BOLD activity induced by thalamic and cortical microstimulation in behaving monkeys

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Abstract: The pulvinar nucleus, the largest thalamic nucleus in primates, is reciprocally connected with an extensive array of cortical areas including strong anatomical connections with the lateral intraparietal area (LIP). Using the combination of event-related BOLD fMRI and electrical microstimulation we found strong overlap between the effective connectivity patterns of the pulvinar and LIP, identifying the pulvinar as a functional node of an extensive cortical and subcortical network involved in spatial attention and visuomotor planning of eye movements.

Zusammenfassung: Der Pulvinar, der größte thalamische Nucleus der Primaten, hat reziproke anatomische Verbindungen zu zahlreichen kortikalen Hirnregionen, darunter auch das laterale intraparietale Areal (LIP). Mit der Kombination von ereigniskorrelierter BOLD-fMRT und elektrischer Mikrostimulation konnten wir große Gemeinsamkeiten zwischen der funktionellen Konnektivität von Pulvinar und LIP finden und somit den Pulvinar als wichtigen Knotenpunkt des funktionellen Hirnnetzwerkes identifizieren, das eine wichtige Rolle bei räumlicher Aufmerksamkeit und visuomotorischer Planung Augenbewegungen spielt.

Motivation

The pulvinar nucleus is reciprocally connected with an extensive array of cortical areas. The dorsal portion of the pulvinar (dPul) has strong connections with higher association cortices in frontal, temporal, and parietal lobe (1–2) including area LIP (3), which is an important node of an extensive cortical and subcortical network involved in spatial attention and visuomotor planning of eye movements (4–5). In contrast, the ventral portion of the pulvinar receives its main cortical inputs from primary and early extrastriate visual cortex (1–2). However, the functional specificity of pulvinar-cortical connections is not understood.

Materials and Methods

Two male rhesus monkeys performed either an eye fixation task or a memory-guided saccade task in the scanner (Fig. 1) while in half of the trials we electrically stimulated either the dPul or the dorsal portion of area LIP (LIPd, Fig. 2). In both regions we stimulated a more anterior and a more posterior site

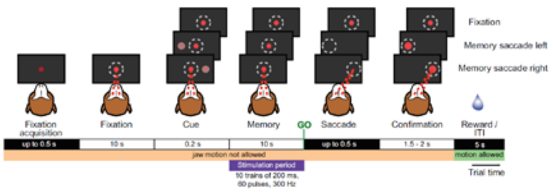

Fig. 1: Long event-related fMRI design of the memory-guided saccade task and the fixation task. In half of the trials we electrically stimulated the pulvinar or area LIP.

Stimulation was delivered during the 10 s memory period of the saccade task or during the corresponding time window of the fixation task (200 ms trains of biphasic pulses with a frequency of 300 Hz, 200-250 µA, 10 trains, 1 train per second).

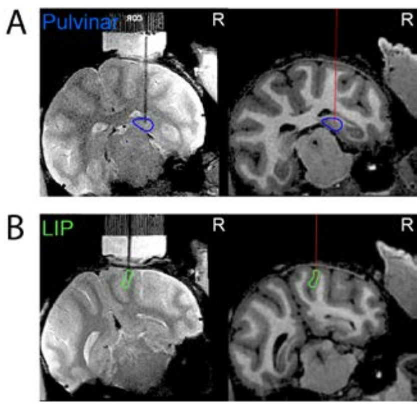

Fig. 2: Electrode localization in an example session of (A) dPul stimulation and (B) LIP stimulation. Left panel: T2-weighted images with the slice package aligned to the vertical axis of the recording chamber. Right panel: T1-weighted image aligned to the T2-weighted image with the reconstructed electrode positions.

Results

Electrical microstimulation of dPul consistently activated a cortical functional network comprising dorsolateral and ventrolateral prefrontal cortex including the frontal eye field (FEF), dorsal and ventral premotor cortex, the dorsal and the ventral bank and the fundus of the superior temporal sulcus (*sts*) as well as posterior parietal cortex (PPC), posterior cingulate cortex (PCC), insular cortex, somatosensory areas, and primary and extrastriate visual cortex (see Fig. 3A).

A similar cortical effective connectivity pattern was found for LIPd with consistent activation in dorsolateral prefrontal cortex (dlPFC), FEF, the dorsal bank and the fundus of the *sts*, widespread activity along the intraparietal sulcus in PPC, and functional connections with PCC, somatosensory areas, and primary and extrastriate visual cortex (see Fig. 3B).

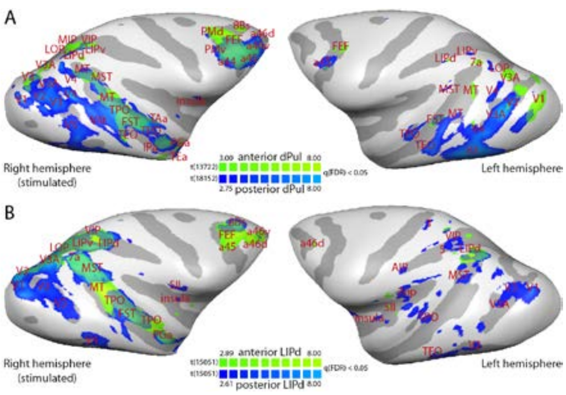

Fig. 3: Statistical t maps showing BOLD activation on the inflated brain surface of one animal during unilateral electrical stimulation of (A) dPul and (B) LIPd.

Importantly, stimulation-induced BOLD activation was not restricted to the stimulated hemisphere but unilateral stimulation also activated various brain regions in the opposite hemisphere.

Discussion

The effective connectivity patterns of dPul and LIP mainly correspond to each region's anatomical connectivity known from histological studies (1–3). We identified dlPFC, FEF, the dorsal bank and the fundus of the *sts*, PPC, PCC, somatosensory areas, and primary and extrastriate visual cortex as the common nodes of the functional networks of dPul and LIP. The similarity between the effective connectivity patterns of dPul and LIPd provides evidence that dPul plays a functional role in the brain network involved in visuospatial attention and visuomotor processing (4–5). Unilateral microstimulation of both dPul and LIP also activated various brain regions in the opposite hemisphere, strongly indicating polysynaptic transmission of the stimulation-induced neuronal signals (6).

Summary

The dorsal pulvinar and area LIP share a functional network comprising dlPFC, FEF, the dorsal bank and the fundus of *sts*, PPC, PCC, somatosensory areas, and primary and extrastriate visual cortex providing evidence that the pulvinar plays a functional role in the brain network involved in visuospatial attention and visuomotor processing. Importantly, neuronal activity induced by electrical microstimulation was transmitted monosynaptically as well as polysynaptically.

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