Comment

How to distinguish between referent configuration and internal models hypotheses of motor control?
Comment on "Laws of nature that define biological action and perception" by Boris I. Prilutsky

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In his review [1], Mark Latash provided a description of the referent configuration hypothesis of motor control (RC-hypothesis), a generalized version of the lambda-model of the equilibrium point hypothesis [2, 3], using a physical approach to biological functions. Namely, he framed the actions in motor control and perception as processes resulting from active control of parameters (i.e., muscle length thresholds of tonic stretch reflex) of a biology-specific law of nature – the tonic stretch reflex; see also [2]. The RC-hypothesis offers an elegant solution to the extremely complex problem of movement control of animal multi-segmented bodies. According to the RC-hypothesis, the nervous system does not compute the numerous variables of planned movements (muscle forces, joint angles, limb endpoint trajectory); rather, it simply shifts the equilibrium (referent) configuration of the limb (or changes stretch reflex muscle length thresholds) to a new location, and limb moves to the new configuration due to reflex-evoked muscle activities; e.g. [4]. The RC-hypothesis is based on solid foundation in physics and neurophysiology and has been able to account for a large body of experimental evidence [1, 5, 6]. Roboticists also have recognized the advantages of this type of movement control of multi-segment mechanical systems; e.g. [7]. Yet, the RC-hypothesis still is not commonly recognized as the primary hypothesis of motor control. The internal models/optimal feedback control hypothesis [8, 9] has been equally influential. The fact that the above hypotheses have not been unambiguously rejected or supported can be explained by difficulties of designing a rigorous experiment, in which critical parameters and variables of the hypotheses (supraspinal commands changing lambda thresholds, predicted afferent signals of the ongoing movement, or optimal corrective commands) could be directly measured rather than inferred and/or in which the experimental outcomes allow for an unambiguous interpretation; see also [10].

Here, I would like to offer an experiment that might distinguish between the two hypotheses. It is based on the fact that a moving limb resists mechanical perturbations, e.g. during arm reaching [11, 12] or leg swing in locomotion [13]. Perturbations directed towards the target tend to evoke muscle activity that slows the limb; opposite perturbations accelerate the limb to the target. These experimental outcomes appear consistent with both the RC and internal models hypotheses. According to the RC-hypothesis, assisting/resisting perturbations shift the actual limb configuration closer to/away from the referent configuration, which is gradually moving towards the target. This evokes muscle activity roughly proportional to the spatial difference between the actual and referent limb configurations. According to the internal model/optimal feedback control hypothesis, the corrective muscle activity in response to perturbations arises because sensory consequences of the planned movement, computed based on the efference copy of motor commands, differ from the actual sensory feedback.

In the proposed experiment, subject's arm is placed in a robotic exoskeleton arm that supports subject's arm against gravity and is capable of moving subject's arm in a horizontal plane using servo control. The subject is instructed to reach a target in a horizontal plane by the hand fast and accurately and do not correct possible perturbations. If the servo-controlled robotic arm moves subject's arm with the speed of a presumed referent configuration shift towards the target, no muscle activity above the initial baseline level is measured by the servomechanism and no robot movement correction is necessary. If the arm moves slower than the referent configuration, the corresponding muscle activity is recorded and the servomechanism accelerates the arm to reduce muscle activity to the baseline level. The robotic exoskeleton should be sufficiently fast and strong to move the arm to the target with about twice the speed of the actual reaching [4, 11].

To verify that the subject follows the instructions and actively moves the hand to the target, catch trails should be randomly introduced, in which the robot would move subject's arm faster or slower than the referent shift in different phases of reaching to cause re-emergence of activity in the appropriate muscles.

If the outcome of this experiment is as described above, it would support the major premise of RC-hypothesis – the muscle activity, limb kinematics and dynamics are not directly controlled by the nervous system but emerge as a result of a referent limb configuration shift and reflex-evoked muscle activities. Since the internal model/optimal feedback control hypothesis requires planning of muscle activity and movement characteristics, it would predict corrective muscle responses each time the arm moves faster (or slower) than expected. Thus, it would not be possible for the servomechanism to find the arm movement speed at which no excess of muscle activity above the baseline is present and deviations from that speed cause re-appearance of muscle activity.

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Declaration of Interest Statement

I declare that I have no conflict of interests.

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