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Anticipative adaptive muscle control: forward modeling with self-induced disturbances and recruitment

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A motor system must be able to adapt to perturbations in a fast and robust way. Additionally, in the long run learning leads to motor skills which, for example, allow humans to move the forearm with varying speeds. A generally excepted view on motor learning includes forward models that are generated on top of an existing control loop provided by reflexes. Through closed-loop feedback control a much improved motion sequence "without thinking" can be executed and later be adapted to changes in the environment. In this study we show that it is possible to combine temporal sequence learning with compliant joints and antagonistic muscle control to learn a forward model of a reflex.

We also show that the model is executed with the required strength, which depends on self-induced perturbations or external forces. Here self-induced perturbation means, for example, the change of torque by accelerating the forearm. For this purpose we apply a learning rule paired with recruitment which we have recently introduced. The rule correlates the mono-synaptic reflex loop provided by each muscle with an anticipative control signal which is used to move the upper arm segment of a two-joint arm. Without learning the deviation is compensated after some delay. After learning the antagonistic muscle pair stiffens and immediately reacts to the self-induced disturbance with the required muscle force. With this simple recruitment mechanism it is also possible to compensate different forces, caused by varying upper arm accelerations, without delay and re-learning. This kind of learning creates a forward model of the already existing mono-synaptic feedback loop and we are able to show that applying learning with recruitment to a compliant motor control structure quickly compensates self-induced disturbance.

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