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The Pulvinar Thalamic Nucleus of Non-Human Primates: Architectonic and Functional Subdivisions

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Chapter 10
Modulation of Pulvinar Neuronal Activity by Arousal

In contrast to electrophysiological recordings in the early visual cortex, neuronal activity in the pulvinar is particularly sensitive to anesthesia. Accordingly, under deeper levels of anesthesia, Gattass et al. (1978b) were unable to obtain consistent physiological responses in the pulvinar of the capuchin monkey. Anesthesia level was accessed, for example, by EEG recording in the parieto-occipital region, which typically displayed slow-wave oscillatory patterns associated with drowsiness or initial stages of sleep. In the absence of intentional sensory stimulation, pulvinar neurons could be characterized by spontaneous low-frequency rhythmic bursts of spiking activity. However, multisensory stimulation capable of arousing the animal from deeper anesthesia levels could reestablish the necessary neuronal dynamics and switch the pulvinar into an active state. Under these conditions, cortical slow-wave activity was substituted by a higher-frequency oscillatory pattern associated with arousal. Two types of transitions in pulvinar activity pattern could be observed when arousing the animal with multisensory stimulation (e.g., somatosensory or auditory stimulation). The first type consisted in a profound shift in neuronal firing pattern where, after either somatosensory or auditory stimulation, pulvinar single units changed their dynamics from low-frequency rhythmic activity to higher-frequency rhythmic activity (Fig. 10.1). Note that the interspike interval (ISI) distribution that arises during epochs of multisensory stimulation is compatible with the induction of gamma oscillations (~40 Hz) for the single unit being recorded. Neurons undergoing this type of transition appeared to respond exclusively to visual stimuli, despite the fact that stimulation with other sensory modalities influenced their activity. For example, there was a clear temporal relationship between stimulation onset and neuronal activity for visual stimulation, but not for stimuli of other sensory modalities.

The second type of state transition taking place in the pulvinar affected solely the firing rate level of the neurons instead of their firing pattern and generally required more than one modality of sensory stimulation (Figs. 10.2 and 10.3). Typically, these units exhibited fatigue and habituation for sensory modalities other than the

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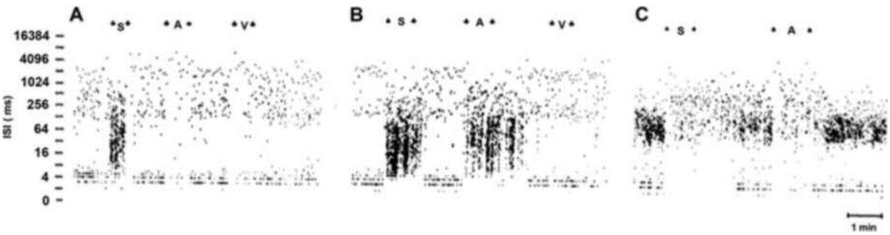

Fig. 10.1 Multisensory stimulation induces change in firing rhythmicity of pulvinar neurons. (**a**), (**b**) and (**c**) show three single units recorded in P1. The single unit depicted in (**a**) increases its firing rate and changes its oscillatory pattern during somatosensory stimulation, but decreases its firing rate during auditory and visual stimulation. The single unit depicted in (**b**) increases its firing rate and changes its oscillatory pattern during somatosensory and auditory stimulation, but decreases its firing rate during visual stimulation. The single unit depicted in (**c**) desynchronizes to somatosensory and auditory stimulation. The firing rate is decreased during stimulation. (Modified from Gattass et al. 1979)

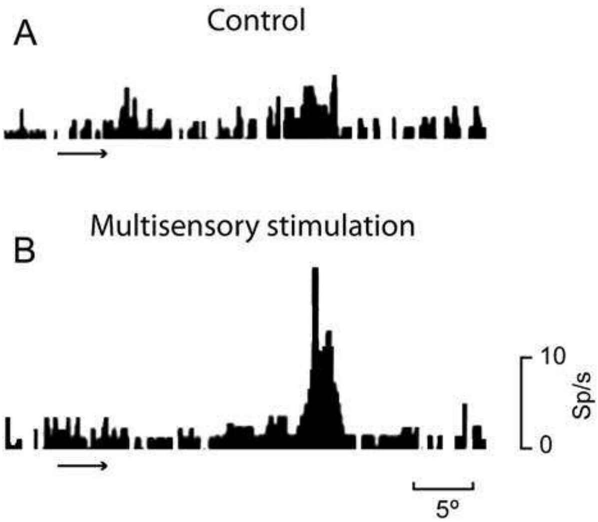

Fig. 10.2 Multisensory stimulation enhances visual responses recorded from a P1 single unit (Group 2 neuron). Visual responses to a moving full slit stimulus (2° wide) are represented in PSTHs before (**a**) and during (**b**) somatic-auditory stimulation. Prior to multisensory stimulation (**a**), the single unit exhibited a rhythmic-cyclic pattern of neuronal activity. Subsequently, when the animal was aroused by multisensory stimulation, the single unit becomes more responsive to the visual stimulation and starts to exhibit direction selectivity. (Modified from Gattass et al. 1979)

visual. Contrary to the pulvinar neurons undergoing the first type of transition, most of these units appeared to be de facto multisensory in a way that they were sensitive to visual, somatic, auditory, and olfactory features of the stimulus. Effective somatosensory stimulation could consist in stimuli applied over a large area of

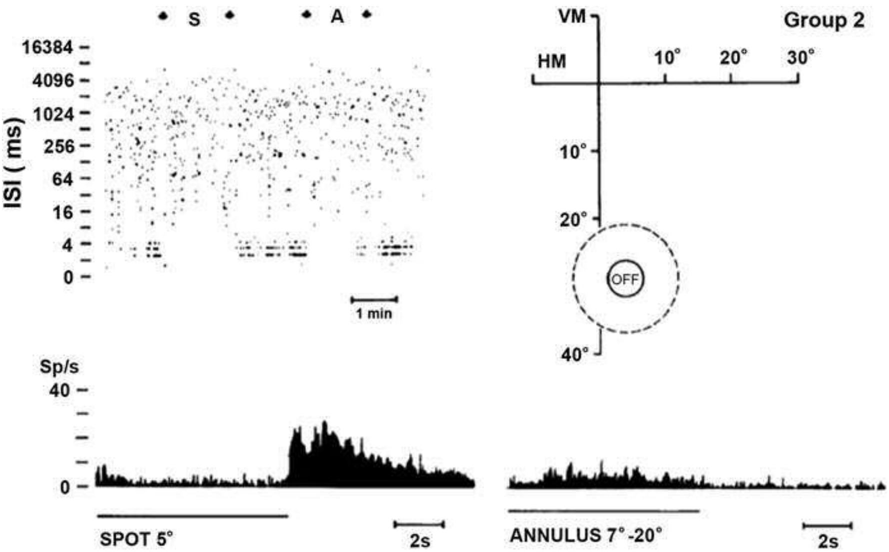

Fig. 10.3 Effect of multisensory stimulation on the visual responses of a single unit recorded in P1 (Group 2). Interspike interval values (ISI, plotted in logarithmic scale) as a function of time (X-axis, linear scale) reveal the rhythmicity of the neuron before, during and after somatosensory (S) and auditory (A) stimulations (Upper left panel, stimulation intervals delimitated by arrows). Each dot represents one spike event. The rhythmicity of the single unit changes from a burst activity, separated by long intervals, to a more homogenous firing. Burst activity shows interspike intervals ranging from 1 to 4 ms, separated by intervals ranging from 10 to 6000 ms. Somatosensory and auditory stimulation prompts the cell to lose its low-frequency rhythmic burst pattern. Note that this unit responds to the static presentation of a bright 5° circle with an OFF sustained response (lower left panel). Stimulation with a bright annulus reveals a poor ON-response (lower right panel). (Modified from Gattass et al. 1979)

the contralateral body surface. Occasionally, ipsilateral stimulation of the fore and hind limb extremities was effective. Flickering or diffuse light was effective as arousing visual stimuli. Finally, complex natural auditory stimuli appeared more effective than pure tones or clicks, despite the fact that we did not seek to parameterize the optimal arousing stimuli.

If it is indeed the case that the pulvinar is highly dependent on arousal levels in order to function adequately, it is reasonable to speculate that the pulvinar itself might be important to “awaken” the cortex (Zhou et al. 2016), especially due to the rich cortico-pulvinar anatomical interconnection. There is evidence that certain types of arousal phenomena, such allocating expectation in time, are capable of activating large portions of the visual cortex (Lima et al. 2011). The pulvinar may thereby function to promote coordinated arousal of large cortical networks.

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