Motor Related Neuronal Activity in the Cerebellar Thalamus

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Introduction

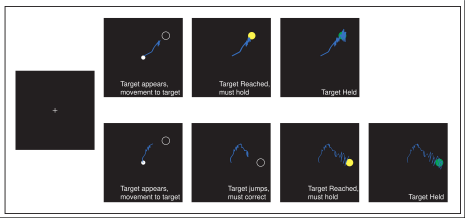
The ventral intermediate nucleus of the thalamus (VIM) serves as a key link between the cerebellum and the motor cortex; however, the fundamental properties of neurons in this thalamic relay are not fully understood. Anatomically, the VIM connects the cerebellum to primary and supplementary motor cortices. Certain features, such classical direction tuning, have been demonstrated in the vast majority of motor areas including cerebellum and cortex but have not been previously reported in VIM.

Methods

We obtained VIM single neuron recordings from 6 essential tremor patients during DBS electrode implant surgery. Waveforms surpassing a voltage threshold were sampled at 40 kHz and sorted using principal components. During recording, patients performed an 8-direction "center-out" task using a joystick to move a cursor to a target positioned around a circle. On some trials, the target jumped to a new location just after movement onset. Statistical significance for all findings was determined by comparing empirical values to a null distribution generated using non-parametric bootstrap methods.

Figure 1: Center-Out Task

The task is designed to test how VIM responds to movement and visual cues. Six patients performed 1–4 sessions each of an 8-location center-out movement task, in which they moved a joystick to manipulate a cursor toward a target. On some trials, the target changed position as they began to move, requiring a movement correction.

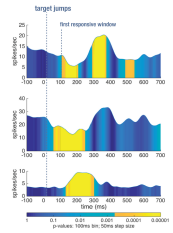


Results

Each neuron was tested for task-related responsiveness by comparing baseline firing rates to firing rates cued to specific task-related events. Of 59 neurons recorded, ~50 percent responded to at least one task-related visual cue or motor event. Multiple subsets of responses were categorized, including responses selective for visual cues or motor events. Other neurons demonstrated similar responses to both visual and motor events, suggesting that these neurons may be involved in visual motor transformation. Approximately 20 percent of all neurons exhibited classical directional tuning. A small subgroup of neurons responded significantly more to the appearance of a "jumped" target and the associated movement correction. These neurons may be directly related to the transmission of a motor error correction signal.

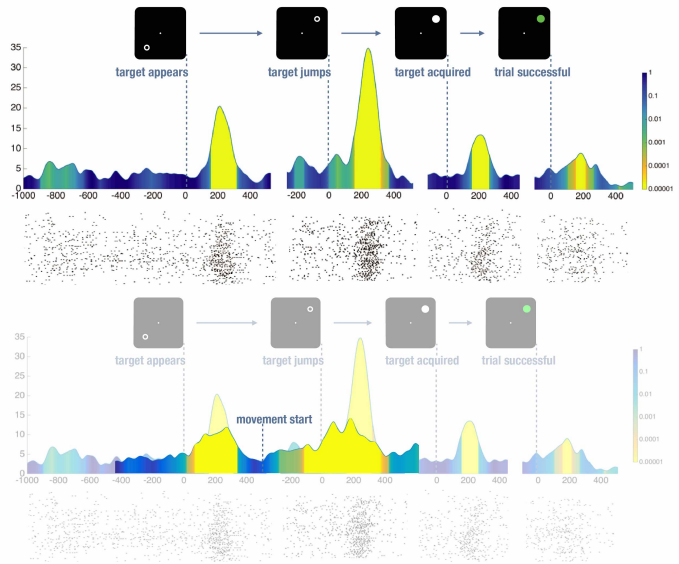
Figure 2: Movement related neuronal activity

Responsive To:	Single units (n)	Percent of total n
Target appearance	17	25.0
Target jump	21	30.9
Movement start	17	25.0
Movement correction	11	16.2
Any of the above	36	52.9



Unit responses were aligned to behavioral cues on each trial. Spike rates were smoothed with a Gaussian kernel and significance was calculated with rate comparisons between bins in different epochs. In all panels, yellow/orange colors denote significance ($p < 0.001$). In all, neurons responded significantly to a number of visual and motor cues (left, table). Three neurons are shown (right) with significant changes in spike rates associated with the target jump.

Figure 3: Visual responses



Significant increases in spike rate for this single unit to multiple visual cues. The same neuron's spike rates aligned to the movement show less strongly active—though still significant—responses.

Figure 4: Visuomotor responses

Examples of similar responses for two cells to both the target appearance and start of movement.

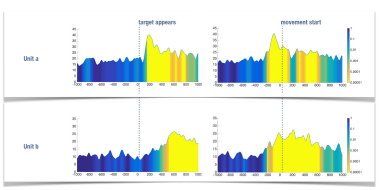
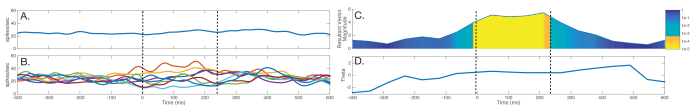
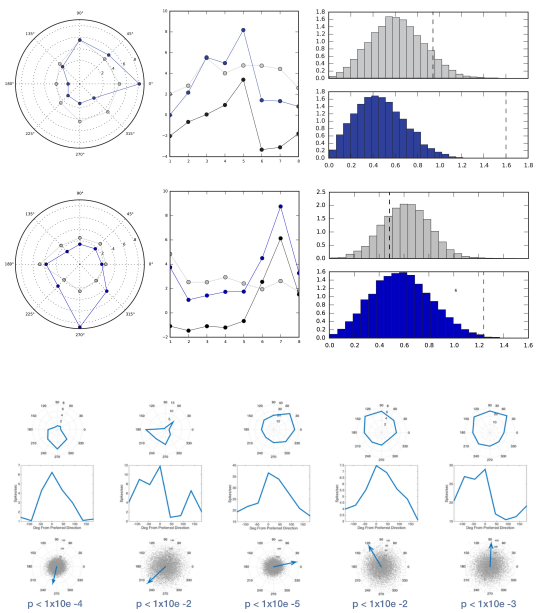


Figure 5: Direction tuning in VIM neurons

Spike rates for a single unit (A) do not appear to show any movement-related modulation until (B) separated by direction, for which the spiking in the preferred direction was (C) significant, and (D) the preferred phase of spiking was constant.



Example cells during movement (blue) and pre-movement (gray). Left panels are polar plots of mean spike rates for each direction. Middle pannels show spike rate as a function of direction, with the difference shown (black). Aggregate vector amplitude was calculated from all trials. A bootstrap resampling ($N=10^4$) recalculated vector amplitudes using shuffled directions with spike rates to generate a null distribution. The empirical amplitudes are noted by the dotted lines and were not significantly different from the null for the pre-movement period. The empirical amplitudes for movement were significantly larger than the null ($p < 1e\text{-}3$, Benjamini-Hochberg corrected).



Conclusions

VIM neurons were actively engaged by this joystick movement task, and many were tuned to the direction of movement. Several also selectively responded to corrections of movement, supporting a role for the VIM in conveying alterations in motor plans from the cerebellum to the cortex.

Acknowledgements

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