Neuroscience and Biobehavioral Reviews xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

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

Review

The mediodorsal thalamus as a higher order thalamic relay nucleus important for learning and decision-making

Anna S. Mitchell*

Department of Experimental Psychology, University of Oxford, South Parks Road, Oxford OX1 3UD, United Kingdom

UNCORRECTED PROOF

ARTICLE INFO

Article history:
Received 1 June 2014
Received in revised form 21 February 2015
Accepted 1 March 2015
Available online xxx

Keywords:
Associative learning
Glutamate
Human
Macaque
Prefrontal cortex
Primate
Recognition memory
Reticular thalamus
Rodent

ABSTRACT

Recent evidence from monkey models of cognition shows that the magnocellular subdivision of the mediodorsal thalamus (MDmc) is more critical for learning new information than for retention of previously acquired information. Further, consistent evidence in animal models shows the mediodorsal thalamus (MD) contributes to adaptive decision-making. It is assumed that prefrontal cortex (PFC) and medial temporal lobes govern these cognitive processes so this evidence suggests that MD contributes a role in these cognitive processes too. Anatomically, the MD has extensive excitatory cortico-thalamo-cortical connections, especially with the PFC. MD also receives modulatory inputs from forebrain, midbrain and brainstem regions. It is suggested that the MD is a higher order thalamic relay of the PFC due to the dual cortico-thalamic inputs from layer V ('driver' inputs capable of transmitting a message) and layer VI ('modulator' inputs) of the PFC. Thus, the MD thalamic relay may support the transfer of information across the PFC via this indirect thalamic route. This review summarizes the current knowledge about the anatomy of MD as a higher order thalamic relay. It also reviews behavioral and electrophysiological studies in animals to consider how MD might support the transfer of information across the cortex during learning and decision-making. Current evidence suggests the MD is particularly important during rapid trial-by-trial associative learning and decision-making paradigms that involve multiple cognitive processes. Further studies need to consider the influence of the MD higher order relay to advance our knowledge about how the cortex processes higher order cognition.

© 2015 Published by Elsevier Ltd.

Contents

* Tel.: +44 01865 271358.
E-mail address: anna.mitchell@psy.ox.ac.uk

http://dx.doi.org/10.1016/j.neubiorev.2015.03.001
0149-7634/© 2015 Published by Elsevier Ltd.

1. Introduction

Q2 Typically it is believed that direct cortico-cortical connections in the brain convey detailed perceptual, sensorimotor and cognitive information, while it has been customary to think of the thalamus as a relay of sensory information to the cortex (Guillery and Sherman, 2002a; Jones, 2007; Sherman and Guillery, 2011). However, anatomical evidence shows that different thalamic nuclei have quite distinct anatomical connections with the cortex and therefore likely quite distinct functional relay roles. The mediodorsal thalamus (MD) is a thalamic relay that contributes to cognitive processes. For example, humans and animals with damage to the MD demonstrate problems with learning and decision-making. Yet it remains to be determined how the MD thalamic relay contributes to cognition via its distinct interconnections with the cortex.

Based on many anatomical studies, mainly from the visual and somatosensory neural networks of the brain, different thalamic relays and their characteristic properties and potential functions have been identified (Guillery, 1995; Sherman and Guillery, 1996, 2006, 2013). At least two types of thalamic relays have been proposed, 'first order thalamic relays' (e.g. the lateral geniculate nucleus), which relay sensory inputs from the periphery via ascending pathways to their interconnected cortical targets (Guillery, 1995), and 'higher order thalamic relays'. The 'higher order thalamic relays' (e.g. MD, and pulvinar) are reciprocally interconnected to the association cortex via cortico-thalamo-cortical connections (Guillery, 1995). Higher order thalamic relay nuclei receive very little, if any, sensory inputs. Instead their main 'driver' inputs are shown to originate from layer V of the cortex. These main 'driver' inputs are capable to relaying already processed cortical information onto other cortical areas. However, these cortical drivers represent a very small proportion of the inputs (possibly only 5%) that the higher order relays receive (Van Horn et al., 2000). Higher order thalamic relays also receive other cortical and subcortical inputs that have either an excitatory or modulatory function. These other 'modulator' signals include inputs from cortical layer VI, thalamic interneurons, the reticular thalamus, and other structures of the forebrain, midbrain and the brainstem (Rovo et al., 2012; Sherman and Guillery, 1996, 2002). The dual cortico-thalamic input to the MD from both layers V and VI of the PFC suggests that cortical input to the higher order thalamic relays regulates neural activity in a different way to that of the first order thalamic relays (Schwartz et al., 1991). In contrast, to the higher order thalamic relays, the main 'driver' input first order thalamic relays is from the periphery (i.e. for the lateral geniculate nucleus, this input is from the retina, despite it representing less than 10% of the total inputs received, Van Horn et al., 2000). The lateral geniculate nucleus (like higher order relays as well) also receives other inputs that have a modulatory function. These other 'modulator' signals to the lateral geniculate nucleus include inputs from cortical layer VI, thalamic interneurons, the reticular thalamus, and the brainstem. These additional signals are proposed to regulate what 'driver' signals get relayed to cortex (Sherman and Guillery, 1996, 2002).

How generalizable this proposed categorization of 'driver' and 'modulator' inputs is for all thalamic nuclei still remains to be investigated. For example, recent evidence from anatomical studies in rats suggests a lack of glutamatergic driver inputs from the cortex to the motor thalamus (Nakamura et al., 2014). Nonetheless, these proposals, based on extensive research of the visual and somatosensory systems of the brain, help to highlight that there are differing functional relay roles amongst the different thalamic nuclei (Theyel et al., 2010; Viaene et al., 2011a,b) (for review see Sherman and Guillery, 2013). Consequently, asking what signals are primarily responsible for driving thalamic relay neurons, how the other signals are modulating these relays, and investigating what messages these higher order thalamic relays are transmitting to influence the cortex is critical to understanding how the cortex is functioning (Sherman and Guillery, 2013). In relation to the MD, this endeavor is specific to beginning to understand its role in supporting the interconnected cortex during cognition.

In this review, I will provide an overview of the anatomy of the MD in the context of its proposed role as a 'higher order thalamic relay'. In addition, there will be a summary of the impact on behavior and cognition after damage in the MD. Evidence from humans, rodents, and primates will be discussed to show how the importance of investigating the effects of MD as a possible higher order thalamic relay may further develop our understanding about the role of the cortex in cognition. Further sections will then focus on the underlying mechanisms that might be involved in these MD–PFC interactions and consider how the MD as a higher order thalamic relay might be supporting cortical processing of information. These sections suggests ideas for some future work combining various neuroscience techniques that could lead to further causal evidence that helps develop our understanding of the MD higher order relay functions in cognition.

2. The MD as a higher order thalamic relay

Sherman and Guillery have proposed that some of the cortical inputs to thalamic nuclei that originate in layer V are referred to as 'driver' inputs and are capable of transmitting an already processed cortical message across other cortical areas depending on the characteristics of the glutamatergic receptors (Sherman and Guillery, 2006, 2013). These 'driver' inputs represent a very small minority of connections originating from the cortico-thalamic pathways (Van Horn and Sherman, 2007; Wang et al., 2002). Instead, the majority of these excitatory cortico-thalamic inputs are modulators coming from layer VI of cortex. The relay functions of the higher order thalamic relays may help support cortico-cortical communication via this trans-thalamic route of transmitting the received message from layer V onto other interconnected areas of the cortex (Guillery, 1995; Guillery and Sherman, 2002a; Jones, 1998, 2007; Schwartz et al., 1991; Sherman and Guillery, 2011). The MD is classified as a higher order thalamic relay based on the inputs from layer V of prefrontal cortex (Guillery, 1995; Sherman and Guillery, 2006). Xiao et al. (2009) showed that about 20% of the PFC projections terminating in the MD are from layer V, mainly from the dorsal and medial PFC areas. In addition to these driver inputs, MD also receives excitatory inputs from many other brain structures in the medial temporal lobes, and modulator inputs from the pallidum, the reticular thalamus, MD interneurons, midbrain and brainstem, all of which are summarized below (Kuroda and Price, 1991a,b; Sherman and Guillery, 1996). All of these modulator inputs, rather

Download English Version:

https://daneshyari.com/en/article/7303416

Download Persian Version:

https://daneshyari.com/article/7303416

Daneshyari.com