

The Dynamical-Systems Approach to Studying Athletic Injury

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TRADITIONAL MEASURES of movement in sports-medicine research have viewed increases in variability as extraneous noise, as error, or as being representative of pathological dysfunction.^{1,2} In the past 20 years, however, motor-control researchers have developed a theoretical framework for studying movement variability using nonlinear dynamics that might be applicable to sports medicine. This has led to the theory that movement variability is essential for the stability and function of the sensorimotor system.³ The model that considers this type of inherent movement variability as essential is known as the dynamical-systems approach to motor control.¹⁻⁵

Variability in movement patterns has traditionally been viewed as nonoptimal deviation from invariant, repeatable patterns of movement for particular skills.² Any variability in these patterns was considered either unnecessary noise or as representing impairment in pattern-generated movement. There is a growing consensus, however, that there is a functional and essential role of variability in maintaining health and homeostasis.^{1,4,6} This approach has been used in research on pathological conditions related to severe neuromuscular dysfunction such as Parkinson's disease, but its role in sports-medicine research is in its infancy.

From the dynamical-systems perspective, there is a great deal of redundancy within the biomechanical degrees of freedom (DOF) of multiple joint segments, affording the sensorimotor system numerous options in executing specific movement tasks.^{1,2,4,5} An example of this process is an upper extremity reaching task. The upper extremity has multiple DOF (three at the shoulder, one at the elbow, and three at the wrist), and a reaching task requires far fewer DOF than are available in the entire extremity. By alter-

ing the contributions of the available DOF, there are multiple combinations of joint movements possible to enable task execution. If one of the components in the extremity fails to perform, the other components can alter their contributions to accomplish the same result.² This results in the ability to use various combinations of DOF to accomplish the same task. These DOF are organized into coordinative structures, or muscle synergies spanning multiple joints, through the process of self-organization based on task, environmental, and organismic constraints (Figure 1).² The sensorimotor system will organize itself based on the complexity of a specific task, the environment in which the task is being performed, and the ability (or disability) of the organism to execute the task. The functional role of variability might be protective. By having multiple possible ways to accomplish a particular task, variability serves to reduce the repeated stress on tissues and might allow for greater flexibility in dealing with unexpected perturbations.

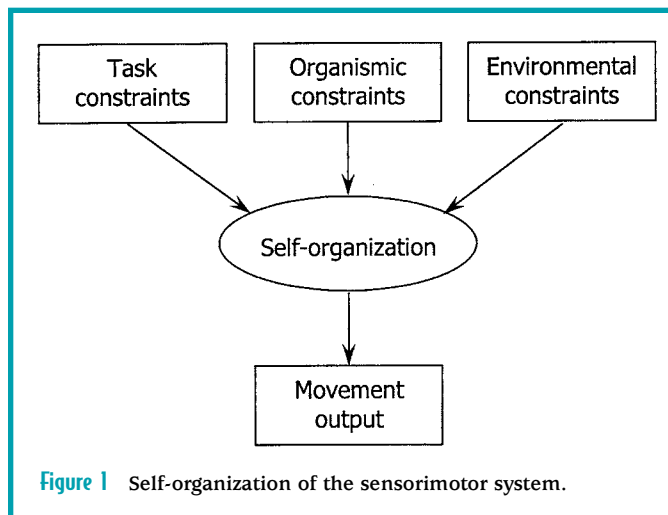


Figure 1 Self-organization of the sensorimotor system.

Organismic constraints such as those caused by neuromuscular injury or disease affect the coordinative ability of the sensorimotor system. If there is a reduced use of the DOF of a coordinative structure as a result of injury (e.g., decreased joint range of motion), decreased variability in task execution will result. In functional testing, researchers control as many task and environmental constraints as possible in order to gain a better understanding of the role that injury (organismic constraint) plays on the sensorimotor system. Several research methodologies have been developed to examine the role of functional variability in the sensorimotor system. We will focus on specific methodologies related to postural control with relevance to sports medicine.

Postural Control

The study of postural control has been used to assess functional deficits related to pathologies such as ankle sprains and cerebral concussion. Testing has traditionally been done in a quiet room that is free from visual distractions in order to isolate the organismic constraints acting on the sensorimotor system as a result of injury. Stabilometry is the most common technique in the evaluation of quiet standing in single- or double-leg stance. A stabilogram plots the movement of the center of pressure (COP). COP is the composite measurement of three-dimensional reactive forces and moments stemming from the interaction between the foot and the surface of a force plate during stance. A stabilogram is a two-dimensional representation of the movement of the COP expressed in the anteroposterior and mediolateral directions. Summary measurements have been used to evaluate COP excursions, including area, length, velocity, and various versions of sway index that incorporate the amount of available sway range used in a particular balance task. These methods, however, have often yielded inconsistent and contradictory findings.⁷ The premise of these studies is often that greater COP excursions are considered indicators of dysfunction, but these dependent variables are often based on simple descriptive statistics (*M* and *SD*) that do not take into account the structural variability of COP excursions.

There have been several methods developed to examine the data from stabilograms through the dynamical-systems approach that might provide insight into the consequences of athletic injury for postural control. Rather than viewing an increase

in variability as a sign of dysfunction, each of these methods takes into account the component parts of the stabilogram and looks for relationships between stability and variability. Each method provides an estimation of the complexity of structure and variability in the data stream collected during task execution. A breakdown in complexity, or a loss of variability, in the movement process is viewed as a sign of dysfunction. One of these techniques is time to boundary (TTB).

TTB is a spatiotemporal method of analyzing COP.⁸ Rather than using summary analysis of the entire COP data set, TTB uses the relationships of specific data points in a stabilogram. By modeling the foot as a rectangle, the boundaries of the base of support can be determined. By calculating the distance and direction between two consecutive COP data points, the instantaneous COP velocity is determined. The distance from the second data point to the directional boundary is then calculated, and this is repeated for the entire trial. By dividing the distance to the boundary by the instantaneous velocity, the amount of time it would theoretically take to reach the boundary of support can be determined. TTB represents the amount of time it would take the COP to reach the boundary of support should the direction and velocity of the COP remain unaltered. TTB takes into account both the velocity of COP excursion and the position on the foot where the excursion occurs. For example, a high-velocity COP excursion when the COP is in the middle of the foot is less precarious than a high-velocity excursion occurring close to the boundary of the foot. A lower TTB value indicates postural instability, as the individual has less time to respond to the COP close to the boundary of stability.

Calculating TTB across a set of COP data produces a series of peaks and valleys as the individual makes postural corrections (Figure 2). The valleys are considered minima and represent points where the individual is closest to losing balance. The lower the minima of TTB, the closer the COP is in time to reaching the boundary of the base of support. Specific variables used in the evaluation of TTB include the absolute minimum (the smallest TTB measurement in a data set), mean minimum (the average of the TTB minima), and the *SD* of TTB minima. The *SD* of the TTB minima represents a measurement of the complex variability of the COP excursions.⁹

Olmsted and Hertel¹⁰ used this technique to evaluate postural control in individuals with and without chronic ankle instability. They used both traditional

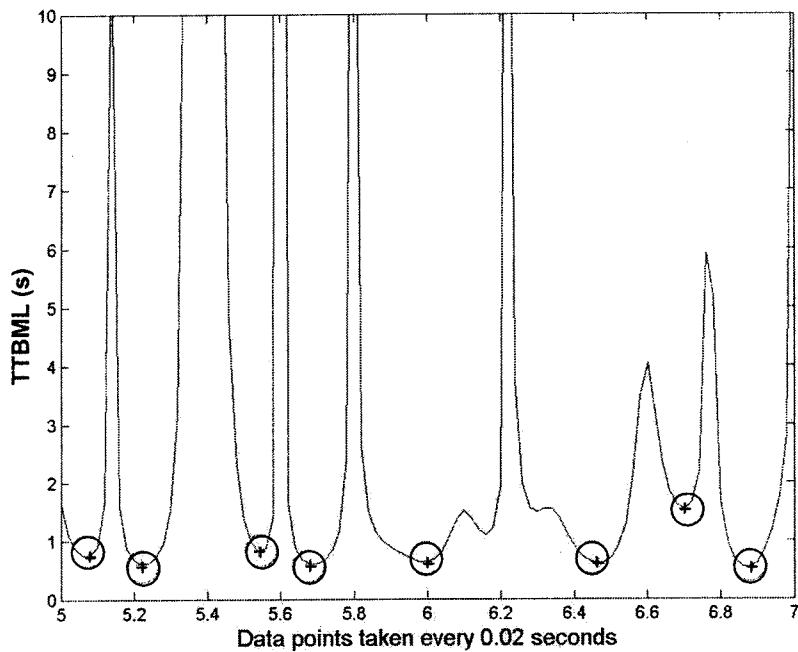


Figure 2 Time-to-boundary measurements in the mediolateral plane (TTBML). The x axis represents data points within a sampling rate of 50 Hz, and the y axis represents time-to-boundary in the mediolateral plane. The circled areas represent the minima of the time to boundary (valleys)—the times when the center of pressure is closest to the base of support. From these measurements, the absolute minimum, the mean minimum, and standard deviation of minima can be calculated.

summary measures of postural control and TTB measures. Chronically unstable participants had significantly lower absolute minima, mean minima, and SD of minima TTB measurements than healthy controls. The lower absolute and mean minima TTB in the chronically unstable group indicate that these participants were balancing in a manner that placed them closer to the boundaries of the base of support than the controls were. The lower SD of the TTB minima in the unstable group indicates that they had significantly less variability in TTB than did the controls. This reduction in postural variability in the presence of chronic ankle instability might result in the inability to respond appropriately to external perturbations in the maintenance of balance. Significant differences between groups were not found with the traditional summary measures.

Conclusions

Advances in nonlinear dynamics of motor control have led to the theory that variability is an essential

component of neuromuscular control in both static and dynamic tasks. We have provided examples of reduced variability in postural mechanics associated with various athletic injuries that counter the traditional viewpoint that increased movement variability is associated with musculoskeletal pathology. Going beyond simple summary descriptions of movement measurements and using techniques that incorporate a dynamical-systems approach to motor control might provide greater insight into postural-control deficits associated with athletic injuries. ■

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