Title	Effect of adaptive coupling on enhancement of cerebellar learning
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Citation	
Issue Date	2011-09
Type	Thesis or Dissertation
Text version	author
URL	http://hdl.handle.net/10119/9934
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Description	Supervisor: Associate Professor Masashi Unoki, 情報科学研究科, 修士

Effect of adaptive coupling on enhancement of cerebellar learning

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August 10, 2011

Keywords: cerebellum, inferior olive, synchronization, chaotic resonance.

Among cellular components of the cerebellum, Purkinje cells (PC) form the heart of the cerebellar learning because they provide the only output of the cerebellar cortex. Purkinje cells receive two types of excitatory inputs: (i) about 200,000 parallel fiber from Granule cells, and (ii) a sole but powerful climbing fiber, which is an axon from an inferior olive neuron, that has been shown to transmit error signal. When conjointly activated at Purkinje cell synapses, these two inputs cause long term depression (LTD) that decreases the influence of the parallel fiber-PC synapse transmission. LTD has been shown to be very important in cerebellar learning. Although the physiology of inferior olive has been clearly explored, the effect of the coupling on error transmission from inferior olive is still an open question: how the IO transmits error signals at high temporal resolution despite its low firing rates?

To tackle this problem, the hypothesis of chaotic resonance was proposed in which IO neurons are coupled via gap junctions to induce irregular or even chaotic firing activities. Tokuda *et al* found that an intermediate coupling strength between IO neurons could enhance error transmission from IO, and thus to enhance the cerebellar learning. However, this study has no consideration on how the optimal coupling is realized in the real IOs. Recently, the idea of controlling coupling between IO neurons in two phases of learning is hypothesized by Kawato *et al* as follows. In the early stage of learning, coupled IO neurons and its innervated PCs should have strongly and synchronously firing activities in order to modulate motor commands quickly, since the error signals are large. By contrast, in the late stage of learning, because the learning is smooth and the error signals are small, IO cells and innervated PCs are asynchronously fire to realize sophisticated learning. As a summary, in the early stage of learning, strong synchronization is useful while weak or desynchronization might be beneficial in the late learning phase.

Hence, purpose of the thesis is to propose a cerebellar model, which physiologically controls the coupling of IO neurons in two phases of learning. To simplify the approach, we firstly use two simple adaptive patterns to check whether adaptive coupling could realize an efficient learning than fixed coupling. In order to evaluate these adaptive patterns, feedback error learning is implemented as a simulation of multi-joint human arm control. Moreover, IO activities are also observed by these two mechanisms: mutual information measures information transmission from IO, since synchronization index detects synchronous activities of a population of IO cells.

Next, since there are some anatomical evidences show that cerebellar nucleus send GABAergic input to control electrical coupling between IO cells, the thesis proposes a computational model of Purkinje cell-cerebellar nucleus-inferior olive circuit for optimally controlling the coupling between inferior olive neurons based on the following scenario. Initially, the PF-PC synapses are relatively strong (before LTD), which activate the PC. This makes the inhibitory effects from PC to cerebellar nuclei strong and thus the CN activity is weak. The weak CN activates the IO, since the inhibitory effect from CN to IO is weak. As a consequence, the firing rate of the IO is high, making the coupling strength of the IO strong. As the learning proceeds, the opposite situation takes place that makes the IO coupling weak and converges to a possibly optimal value.

Results from our experimental simulations show advantages of adaptive patterns compared with fixed coupling $g = 0.05$, which has been shown to minimize learning error in previous study of Tokuda *et al.* Not only the final error but also the quick decay of error can be obtained. Moreover, the two observations of mutual information and synchronization index also support interpretation of significant enhancements of two-phase learning. In the early stage, synchronously coupled IO cells could correct motor commands quickly despite its poorly information transmission. In the contrary, weakly coupled IO neurons could convey much information in the late phase of sophisticated learning.

As a conclusion, we could state that adaptive coupling could enhance two-phase learning of the cerebellum and the triangle closed circuit of PC-CN-IO provides a novel approach for optimally control the coupling between IO cells.