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Human Kinetics
COMMENTARIES

Toward Prospective Application of the UCM Method

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The hand is essential to human motor behavior and is one of the most studied and complex motor systems. Dr. Latash reminds us its elaborate biomechanical and neural control architecture that underlies its ability and function. On the way to realize an incredible range of manipulative behaviors, a creative and effective quantification tool has been proposed, validated, and broadly applied to reveal the mechanism underneath the comprehensive hand control. In this commentary, I will mainly discuss this sophisticated tool as an experienced terminal user and faithful believer in the framework of UCM, however, not much on its technique applications in practice, but more on its prospective development in theoretical perspectives.

A few key terminologies can't be skipped when referring UCM. This methodology was derived in the context of searching solutions for *motor redundancy*, one of the most fundamental problems in motor control. Being associated with the principle of abundance (a nontraditional control mechanism without omitting any DOFs in a redundant system), the concept of *motor synergy* has been established by using UCM's unique quantification ability on *motor coordination.* Note the motor synergy here is mainly referred as *error compensation*, one of the two forms of motor synergies (the other form is *sharing*). This recently developed technique, being applied in terms of mathematician's language, provides a revolutionary theoretical framework embryo. Some unique features integrated in the framework of UCM contribute to start the ball rolling in drawing a map of movement control. One of the elegances attributes the success to the quantification power for motor coordination, a widely used but obscurely defined terminology in motor control field. Motor coordination among DOFs in a redundant system, therefore, can be expressed through various specified motor tasks by quantifying the relation between elemental and performance variables' variation. Secondly, the theoretical basis of the UCM concept allows the possibility of universal application in almost all the redundant systems integrated in human body. Elemental variables associated with DOFs can be varied in different task spaces (e.g., ranging from force (N) in multidigit force production tasks to joint angle (degree) in pointing tasks), with different physiological basis (e.g., ranging from individual digits to muscle fibers), or in a different sequence (e.g., in series or parallel).

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While we appreciate for these great build-in features of UCM, this theoretical framework deserves to be deeply discussed thus to enlighten directions for its prospective development. The following discussion will not be focused on technical issues, even though technical difficulties exist (e.g., determination of the task-specific *Jacobian* matrix) to prevent the application of UCM from being realistic in different motor task designs. Let us assume that we have broken ice on technical problems to ensure all the constraints to apply UCM are strictly met (e.g., elemental variables are independent of each other), UCM framework would be ultimately adopted in more general and much broader experimental designs. However, is this ultimate goal of the UCM concept? A perspective to construct this newly developed framework and its relevant issues can be discussed from a theoretical vision.

Does Abundance Principle Solve or Bypass the Problem of Motor Redundancy?

No doubt that the abundance principle is a revolutionary innovation. By viewing the DOFs comprising a redundant system as abundant, it subverts all the traditional solutions that attempt to simplify a redundant system with frozen or omitted DOFs. According to the abundance principle, all DOFs forming a redundant system are not a mathematical burden, but rather are contributors to 1) task-specific motor coordination patterns, 2) mechanism of resistance to mechanical perturbations, and 3) flexible motor adaptation in task alterations. However, can we conclude that the redundant problem is absolutely hammered out? When facing a redundant system, e.g., a two-digit force-producing example, one of the most commonly raised questions is: How does the CNS select one particular force distribution pattern out of numerous possible solutions? This is equivalent to solve a mathematical problem with two unknowns (individual forces) given one known (total force) variable. One would be disappointed if he expects an answer to this question according to principle of abundance, since there is none. Instead, this question is determined as a nonvalid one assuming all the elements are self-organized units, which can interact with others in a coordinated pattern. Assuming there is a solution pool, which consists of all the possible task-specific solutions (a UCM subspace where no change in the performance variable take place), as long as the self-organized elements' outputs lie in the solution pool thus to satisfy the task, CNS does not need to make an effort to determine, which solution to be selected out of so many. If a particular motor pattern observed in one trial is just randomly chosen from the solution pool (the UCM subspace), can we assume such solution pool is formed by CNS before the start of a motor task? If so, with the solution of motor redundancy problem, new questions will be raised. How and when does CNS recognize, form, and retrieve a solution pool responsible to solve a specific motor task?

Does UCM Framework Purposely Ignore the Learning Phase for a Motor Synergy?

Across a broad range of UCM applications, motor coordination has been extensively studied and quantified after subjects learned or adapted to the task (see review in

Latash et al., 2007). From a novel task to an experienced task, however, how does CNS recognize, form and retrieve a solution pool is still a myth. In other words, how is the self-organized order in a system achieved? To investigate the motor synergy learning process, recent studies have documented the practice-induced changes on synergy determinants (e.g., variance components defined in UCM) (see review in Wu & Latash, 2014). The structural changes of variance of elemental variables relative to variance of performance variable are introduced by repetitive motor practice, leading to emergence of motor synergy. However, the subtle learning or developing process of motor synergies is generally omitted from the UCM analysis, i.e., motor synergies were quantified either without the first couple of learning trials for one specific motor task (e.g., Latash, Yarrow, & Rothwell, 2003), or skipping the practice period (e.g., Wu, Pazin, Zatsiorsky, & Latash, 2013). An unfortunate consequence, therefore, results from the motor synergy's across-trial variance quantification, which is, emergence of motor synergy in the basis of within-trial or trial-to-trial timeframe has been ignored. Furthermore, in terms of error compensation, error (variation) detected in one elemental variable can be compensated by deviations from another element(s) in stabilization of the performance variable(s). Accordingly, it is reasonable to assume the existence of time delay(s) between error-making and -compensating elements, at least during explorative learning trials when CNS is updating the solution pool. However, this motor coordination mechanism has not been tested as a sequence of events with temporal lag(s). Yet, one thing is sure—- evidence of more subtle events encoded in the learning process of motor synergy would unmask its nature as a driving mechanism to operate a control system, thus contribute to reveal a larger picture in the jigsaw puzzle of movement control.

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