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Nikolai Bernstein, Russian Physiologist, 1896-1966

Sherrington and Pavlov's basic understanding of simple reflex action dominated the field of neuro-physiology throughout the 1920s and 1930s, while researchers attempted to apply their "reactive theories" to explain all motor activity. In the 1920s, Bernstein was among the few earlier dissenters to argue that not all movement could be explained by simple reflex action. Instead, he believed that movements were active and goal directed and that a reactive theory could only explain behavior based on relatively static environmental stimuli. As Bernstein saw it, when exploring the environment, a person does not simply wait for stimuli to trigger his responses as a reactive theory would suggest, but instead formulates needs and dynamically adjusts his actions in an attempt to satisfy those needs.

It was from this position that Bernstein analyzed the biomechanics of posture and movement and used his findings to theorize how the mechanics of movement could be solved by the nervous system, its pathways, circuitry, and neurosensorimotor mechanisms to explain behavior. Bernstein was among the first to explore movement in this way, laying the foundation for what is now commonly referred to as motor control.

Bernstein published remarkable discoveries on movement coordination in the 1930s and1940s, and until his death in 1966, some of which have not yet been be translated into English. His main interest was in understanding how humans control voluntary movements. (Schmidt & Lee, Motor Control and Learning, p. 9) His analysis of coordinated movements evolved into the study of biomechanics, a term that he defined, and his findings remain relevant today, providing a basis for present day research in the fields of human anatomy and robotics. Among his most important contributions to motor control and reflex understanding include his concepts of degrees of freedom, hierarchical structure of motion control, and the motor engram.

Degrees of Freedom
One of Bernstein's most fundamental concepts is the notion of degrees of freedom. The body is complex and has many independent parts to coordinate in generating a movement. Bernstein conjectured that while the brain must control some aspects of movement, the sheer number of muscles and body parts involved in our moment-to-moment movements would quickly overwhelm our conscious thought. He therefore posed the problem for motor scientists as one of understanding how the body coordinates this complex movement with so many degrees of freedom. This concept has become known as the Bernstein Problem, and remains a puzzle for modern day scientists building on Bernstein's early work.

Hierarchical Structure of Motion Control
To address this problem, Bernstein hypothesized that the movement-control system is a hierarchical structure in nature where complexities are addressed by subsystems as low as possible in the hierarchy (Latash, Progress in Motor Control, 1998, p. 384). In this regard, he was influenced by Hughlings Jackson's hierarchical approach to brain function. To illustrate this idea, Bernstein wrote in his 1947 monograph, On the Construction of Movements, "The higher sections of the nervous system determine the chains of motor activity, the lower level ties movements to spatial coordinate. Still lower levels solve the motor problem as such by organizing the necessary interaction of elements (muscles, joints, limbs) and by operatively controlling their work."

The Motor Engram & the Impact of Degrees of Freedom
Bernstein addressed this hierarchical motion-control problem with his concept of the motor engram, which has become the basis for today's understanding of motor programs stored in the body and recalled when coordinated movement is required. An example of a motor engram can be seen when a child learns a skill such as throwing a ball. The automaticity in the action is achieved through repetition and is stored as a set of instructions (i.e., motor memory) in the body in the form of a motor engram. In this way, the brain/body coordinate to regulate movements, neither dominating the other, but both part of a coordinated system.

One of Bernstein's ideas that has received considerable attention is his characterization of skill development as a problem of increasing the number of active degrees of freedom. In the early stages of learning, joints may freeze or have a limited range of motion. As skills are learned, the range of motion increases. For example, imagine a child learning to write. At first, the range of motion in the fingers and wrist joints will be small or even frozen and the entire arm will be engaged as he struggles to put letters to paper. As the child progresses in skill development, the lower joints unlock and gain in their flexibility. With practice, greater overall flexibility leads to fluid movement, fluid movement to mastery and control, and finally the skill becomes automatic.

Generalized Motor Programs Today

Bernstein's work in degrees of freedom, hierarchical structure, and motor engrams all play into today's current understanding of generalized motor programs. A program, like an engram, refers to a particular class of general motor activities (ranging from simpler motor reflex movements to progressively more complex patterns, and then schemes) stored within the neuro-motor system. The stored program, general in nature, has the ability to dynamically adjust a reflexive activity in the process of its engagement, based on a continual loop of environmental/sensory feedback. This adjustment occurs in real-time (in the process of engagement) so that in its final execution, the resulting reflex response reflects the unique circumstances surrounding its execution. Because the program is stored as a "general template" that can be actively adjusted while engaged, it is referred to as a generalized program. (Motor Control and Learning: A Behavioral Emphasis, Schmidt, R., Lee, T., 2005, p. 193) The concept of generalized programming can apply to either an innate or learned reflex.

Bernstein's work remained largely hidden to Western scientists until the early 1960s when his work slowly began to be translated. As Bernstein's work is translated, many of the concepts he revealed between 1930 and his death in 1966, were just being revealed in the Western world, demonstrating in retrospect his prolific brilliance.