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Research Report

Differential modulation of thalamic neurons by optokinetic nuclei in the pigeon

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ABSTRACT

The visual system in the pigeon is composed of the tectofugal, thalamofugal and accessory optic pathways. Though their anatomy and physiology have been extensively studied, the functional interactions between these pathways are largely unknown. The present study shows by using multiple electrophysiological techniques that firing activity in the nucleus opticus principalis thalami (OPT) of the thalamofugal pathway is differentially modulated by the pretectal nucleus lentiformis mesencephali (nLM) and the nucleus of the basal optic root (nBOR) of the accessory optic system, two optokinetic nuclei responsible for generating eye movements to stabilize the image on the retina. Reversible inactivation, electrical stimulation, microiontophoresis and receptive field mapping experiments all consistently indicate that the nBOR-OPT pathway is inhibitory and mediated by GABA as a transmitter and its $GABA_A$ receptors, whereas the nLM-OPT pathway is excitatory and mediated by glutamate as a transmitter and its NMDA receptors. They also differentially modulate the size and/or responsiveness of receptive fields in OPT cells as well. Numerous electrode tip sites were histologically confirmed in the neural structures under study. The results suggest that these optokinetic nuclei may dually modulate the transfer of visual information from the retina to the telencephalon at the thalamic level during eye movements.

1. Introduction

The visual system in birds consists of the tectofugal, thalamofugal and accessory optic pathways, which are homologous to the colliculo-pulvinar-cortical, geniculocortical and accessory optic pathways in mammals, respectively (Karten, 1969; Shimizu and Bowers, 1999). The thalamofugal pathway in birds goes from the retina to the nucleus opticus principalis thalami (OPT) in the thalamus to the telencephalon; this thalamic nucleus is also designated as the nucleus geniculatus lateralis pars dorsalis (Gunturkun and Karten, 1991; Karten et al., 1973) and thought to be homologous to the lateral geniculate nucleus in mammals. Visual cells in the avian OPT are characterized by a large receptive field and selectivity for the direction and speed of object motion (Britto et al., 1975; Jassik-Gerschenfeld et al., 1976; Yang et al., 2005). In addition to afferents from other brain regions, OPT also receives inputs from the pretectal nucleus lentiformis mesencephali (nLM) and the nucleus of the basal optic root (nBOR) of the accessory optic system (Wild, 1989; Wylie et al., 1998), which are homologous to the nucleus of the optic tract and the terminal nuclei of the accessory optic

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tract in mammals, respectively (Fite, 1985; McKenna and Wallman, 1985). Both nLM and nBOR are involved in generating optokinetic nystagmus, an oculomotor reflex for stabilizing the image on the retina by slow-following and saccadic movements of the eyes (Gioanni et al., 1983, 1984; McKenna and Wallman, 1981). Optokinetic neurons are sensitive to the direction, speed and acceleration of visual motion (Cao et al., 2004; Crowder and Wylie, 2002; Frost et al., 1990; Fu et al., 1998; Wolf-Oberhollenzer and Kirschfeld, 1994; Zhang et al., 1999).

Though these visual pathways in birds have been extensively investigated anatomically and physiologically, their functional interactions are still largely unknown. The present study attempted to explore whether and how the accessory optic system would modulate the thalamofugal pathway in general and the optokinetic nuclei, nLM and nBOR, would modulate firing activity of OPT cells in particular, by using single unit recording, reversible inactivation, microiontophoresis, electrical stimulation and receptive field mapping techniques. In some experiments, the electrode tip sites for extracellular recording, drug injection and electrical stimulation were marked for their histological verification.

2. Results

The present study provided several lines of evidence that the nBOR-OPT pathway in pigeons is inhibitory, whereas the nLM-OPT pathway is excitatory, and these pathways differentially modulate visual activity in OPT cells. Its main findings are described in two parts as follows. The first part contained 144 OPT cells that were examined for firing activity modification by pharmacological manipulations of nBOR and nLM; the second part included 36 OPT cells that were examined for receptive field modification by these manipulations. Finally, 44 electrode tip sites for recording, drug application and electrical stimulation were marked with either dye staining or electrolytic lesion to histologically verify their locations in these structures.

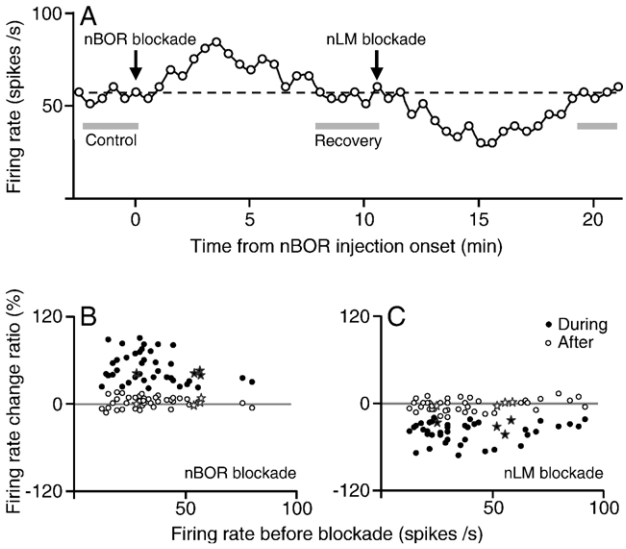

Fig. 2 – Afferents from nBOR and nLM converge onto the same OPT neurons. Visual responses of an OPT cell were increased by nBOR blockade (lidocaine, 90 nl) and then decreased by nLM blockade (GABA, 90 nl) (A). Three repeats are averaged. Statistical analysis of 43 OPT cells in each of two groups shows the change ratio of firing rate (see the Experimental procedures) during (solid symbols) and after (empty ones) blockade of activity in nBOR (B) and nLM (C), indicating that firing rate in these cells were significantly increased by nBOR blockade and decreased by nLM blockade, and the firing activity returned to normal after blockade. Stars represent four OPT cells showing convergence of nBOR and nLM inputs on the same OPT cells examined as in panel A.

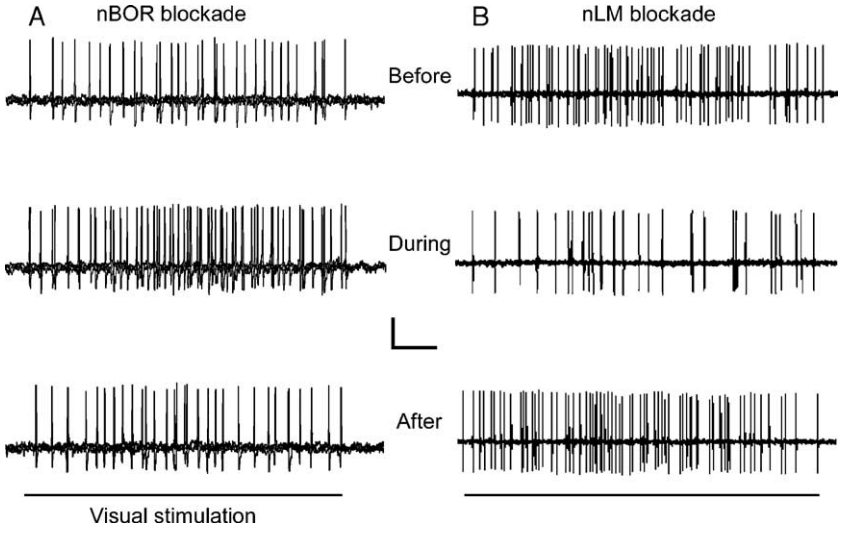

Fig. 1 – Changes in visual responses of two OPT neurons before, during and after blockade of activity in nBOR and nLM. The firing rate of cell A was increased by 48% during nBOR blockade by lidocaine (90 nl), whereas that of cell B decreased by 47% during nLM blockade by GABA (90 nl). Their firing rates were recovered to control values 5–8 min after blockade. Horizontal lines symbolize duration of visual stimulation. Three repeats were superimposed. Scales: 100 ms, 50 μV.