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COMMENTARY

An Ecological-Dynamical Perspective on Latash's Misnomers in Motor Control

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In his target article, Latash (2024) aims to improve the field of motor control through promoting the use of clear and appropriately defined terms, which is a prerequisite for good and productive science and an overall objective we support. The domain of motor control requires selecting appropriate terms and defining them because it often uses principles or theories from other scientific domains, such as mechanics, or control theory. However, these other scientific domains concern the in-animate world, whereas motor control pertains to the animate world that contains extraordinary physical systems that require unique terms and definitions.

In scrutinizing the terms used in motor control, Latash started from the postulate that motor commands generated in the brain cannot prescribe the time evolution of end-effector movement (cf. Bernstein, 1967). This postulate complies with the notion of context-conditioned variability implying that there is no one-to-one correspondence between muscle activation and the resulting movement but the end-effector movement resulting from a muscle activation depends as much on the posture and the context as on the activation (Turvey et al., 1982). This position requires a radical approach to motor control that is very different from other approaches in motor control (e.g., Leib et al., 2023). This radical approach entails explanations of movement generation grounded in laws of nature in which control is exerted through setting parameters of dynamical equations.

Laws are generally conceived as regularities between variables coupled through parameters and natural laws are specific laws in living systems. Latash (2016) argues that natural laws should be grounded in classical physical laws and since living systems are exceptional physical systems they constitute new physical laws. In his work, Latash has primarily sought laws at the level of human physiology (e.g., the functioning of the tonic stretch reflex; Feldman, 1986) and he argues that these new natural laws should be grounded in classical physical laws (Latash, 2016, 2019), which describe linear causes. Many proponents of the

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ecological-dynamical approach seek laws in nomic constraints rather than in something akin to the causal structure of classical mechanics. In this approach, laws describe possible events that require conjunction with constraints to describe behavior that takes place. In this constraints-based approach, if a feature of the organism–environment system is sufficiently regular to be a nomic constraint then that feature is deemed lawful enough to serve as the basis for successful perception and action (Petrusz & Turvey, 2010).

This lawful regularity exists not only in internal biophysical constraints and external physical constraints, but also in the informational constraints relating the two (Gibson, 1979; Petrusz & Turvey, 2010). At this ecological scale, nomic constraints provide regularities to which agent-environment systems become attuned, such as the optic flow fields generated when moving through the world that have regularities that can be used to control those movements. For instance, an outfielder can arrive at the landing location of a fly ball employing a strategy of optical acceleration cancellation (Michaels & Zaal, 2002). This implies that behavior can be controlled by following a control law that relates the specifying information (i.e., vertical optical acceleration decreases or increases, functioning as a nomic constraint) to a behavioral mode (i.e., moving backward or forward, respectively). This constraint-based approach to seeking laws has led its proponents to adopt the tools of complex systems science and nonlinear dynamics in developing its models and analyses of human behavior (e.g., Kugler & Turvey, 1987; Turvey & Fonseca, 2014). Therefore, we agree with Latash that explanation of motor behavior should be sought in law-like regularity, but we potentially differ on what we believe to be (a) the most promising domain in which to seek laws and (b) the best approach to characterizing the form of those laws.

Latash's target article distinguishes useful misnomers in motor control: reflex, synergy, and posture, and we will now turn to discussing these terms from an ecological-dynamical perspective. In an ecological-dynamical framework, the different components of the system interact and from that interaction behavior emerges. It is important to realize that all components interact on equal footing and that these interactions take place at all levels of analysis. From this perspective, the neural mechanisms that sometimes are labeled as a reflex are conceived of as neural constraints on the interactions among components from which behavior emerges. These interactions among components lead to temporary functional units in which components are linked and we call these units synergies (Profeta & Turvey, 2018). Note that these synergies can be formed at different levels of analysis of the system. Perceptual information acts as nomic constraints affecting these interactions so that the proper synergies are formed to reach a goal. In this way, perceptual information constrains the degrees of freedom in the body into a postural configuration that maintains a stable relation with the environment.

From the framework laid out in the above, we question whether it is relevant to establish a clear distinction between reflexive behavior and other behaviors, since all behavior results from the interaction of components of the system. Neural mechanisms that often are labeled as reflexes put specific constraints on these interactions, specifically with respect to the dimensions listed in Table 1 of Latash. However, the "reflexive" neural mechanisms are not the only constraints active at this level of analysis, see below where we discuss muscle tone. This supports the viewpoint that these mechanisms act as one of many constraints on the interactions from which behavior emerges.

The notion of synergy is an important concept in understanding motor control and we agree with Latash that different authors and different fields use the term in a different way, which is often confusing for students learning about motor control. Latash clearly outlines the different perspectives on synergy in the field. However, from our perspective we question whether it is required to limit the study of synergies to the level of neural control. The functional units that we see as synergies are an abstract principle, functioning as a natural law at different levels of analysis of the movement system. This law has been shown using perturbation experiments where the tasks or components of the synergy were perturbed. For instance, different muscles of the speech organ function as a synergy when speaking (Kelso et al., 1984) and different fingers of the same hand (Kamp & Zaal, 2007) and of different hands (Zaal & Bongers, 2014) form a grasping synergy. Together this shows that synergies are formed at different levels of analysis to coordinate the degrees of freedom.

These synergies emerge on the basis of the information that guides the behavior in the task and this is what we see in postural control. That is, while we agree with the definition of posture as ensuring dynamical stability of a geometric variable, as Latash does, we propose to not just focus on the neural control mechanism but instead consider postural control resulting from a general control mechanism where perceptual information constrains the posture stabilizing synergy. Also, in this perspective there is no principal difference between posture and movement. A prime example of this can be seen in the "moving room" experiments in which the visual flow field can be used to perturb standing posture of children (Lee & Aronson, 1974) and postural sway couples onto the visual sway pattern (cf. Dijkstra et al., 1994), while at the same time structure in the visual flow field can be used to control a grasping movement (Zaal et al., 1998). Together this discussion demonstrates that in the ecological-dynamical framework the useful misnomers of Latash can be conceived in a coherent and connected framework.

We can be short about the misleading misnomers in motor control that Latash presents. We agree with Latash's conclusions that claims of representations of skilled action in the central nervous system that possess anything more than the most abstract "functional" characteristics (e.g., possessing the abstract topological character of engrams) are infeasible on theoretical grounds given the fundamental conceptual challenge posed by the problem of context conditioned variability (Turvey et al., 1982) and the lack of lawfulness of those concepts. We consequently also agree that elaborated conceptions of motor programs and internal models are likely devoid of meaningful content (Kugler et al., 1980). Another point of agreement for us is Latash's claim that the alternative to ascribing the functional form of human behavior to internal representations and/or motor programs is to seek (a) context conditioned control variables and (b) new physical laws that apply to living systems.

Latash distinguishes three terms that are potentially useful but they require improvement in their definition, of which we discuss two. Latash adopts Bernstein's definition of muscle tone as a "state of preparedness for future action." He further posits that this preparedness results from the difference between muscle length and the λ command in a relaxed state. Thus, Latash's perspective on muscle tone emphasizes the modulation of the stretch reflex. We align with Latash's concept of preparedness; however, as we have previously argued, one of the core principles of the ecological-dynamical approach is that perception–action systems are complex, with behavior emerging from interactions among subsystems rather than being determined by any single subsystem. Specifically, focusing solely on neural influences on muscle tonus overlooks the essential role of connective tissue in maintaining overall body tension, achieved through various forms of lateral tension transmission (see Huijing, 2007). The resistance of a muscle to stretch cannot be viewed in isolation from the resistance provided by the associated connective tissue, indicating that muscle tone is a property of the integrated muscular-connective tissue-skeletal system (Turvey & Fonseca, 2014; Profeta & Turvey, 2018). This integrated property aligns with tensegrity systems, which maintain mechanical integrity through continuous tension and intermittent compression (Levin, 2006). When perturbed, a tensegrity system redistributes tension across the entire system due to its inherent prestress, even in the absence of external forces. This prestress is critical for the global responsiveness of muscle-joint complexes, supporting both posture maintenance and movement production and should be taken into account when thinking of muscle tone.

We agree with Latash that approaching the number of degrees of freedom in our moving system as redundant has shaped the field of motor control for decades and has also figured prominently in the ecological-dynamical approach (cf. Turvey, 1990). However, the perspective on the degrees of freedom is also shifting in the ecological-dynamical approach and this approach embraces the notion of abundancy since it allows to account for flexibility in performance and for learning (Bongers, 2021; Tuitert et al., 2020). Within an ecological-dynamical approach, the challenge of understanding how an appropriate synergy is "selected" from abundant degrees of freedom must be framed in the context of understanding the dynamical processes of detecting action-specific information and the coconstraining interplay of perception and action. In this perspective, abundance becomes an integral part of the explanation of movement coordination because nomic constraints are believed to arise as a direct consequence of the complexity of the situation rather than in spite of it (Gibson, 1979; Turvey & Fonseca, 2014).

In sum, we agree with Latash that terms used in explanations of the control of movements need to be defined clearly. We also agree that motor control should be explained using laws that are able to explain biological phenomena, but we believe that these laws should be searched from an ecological-dynamical framework. From this perspective, we broadly agreed with Latash's distinction of useful and useless misnomers in motor control and terms that need more precise definitions.

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