Appendix 1. Selected Evidence Supporting the Existence of Movement System Multifractality

Recent work has examined how healthy adults wield unseen objects by the hand.[20] Participants grasp an object behind a curtain only by the object's handle, and they wield it to get a feeling for the object's inertial distribution. This effortful type of touch perception recruits limbs, joints, muscles and tendons, profiting from the hierarchical organization in which each muscle fiber sits within a muscle group, each muscle group encompasses a joint, joints together compose an entire limb, and all is woven together by fascia and skin.[17] This hierarchical organization of movement system components requires multifractal modeling for its description generically.[17] Measuring wielding movements in terms of their multifractality actually predicts (1) how participants make different use of the same object's inertial distribution to generate judgments of object length, and (2) differences in length judgments over different trials and across different participants. If we provide participants in the wielding study with visual feedback on their judgments, their attention to visual feedback depends on head-sway multifractality; providing visual feedback prompts head-sway multifractality to have a more lasting effect in promoting multifractality in hand wielding.[20] The multifractality of wielding simply exemplifies the more general hierarchical organization of movement variability that allows an organism to accumulate and coordinate information for action.

In motor development during infancy, we find a long-standing understanding that infants' spontaneous kicking movements are exploratory.[53] Presumably, this exploration entails that spontaneous kicking should carry information from beyond the movement system, from more peripheral degrees of freedom (e.g., the ankle) to more central degrees of freedom (e.g., the hip) closer to the torso. Here again, we can leverage the same usefulness of multifractal measures for indexing the sharing or spread of information across the movement system. Typically-developing infants' spontaneous kicking yields an intermittent series of joint-angle excursions as infants wiggle, squirm, and kick by turn. One study of typically developing infants sampled several minutes of this spontaneous kicking and examined consecutive 30-second segments of joint-angle time series. We used multifractal analysis to assess multifractality in each segment for the hip, knee, and ankles of each infant, and causal modeling provided evidence that joint-angle kinematics exhibited a spreading of multifractality from ankle to knee, and from knee to hip.[54] This contingency of multifractality from more peripheral to more central degrees of freedom follows just the sort of flow from periphery to torso that, as noted above, would be consonant with an exploratory role for spontaneous kicking. This example thus used a known exploratory aspect of the movement system to lend further weight to the idea that multifractality is a key feature of exploratory movement variability.

Adults show a similar coordination of multifractal patterning across different muscles participating in the same synergy. Intriguingly, they only show this coordination when their movement is intentional. One study examined EMG signals from muscles in the arm that produce elbow flexion. EMG was collected in under two conditions, one in which elbow flexion was active, i.e., initiated by the participants on their own intention and motive force, and one in which the flexion was passive, i.e., initiated by an experimenter. EMG shows closely coupled multifractal patterns when the movement system is actively flexing the arm, but not when the experimenter provided the motive force behind the flexion movements. Thus, multifractal fluctuations appear to be a specific hallmark of the intentional cooperation of multiple degrees of freedom.[55]

Neural signals themselves carry multifractal patterns that serve to translate motor command into movement trajectory.[18] Even their supporting fascia has been shown to display a multifractal geometry.[17] Thus, neural signals contain and are contained by temporal and spatial multifractal structure.

Reference list given in: Cavanaugh J et al. Multifractality, interactivity, and the adaptive capacity of the human movement system: a perspective for advancing the conceptual basis of neurologic physical therapy. *J Neurol Phys Ther*. 2017; Oct 40 (4).