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The origin of the frequency selectivity in VOR motor learning revealed by a realistic cerebellar spiking neuron network model

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The vestibuloocular reflex (VOR) counter rotates the eyes in the orbit during head rotation to obtain stable vision. It has been a popular model system to investigate cerebellar motor learning. The gain of the VOR (eye velocity / head velocity) can be modified by giving visual stimuli in- or out-of-phase with vestibular stimuli to the subject [1]. It has been shown that VOR motor learning exhibits frequency selectivity. Namely, the greatest gain change occurs at the frequency used for training, and less changes at frequencies further from the training frequency [2,3]. Existence of multiple frequency channels to process different frequency bands has been proposed to explain this phenomenon, although corresponding neuronal circuitries have not been identified anatomically or physiologically. In support of the multiple frequency channels for the VOR, it has been demonstrated that VOR gains can be changed differentially at 2 different frequencies simultaneously (ex. gain decrease at 0.05 Hz and gain increase at 2.5 Hz) in squirrel monkeys [4] and goldfish [5].

Methods

In the present study, we investigated the neural origin of the frequency selectivity in VOR motor learning by using a realistic mathematical model of the VOR in which cerebellar cortical neuronal circuitry is explicitly composed by spiking neuron models of granule, Golgi, basket/stellate, and Purkinje cells. The parallel fiber-Purkinje cell synaptic plasticity (both LTD [6] and LTP [7]) induced by climbing fiber input is implemented in the model. The model was constructed by revising our previous model [8] to be more physiologically plausible.

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Conclusion

When the model was trained at 0.5Hz, frequency selectivity similar to that observed in the behavioral experiment [3] emerged after both gain decrease and increase trainings. Analyses of the model properties before and after the VOR trainings revealed that the cerebellar circuitry formed band-pass filters in response to vestibular and/or efference copy of eye movement signals after the trainings. The results suggest that the apparent multiple frequency channels in the VOR neuronal pathway are implicitly composed in the cerebellar cortical neuronal circuitry as band-pass filters for vestibular and/or efference copy of eye movement signals that are formed by the cerebellar synaptic plasticity.

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