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Comment

Pushing the boundaries of a physical approach for the study of sensorimotor control

Comment on “Laws of nature that define biological action and perception” by Mark L. Latash

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Mark Latash’s review article [1] provides a thorough discussion about limitations and opportunities for sensorimotor control research. The author’s views, and his extensive research work, are anchored in a bottom-up approach based on “laws of nature”. This framework leads to a critically important concept: Unlike inanimate objects, changes in motion of biological systems are generated by changing parameters, rather than variables. This proposition is the very foundation of the lambda (λ) model and its more recent formulation, the reference configuration (RC) hypothesis. Consequently, interactions between biological systems and the environment could theoretically be regulated by controlling one time-varying parameter, λ, representing the stretch reflex threshold. This theoretical framework is reviewed in the context of a wide variety of experimental findings supporting the RC-hypothesis. Although the review article provides multiple intriguing avenues for reflection and discussion, here I will focus on the ‘building blocks’ that would be required to implement RC-based sensorimotor control and potential future research avenues to identify the underlying neural mechanisms.

One of the appealing features of the RC-hypothesis is its apparent simplicity: The nervous system does not need to perform any type of ‘computation’, as other motor control theories seem to imply, to control specific variables or minimize cost functions, as pointed out in [1]. However, some of these theories have also highlighted the importance of frame of reference transformations [e.g., [2,3]; reviewed in [4,5]], i.e., processes that would modify sensory inputs – received in the sensory, receptor-specific frame of reference (e.g., retinotopic frame of reference for visual inputs) – to enable delivery of motor commands in an effector-based frame of reference (e.g., muscles or joints). This concept is also present in the RC-framework (Fig. 2). The author also addresses the inevitable explosion in the number of RC spaces using the *principle of abundance*, which affords the system with multiple solutions to ensure stability of performance. These considerations, together with the experimental evidence reviewed by the author, make for a compelling case in support of the RC-hypothesis. However, here one is left wondering if the higher-levels of the nervous system (e.g., primary and sensory cortices; premotor cortex; posterior parietal cortex) can be experimentally probed to effectively identify the processes through which a given RC might be built through development or modified

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through motor practice for skill acquisition. This objective would require addressing how these higher-level RCs are actually transformed in more numerous RCs at a lower hierarchical level.

Non-invasive neuromodulation (e.g., transcranial magnetic stimulation, TMS) and neuroimaging approaches (e.g., electroencephalography, EEG) come to mind as some of the tools for identifying functionally-important hubs in cortical networks (note that invasive approaches have been used in animal models in the above-cited work to identify neural processes underlying frame of reference transformation). Indeed, the authors' collaborators have used single-pulse TMS to address the involvement of cortical mechanisms in setting RC's by probing the excitability of the corticospinal tract [6,7]. Following up on this prior work and based on the above-cited literature on frames of reference transformation, targeting additional cortical areas, such as posterior parietal cortex, could be advantageous. Similarly, system-identification techniques to create 'virtual lesions' allow causal inferences of the functional role(s) of specific nodes of cortical network targeted by TMS. For example, we have used continuous theta burst stimulation [8] to infer the role of primary motor and sensory cortices for sensorimotor transformations underlying the control of dexterous manipulation [9], and the role of premotor dorsal area in conditional learning [10]. Similarly, EEG could be used to identify mechanisms in the time and/or time-frequency domains underlying sensorimotor adaptation and related phenomena, i.e., the interference of having performed a motor task in a given context on performance of the same movement in a different context [11]. Interestingly, these phenomena offer the opportunity to compare predictions from the RC framework and other motor control theories to understand how RC that are built by practice can potentially be transferred – or be detrimental – to different contexts, i.e., is the interference of the previous context caused by the inability of the system to rapidly create a new reference configuration?

I would advocate for incorporating the above approaches to complement behavioral approaches (i.e., motion and force tracking, EMG) to bridge how the (more easily measurable) lower-levels of the system respond to higher-level inputs. This might enable bridging the theoretical considerations – how RC's are transformed across system's levels – with behavior, e.g., the phenomenon of force drift described by the author) or physiology (synergies at the motor unit level [12]. The above considerations stem from the fact that the R-hypothesis ultimately requires central mechanisms to set, via habitual or deliberate practice, time-varying descending R- and C-commands. Although these commands will have to be modifiable by segmental mechanisms operating across different frames of reference, identifying the structure of these central mechanisms and network would provide critical evidence for the RC-hypothesis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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