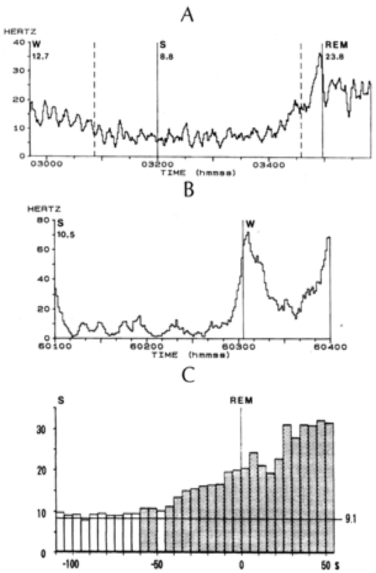
McCormick and Pape, 1990



In relay cells, the burst firing pattern is changed to tonic in response to acethylcholine and norepinephrine

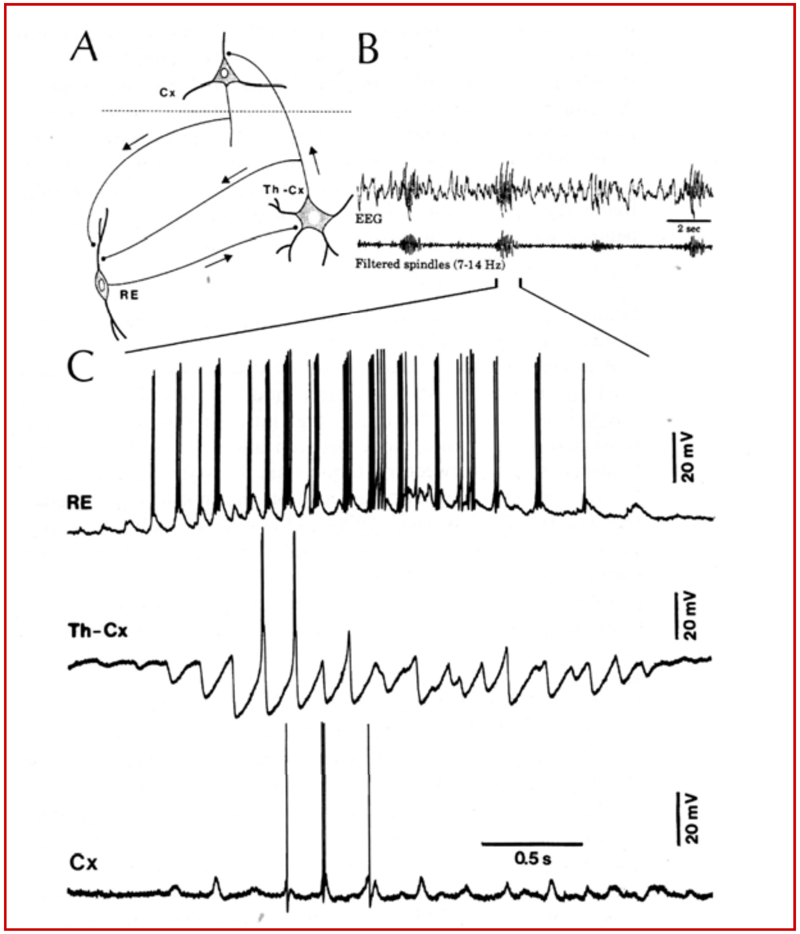


The brainstem ascending activating system



Function of the brainstem „waking" cells during the sleep-wake cycle

Origin of the 7-14 Hz spindle activity in the thalamus



nRt

- **slow depolarization wave, bursts with spindle frequency**

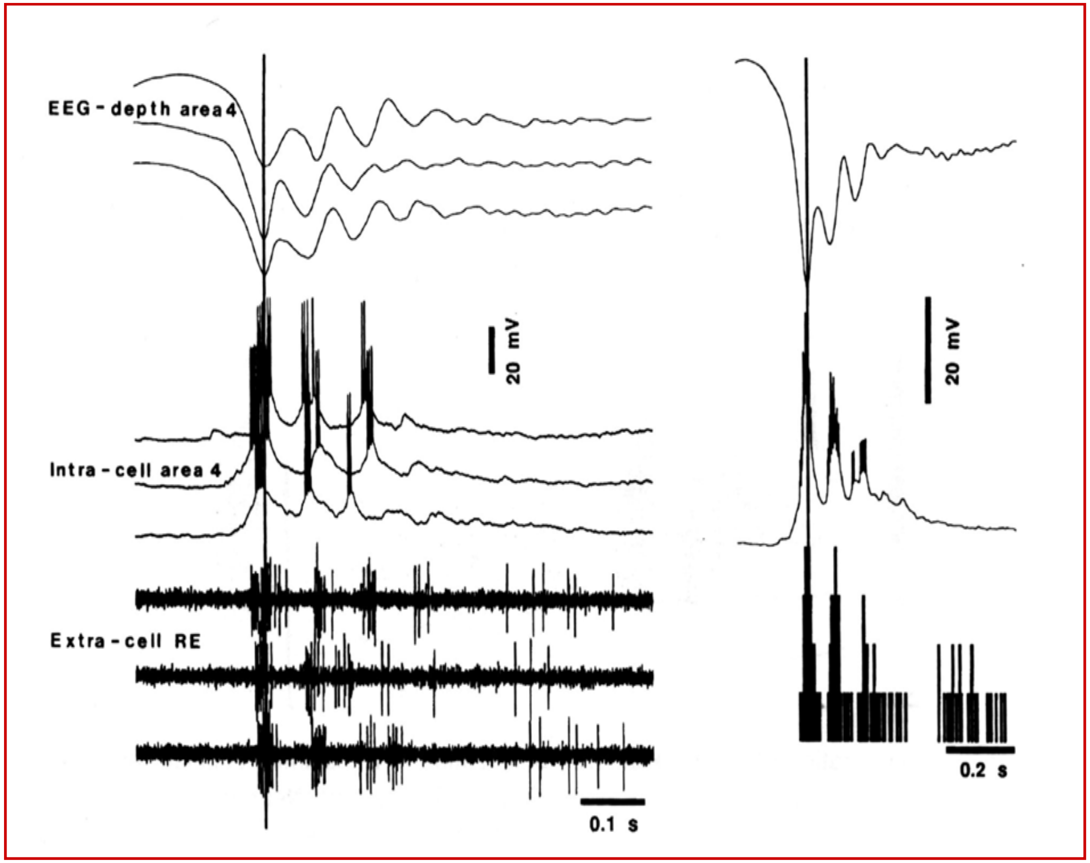
Relay cells

- **rhythmic IPSP sequences, sometimes low threshold burst activity**

Cortical pyramidal cell

- **rhythmic EPSP, sometimes action potentials**

Synchronous oscillation of cortical and thalamic neurons during spindle



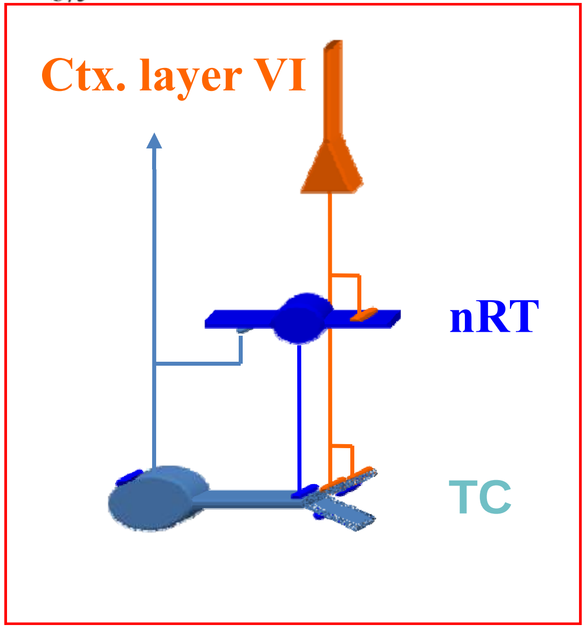
Spontaneous spindle activity

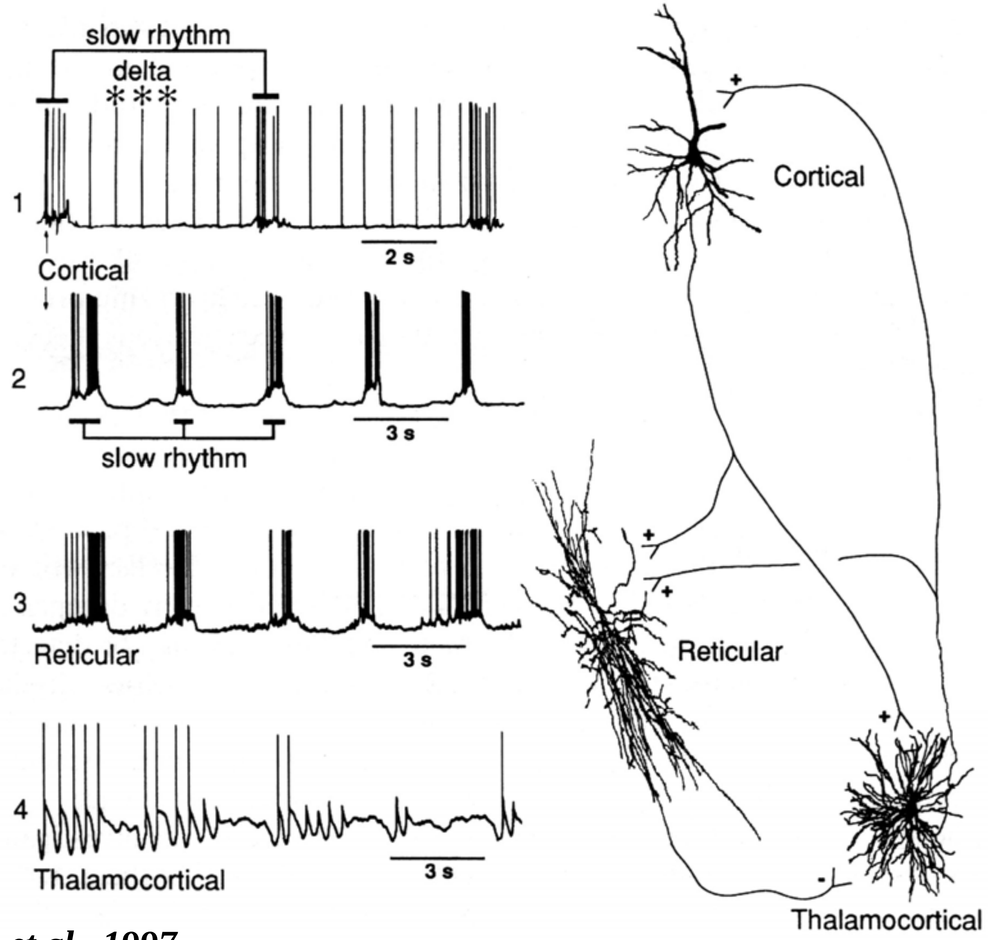
Correlated activity between:

- the EEG
- the cortical intracellular
- and the nRt extracellular events.

Contreras and Steriade, 1995

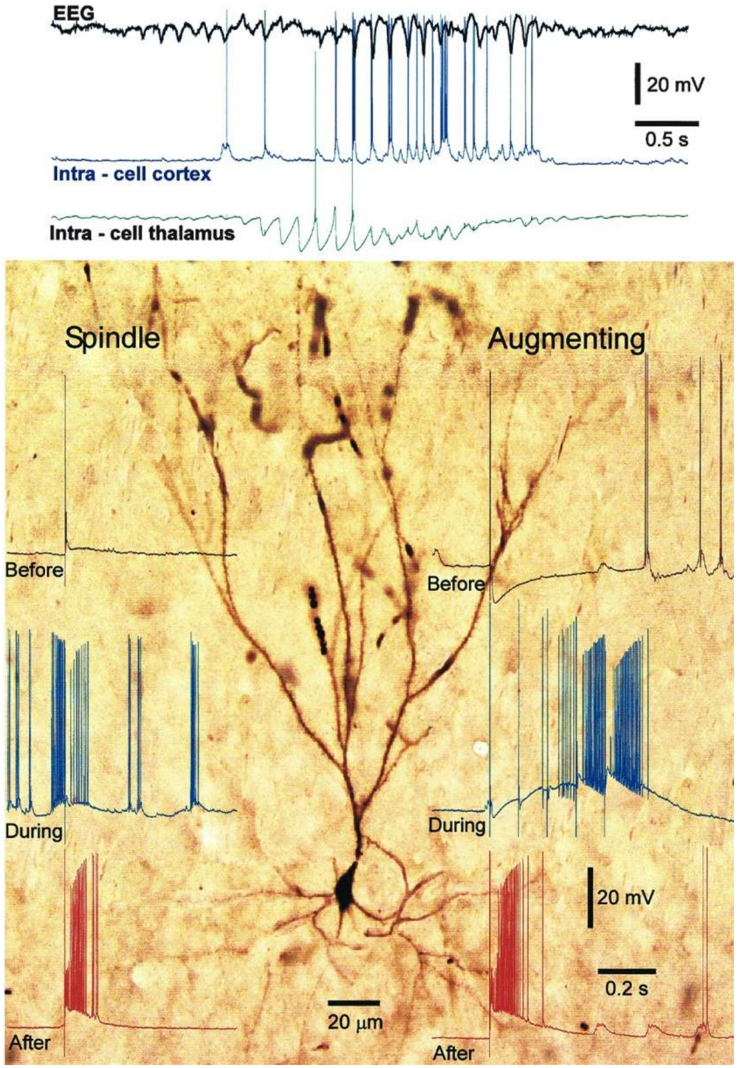
The thalamocortical circuit





The three, continuosly interacting cell types generate the thalamocortical oscillations extending to the whole brain.

Steriade et al., 1997



The cortical response is enhanced following stimulation of the thalamus or after spontaneous spindle activity

Intracellular recording from cortical fast spiking cells

Before stimulation/spindle **:**

In response to the cortical stimulation, the cellular response is an action potential

After stimulation/spindle:

In response to the cortical stimulation, the cellular response is an action potential train

Steriade 2004

SUMMARY

Accordingly to the sleep-wake cycle, the relay cells show tonic and burst activities.

Rhythmic burst activity may evolve merely due to the internal membrane characteristics of the relay cell.

Thalamocortical oscillation is realized by the interaction of the relay, the nRt and the corticothalamic cells.

The large amplitude rhythmic oscillations during sleep may play a role in long-term fixation of certain memory traces.