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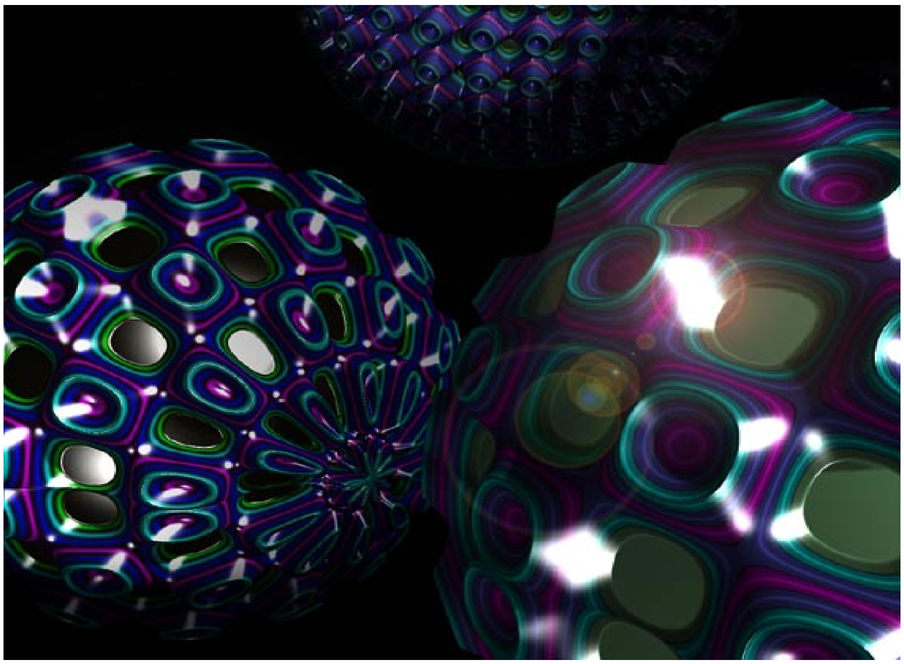
# Nonlinear Dynamics, Psychology, and Life Sciences



## Special Issue on Psychomotor Coordination and Control



In this paper we review recent work from our studies of a nonlinear dynamics of motor learning that is grounded in the construct of an evolving attractor landscape. With the assumption that learning is goal-directed, we can quantify the observed performance as a score or measure of the distance to the learning goal. The structure of the dynamics of how the goal is approached has been traditionally studied through an analysis of learning curves. Recent years have seen a gradual paradigm shift from a "universal power law of practice" to an analysis of performance dynamics that reveals multiple processes that include adaption and learning as well as changes in performance due to factors such as fatigue. Evidence has also been found for nonlinear phenomena such as bifurcations, hysteresis and even a form of self-organized criticality. Finally, we present a quantitative measure for the dual concepts of skill and difficulty that allows us to unfold a learning process in order to study universal properties of learning transitions.

**Dynamics of multi-articular coordination in neurobiological systems**
*Jia Yi Chow, Keith Davids, Chris Button, Robert Rein, Robert Hristovski, and Michael Koh*

Although previous work in nonlinear dynamics on neurobiological coordination and control has provided valuable insights from studies of single joint movements in humans, researchers have shown increasing interest in coordination of multi-articular actions. Multi-articular movement models have provided valuable insights on neurobiological systems conceptualised as degenerate, adaptive complex systems satisfying the constraints of dynamic environments. In this paper, we overview empirical evidence illustrating the dynamics of adaptive movement behavior in a range of multi-articular actions including kicking, throwing, hitting and balancing. We model the emergence of creativity and the diversity of neurobiological action in the meta-stable region of self organising criticality. We examine the influence on multi-articular actions of decaying and emerging constraints in the context of skill acquisition. We demonstrate how, in this context, transitions between preferred movement patterns exemplify the search for and adaptation of attractor states within the perceptual motor workspace as a function of practice. We conclude by showing how empirical analyses of neurobiological coordination and control have been used to establish a nonlinear pedagogical framework for enhancing acquisition of multi-articular actions.

**Soft-Assembly of Sensorimotor Function**
*Christopher T. Kello and Guy C. Van Orden*

Von Holst (1939/73) proposed relative coordination as a general characteristic of sensorimotor functions like locomotion. Its functionality derives from striking a balance between independence versus interdependence among component activities, e.g., fin or leg oscillations in lipfish and centipede models, respectively. A similar balancing act in the Ising (1925) model was found to produce patterns of electron spin alignment, analogous to the soft-assembly of locomotive patterns. The Ising model analog to relative coordination is metastability, and Kelso (1995) hypothesized that metastability is essential to sensorimotor functions across levels and domains of analysis, from individual neurons to neural systems to anatomical components of all kinds. In the present survey, relative coordination and metastability are hypothesized to underliethe soft-assembly of sensorimotor function, and this hypothesis is shown to predict 1/f scaling as a pervasive property of intrinsic fluctuations. Evidence is reviewed in support of this prediction from studies of human neural activity, as well as response time tasks and speech production tasks.

**1/f Scaling in Movement Time Changes with Practice in Precision Aiming**
*Maarten L. Wijnants, Anna M. T. Bosman, Fred Hasselman, Ralf F. A. Cox, & Guy C. Van Orden*

Abstract: When people perform repeated goal-directed movements, consecutive movement durations inevitably vary over trials, in poor as well as in skilled performances. The well-established paradigm of precision-aiming is taken as a methodological framework here. Evidence is provided that movement variability in closed tasks is not a random phenomenon, but rather shows a coherent temporal structure, referred to as 1/f scaling. The scaling relation appears more clearly as participants become trained in a highly constrained motor task. Also Recurrence Quantification Analysis (RQA) and Sample Entropy (SampEn) as analytic tools show that variation of movement times becomes less random and more patterned with motor learning. This suggests that motor learning can be regarded as an emergent, dynamical fusing of collaborating subsystems into a lower-dimensional organization. These results support the idea that 1/f scaling is ubiquitous throughout the cognitive system, and suggest that it plays a fundamental role in the coordination of cognitive as well as motor function.

**Attractor and Lyapunov Models for Reach and Grasp Movements with Application to Robot-assisted Therapy**
*Stephen J. Guastello, Dominic E. Nathan, and Michelle J. Johnson*

The principles of attractors and Lyapunov exponents were used to develop a reaching-to-grasp model for use in a robotic therapy system for stroke patients. Previously known models for these movements, the fifth order minimum jerk and the seventh order polynomial, do not account for the change in grasp aperture of the hand. The Lyapunov model was tested with reaching-to-grasp movements performed by five neurologically intact subjects and produced an average $R^2$ = .97 over 15 replications for 41 different task events, reflecting a notable advantage over the fifth order (average $R^2$ = .58) and seventh order (average $R^2$ = .67) models. A similar level of success was obtained for the Lyapunov model that was specific to grasp aperture. The results indicated that intentional movements can be accurately characterized as attractor trajectories, and as functions of position along two Cartesian coordinates rather than as functions of time. The Lyapunov exponent model requires fewer parameters and provides an efficient platform for real-time implementation.

**Complexity of Postural Control in Infants: Linear and Nonlinear Features Revealed by Principal Component Analysis**
*Regina T. Harbourne, Joan E. Deffeyes, Anastasia Kyvelidou, Nicholas Stergiou*

Nonlinear analysis of standing postural control in healthy adults reveals a chaotic structure of the center of pressure time series. Independent sitting is the first controlled posture during development, and can also be examined for nonlinear dynamics. We performed a principal component analysis on variables extracted from the center of pressure (COP) time series of infants sitting independently. Our purpose was to describe factors that could be interpreted for clinical use in evaluating postural control for infants, and determine if nonlinear measures provide additional information about postural control not quantified by standard linear measures. Four factors were identified: the area or amount of postural sway and the overall variability of the sway (linear); the complexity of the sway in the anterior-posterior direction (nonlinear); power variability or velocity (linear); and the complexity of the sway in the medial-lateral direction (nonlinear). Nonlinear measures, which are used to examine complexity in many physiological systems, describe the variability of postural control that is not described by linear measures. Nonlinear measures may be critical in determining the developing health of the postural control system in infants, and may be useful in early diagnosis of movement disorders. The measurement of nonlinear dynamics of postural control reveals a chaotic structure of postural control in infancy, which may be an indicator of healthy postural control throughout development.

**Art Feature: The Museum of Unnatural Form: A Visual and Tactile Experience of Fractals**
*D. Della-Bosca and R.P. Taylor*

A remarkable computer technology is revolutionizing the world of design, allowing intricate patterns to be created with mathematical precision and then 'printed' as physical objects. Contour crafting is a fabrication process capable of assembling physical structures the sizes of houses, firing the imagination of a new generation of architects and artists (Khoshnevisat, 2008). Daniel Della-Bosca has jumped at this opportunity to create the "Museum of Unnatural Form" at Griffith University. Della-Bosca's museum is populated with fractals sculptures – his own versions of nature's complex objects – that have been printed with the new technology. His sculptures bridge the historical divide in fractal studies between the abstract images of mathematics and the physical objects of Nature (Mandelbrot, 1982). Five of his fractal images will be featured on the cover of NDPLS in 2009.

**Review of *The continuity of mind*, by M. Spivey** (2007). Oxford: Oxford University Press
Reviewed by Deborah J. Aks