Genes, Training, and other Constraints on Individual Performance: A Role for Dynamical Systems Theory?

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Behavioral genetics and psychology provide useful insights into relative contributions of nature and nurture to variation in physical performance in a population, but understanding and exploiting these and other constraints on performance in individual athletes requires an over-arching multi-disciplinary theoretical framework. Dynamical systems theory, which has enjoyed some recent success in accounting for behavior of complex systems, may be the appropriate framework.

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Informative articles in the current and previous issues of Sportscience address the relative importance of innate (genetic) and environmental (training) effects on athletic performance (Hopkins, 2001; Baker, 2001). Hopkins presented the limited evidence that differences in genes and training contribute to differences in sport talent before presenting practical implications of this view that "athletes are born *and* made". Baker evaluated the argument that "sport performance and sport expertise are entirely the result of hours spent in focused, effortful training rather than innate, inheritable traits" and concluded that "future research should also consider an approach to sport expertise that investigates the inter-dependent role of genetic and environmental factors". Both authors alluded to the resolution of the nature-nurture debate via the identification of the proportion of performance variation accounted for by inherited characteristics and environmental influences in populations or groups of athletes. In this commentary, I argue for a new perspective on this continuing debate, one that involves understanding the interacting contributions of genes, training, and other effects on an *individual* athlete. A theoretical framework for capturing and making practical use of the interaction of so many interacting factors in the individual will need to be complex and multidisciplinary. I believe dynamical systems theory is such a framework.

Dynamical systems theory provides explanations for some of the phenomena that arise in complex natural systems, such as the weather and social organizations. Dynamical systems in nature are composed of many interacting parts or degrees of freedom, and are constantly pressurised by constraints to change the state of organization between component parts. This description fits human movement, which is composed of many interacting sub-systems (nervous, musculo-skeletal, endocrine, and so on). Accounts of the application of dynamical systems theory to the acquisition of expert movement behavior can be found in Davids et al. (2001), Davids et al. (2002), and Newell (1986). See also Rosenbaum (1998) for the skeptical view that the theory is, as yet, more descriptive than explanatory.

A key question from a dynamical systems viewpoint concerns how coordination emerges from the interaction between the degrees of freedom during goal-directed movements,

such as catching a ball or performing a triple salto. In the study of the acquisition of sport expertise in humans, dynamical systems theory can explain how movement coordination and control change over time scales required for learning and development (weeks, months, and years).

What influences change in dynamical movement systems? To answer this question, a model of the emergence of expertise under interacting *constraints* is useful. The concept of constraints has a rich tradition in theoretical physics and evolutionary and theoretical biology. Roughly speaking, constraints are factors that shape or guide the organization of multi-component natural systems including, for example, weather systems, termite colonies, and movement systems. Newell (1986) has provided the best account of how constraints influence coordination and control in human movement systems. His model categorizes constraints as "organismic" (exemplified in the current debate by the genetic profile and amount of task-specific practice of each individual athlete), "task" (related to the specific characteristics of each sport or physical activity; examples include rules, boundaries, and equipment), and "environmental" (exemplified by social and cultural influences on behavior). Newell's model shows how these constraints interact together to influence expertise in sport. A radical implication of this approach is that the acquisition of expertise emerges under the interaction of organismic, task, and environmental constraints.

It is important for sport scientists to understand the full range of key constraints on each individual sport performer during the acquisition of expertise in a specific sport or physical activity. Hopkins and Baker are correct in pointing out that major constraints on expertise are genes and training, but it is clear from dynamical systems theory that the constraints on the acquisition of expertise in sport for each individual are many and interacting. Focusing on the interaction of constraints has several implications for the acquisition of expertise in individual athletes.

First, as Hopkins and Baker suggest, we are only just beginning to understand the genetic and training basis for success in some sports. Although inherited traits are significant constraints on the upper limit of performance attainable by each individual, there is no guarantee of success for an individual athlete without extensive and intensive specific practice. Athlete A with a higher genetic disposition for speed endurance, but little desire to train, will not achieve the same level of performance as athlete B, with a solid endurance capacity, but who trains much harder, and has access to quality coaching and facilities. Practice might not necessarily make perfect, but quality time spent in training could give genetically under-endowed learners a better chance of success.

Second, even if genetic screening of individual learners is accepted as ethical, other constraints will limit or enhance the possibility of success at the highest levels. For example, a genetic predisposition for endurance needs to be specifically complemented by psychological characteristics such as mental toughness, tactical astuteness and motivation to endure pain during training and competition.

Third, environmental constraints such as lack of social and familial support could either spur an individual on to greater heights or nip promising careers in the bud. Individuals can react in many different ways to such constraints. Access to good coaching, sport science support, training equipment and facilities are also needed to allow genetic constraints to be expressed.

From a practical perspective, coaches and sport scientists need to understand that there are potential "gradients of success" for each athlete. These gradients, or limits to performance potential, are constrained by many factors, including genetic predisposition, quality of training experiences, exposure to high quality coaching, availability of

comprehensive sport science services, cultural, familial and social expectations and support, and access to equipment and facilities. How the full range of constraints interacts to limit or enhance the performance of each individual athlete can be considered in the form of a performance profile or athlete history. Although developing a checklist of constraints might help our understanding of the acquisition of expertise in a particular sport, the whole is greater than the sum of the parts. Performance at the highest levels of sport cannot be determined in a mechanistic or formulaic manner, since compensatory behavior in some athletes (for example, more rigorous approach to training or acquisition of sponsorship funds to access highest quality of coaching) can mediate effects of key constraints, such as genetic make up. Since expertise emerges under the interaction of key constraints, all of which differ for each individual athlete, compensatory variability in the path to success should be seen as the norm. For example, despite the growing evidence of genetic predisposition for speed endurance, not every Kenyan international long-distance runner ends up as an Olympic medal winner or world champion.

While it is important to know that 25% of variability in athletic performance between individuals may be determined by genes, or that 10 years of task-specific practice needs to be undertaken by most experts, we need to know more about the way genes, training, and other constraints combine to produce expert performances in the individual. Group-based analysis is limited for individual performance behavior, whereas a constraints-led perspective from dynamical systems theory provides a way forward.

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