Multi-Element Synergies in a Variety of State Spaces

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Abstract. *At many levels of description, biological systems are typically characterized as redundant, that is having more elements than necessary for most tasks. Recently, the problem of redundancy has been reformulated based on the principle of abundance. This principle suggests that the apparently redundant sets of elements are not a source of computational problems for the biological systems and their controllers, but a luxury that affords both stability and flexibility of behaviors. A computational approach to analysis of such systems has been developed using the framework of the uncontrolled manifold hypothesis. This approach has allowed to offer an operational definition to the notion of synergy leading to a possibility of its quantitative assessment. We developed and applied such analyses to a variety of motor tasks and spaces of elemental variables, kinetic, kinematic, and electromyographic. A number of synergies have been identified and quantified, in particular those related to stabilization of total force and total moment of force in multi-digit tasks, of the center of mass coordinate and trunk orientation in postural tasks, of endpoint trajectory is multi-joint pointing tasks, and of the center of pressure trajectory in multi-muscle stepping and swaying tasks. Among the most exciting findings is the ability of the central nervous system to produce adjustments in synergies in anticipation of a quick action or a reaction to a perturbation, the emergence and strengthening of synergies with practice in both general population and persons with Down syndrome, deterioration of multi-digit synergies in elderly, the apparent inability of the controller to organize multi-element synergies simultaneously at two levels of a control hierarchy, and the apparent lack of timing synergies. Obviously, I am not going to be able to cover all these topics and will try to select a few most exciting ones as illustrations for the approach. This method of analysis offers direct applications to clinical problems and can be generalized to other multi-element motor tasks and, potentially, to non-motor tasks.*