Neuroscience and Biobehavioral Reviews xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Review

The nonspecific thalamus: A place in a wedding bed for making memories last?

Anne Pereira de Vasconcelos*, Jean-Christophe Cassel

Laboratoire de Neurosciences Cognitives et Adaptatives, UMR 7364, Université de Strasbourg, CNRS, Faculté de Psychologie Neuropôle de Strasbourg – GDR CNRS 2905, 12 rue Goethe, F-67000 Strasbourg, France

ARTICLE INFO

Article history:
Received 28 July 2014
Received in revised form 11 October 2014
Accepted 23 October 2014
Available online xxx

Keywords:
Ascending reticular activating system (ARAS)
Intralaminar nuclei
Memory
Nonspecific thalamus
Reuniens nucleus
Rhomboid nucleus
Rapid eye movement (REM) sleep
Slow-wave sleep (SWS)
Systems-level consolidation
Thalamocortical synchrony
Thalamus core and matrix

ABSTRACT

We summarize anatomical, electrophysiological and behavioral evidence that the rostral intralaminar (ILN) and the reuniens and rhomboid (ReRh) nuclei that belong to the nonspecific thalamus, might be part of a hippocampo-cortico-thalamic network underlying consolidation of enduring declarative(-like) memories at systems level. The first part of this review describes the anatomical and functional organization of these thalamic nuclei. The second part presents the theoretical models supporting the active systems-level consolidation, a process that relies upon sleep specific field-potential oscillations occurring during both slow-wave sleep (SWS) and rapid eye movement (REM) sleep. The last part presents data in the rat showing that the lesion of the rostral ILN or of the ReRh specifically hinders the formation of remote spatial memories without affecting task acquisition or retrieval of a recent memory. These results showing a critical role of the ILN and ReRh nuclei in the transformation of a recent memory into a remote one are discussed in the context of their control of cortical arousal (ARAS) and of thalamo-cortico-thalamic synchronization.

Contents

Abbreviations: 3V, 3rd ventricle; 5HT, serotonin; ACg, anterior cingulate cortex; Ach, acetylcholine; AMPA, α-amino-3-hydroxy-5-methylisoazol-4-propionate acid; ARAS, ascending reticular activating system; BF, basal forebrain; CA, ammons' horn of the hippocampus (CA1, CA2, CA3); CAMKII, calcium calmodulin kinase II; CL, centrolateral nucleus; CM, centromedian nucleus; DA, dopamine; DNMTP, delayed nonmatching to place (or to position); EEG, electroencephalogram or electroencephalographic; fMRI, functional magnetic resonance imagery; GABA, gamma aminobutyric acid; Glu, glutamate; Hz, Herz; IAM, interoanteromedian nucleus; IL, infralimbic cortex; ILN, intralaminar nucleus; IMD, interomediodorsal nucleus; LDTg, Laterodorsal tegmental nucleus; LTP, long term potentiation; LTD, long term depression; MD, mediodorsal thalamus; MFB, medial forebrain bundle; MEG, magnetoencelography; mPFC, medial prefrontal cortex; mRNA, messenger ribonucleic acid; mol, stratum moleculare; MRF, mesencephalic reticular formation; NMDA(R), N-methyl-D-aspartate (receptor); PC, paracentral nucleus; PET, positon emission tomography; Pf, parafascicular nucleus; PGO, ponto-geniculo-occipital waves; PKA, protein kinase A; PPTg, pedunculo-pontine nucleus; PT, paratenial nucleus; PV, paraventricular nucleus; PL, prelimbic cortex; pRe, perireuniens nucleus; Re, reuniens nucleus; REM, rapid eye movement; Rh, rhomboid nucleus; RTN, reticular nucleus; STDP, spike-time-dependent plasticity; SWS, slow-wave sleep; SubCD, subcoeruleus nucleus dorsalis; TC, thalamocortical.

* Corresponding author at: Laboratoire de Neurosciences Cognitives et Adaptatives, UMR 7364 Université de Strasbourg-CNRS, Faculté de Psychologie, 12 rue Goethe, F-67000 Strasbourg, France. Tel.: +33 3 68 85 19 71; fax: +33 3 68 85 19 58.
E-mail address: pereira@unistra.fr (A. Pereira de Vasconcelos).

http://dx.doi.org/10.1016/j.neubiorev.2014.10.021
0149-7634/

1. Introduction

1.1. The nonspecific thalamus: what is it about?

The 'specificity' vs. 'nonspecificity' dichotomy in the classification of the thalamic nuclei derives from a proposal initially made on the basis of neuroanatomical arguments. Analysis of Golgi-impregnated brain tissue demonstrated two patterns of laminar organization of thalamocortical (TC) projections. First, fibers projecting densely in layer IV of restricted cortical targets were said to come from specific nuclei. Second, fibers reaching layer I with sparse termination fields distributed over widespread cortical areas were said to arise from nonspecific nuclei (Lorente de No, 1938; rev Bentivoglio et al., 1991). Thus, the term 'specificity' conveyed the idea of limited cortical innervation territories, 'nonspecificity' that of dispersed ones. Soon thereafter, electrophysiological characteristics of thalamic nuclei provided a further argument in favor of this dichotomy: high frequency stimulation of nuclei labeled as nonspecific led to desynchronization of the cortical EEG and concomitantly elicited arousal. In addition, their repetitive low-frequency stimulation produced 'recruiting' responses over an extended cortical territory, and these were associated with inattention, drowsiness and sleep. At the opposite, low-frequency stimulation of specific thalamus nuclei (e.g., sensory relay nuclei) elicited increasing short-latency responses that were well-restricted to the cortical target to which these nuclei projected (Dempsey and Morison, 1942; Morison and Dempsey, 1942; Moruzzi and Magoun, 1949). Moruzzi and Magoun (1949) suggested that the neurons of the intralaminar thalamic nuclei (ILN) were part of an ascending pathway that originated in the midbrain reticular formation (MRF). Their argument was that electrical stimulation of the MRF and the central thalamus desynchronized the slow large-amplitude waves of EEG activity in anesthetized cats. Confirmation of this anatomical pathway going from MRF to the central thalamus (specifically rostral ILN/median dorsalis) was later provided by detailed electrophysiological studies in cats (e.g., Steriade and Glenn, 1982). This recruiting type of response could be elicited from the medial region of the thalamus including the thalamic reticular nucleus, structures situated at the midline (central medial and ventral), the rostral and caudal ILN, medial and rostral parts of the ventral complex, and a posterior thalamic region bordered by the medial geniculate, the ventrobasal complex and the pulvinar (rev Bentivoglio et al., 1991,1997; Groenewegen and Berendse, 1994). Diffuse cortical activation by ILN thalamocortical nuclei was later confirmed using voltage-sensitive dye imaging in slices (Llinas et al., 2002). The glutamatergic neurons of all these nuclei exert influences on widespread cortical and subcortical targets and are a critical component of the ascending reticular arousal system (ARAS) underlying arousal and sensory awareness (Jones, 2003, see Section 2.2).

Despite these arguments, the concept of a nonspecific thalamus as a critical relay of an arousing system originating in the MRF, projecting diffusely to the cerebral cortex, and representing a homogeneous group within the thalamus was challenged later on (rev Bentivoglio et al., 1991; Groenewegen and Berendse, 1994). The development of more sensitive neuroanatomical tracing techniques allowed to show that the midline and intralaminar nuclei received distinct inputs from the brainstem (Krout et al., 2002) and projected to specific cortical targets – predominantly in the frontal areas (Bentivoglio et al., 1991; Hsu and Price, 2007; Van Der Werf et al., 2002) and striatum (Lacey et al., 2007), with each individual nucleus having restricted cortical fields of termination that only slightly overlapped with those of the adjacent nucleus. For example, the rostral ILN project to prefrontal cortical association areas and the posterior part of the parietal cortex, whereas the caudal ILN project to motor and premotor cortical areas in the frontal lobe and to the anterior part of the parietal cortex. Groenewegen and Berendse (1994) therefore divided the ILN into a rostral group [encompassing the centromedian (CM), paracentral (PC), and centrolateral (CL) nuclei] and a caudal group [made of the centromedian-parafascicular (CM-Pf) complex], forming a rostrocaudal continuum. The midline thalamus was subdivided into a dorsal group [comprising the paraventricular (PV), paratenial (PT), and interomediodorsal (IMD) nuclei] and a ventral group [including the reuniens (Re) and rhomboid (Rh) nuclei]. Based on these anatomical relationships in combination with functional human and animal studies, Van Der Werf et al. (2002) proposed that these nuclei support a role in different aspects of arousal/awareness with (i) the dorsal midline group (PV, PT, IMD) contributing to viscerolimbic functions, (ii) the lateral group (CL, PC, anterior CM) to cognitive functions, (iii) the ventral midline group (Re, Rh, posterior

Please cite this article in press as: Pereira de Vasconcelos, A., Cassel, J.-C., The nonspecific thalamus: A place in a wedding bed for making memories last? Neurosci. Biobehav. Rev. (2014), http://dx.doi.org/10.1016/j.neubiorev.2014.10.021