Dexterity and Its Development

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With *On Dexterity and Its Development*
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BERNSTEIN'S ACCOUNT OF ACTION DEVELOPMENT: REPETITION WITHOUT REPETITION

Most theories of motor development have been built on a very few premises. These premises have seemed to be obviously true, and a considerable amount of experimental research can be interpreted in accordance with these premises. It is Bernstein's greatest achievement in *On Dexterity* to have challenged the very foundations of these traditional theories. These theories are built on the following basic premises:

- Movements are the units of actions.
- Movements are either the results of central nervous system commands or reflexive.
- Movements are more likely to be repeated when they become associated with pleasurable feelings or outcomes.
- The repetition of movements, leading to changes in the frequency of given movements, is the central mechanism in action learning.
- Together these assumptions make up what one might call "associative hedonism"—the idea that associating positive states are what drive motor learning.

One can use such a theory to generate a scenario to explain almost any kind of action learning or development. Certainly one finds these sorts of explanations throughout the literature. For example, Asanuma and Arissian (1984) wrote, "When a subject is trained to pursue a specific movement, the practice produces vigorous circulation of impulses in particular corticoperipheral loops related to that movement. Repeated practice results in an increased efficiency of synaptic transmission in these loops" (p. 224). But is repetition of *movement* really so important in *action* development? Is the mechanistic association of movements with feelings or outcomes really so important as well? The twin ideas that repetition of movement and association of movement with positive hedonic states carve out pathways in the central nervous system are basic to all existing theories of motor development—but Bernstein soundly rejected this whole approach.

Bernstein occasionally summarized his theory of motor learning with the enigmatic phrase, "repetition without repetition." If one understands what this means, it serves as a key for unlocking a whole new way of thinking about behavior. Bernstein's always emphasized that absolute repetition of a movement pattern is not possible because of the inherent variability and complexity of the environment (Reed, 1984). A given pattern of muscle excitation will cause different patterns of limb and body movement when an animal encounters varying circumstances in its environment. This variability is not "noise" for the nervous system, according to Bernstein, but a fundamental environmental fact that exerts selection pressure on the evolution of nervous systems.

Yet, for the traditional theory of motor learning, such variability *is* noise, because it is assumed that what the animal must do when it learns an action is repeat certain behaviors until a specific neural pathway is well established. Bernstein countered this idea with a very striking argument: "It is very wrong to identify the elaboration of a skill with the beating a neural path in the brain. The coefficient of efficacy of this method would be outrageously low, for example, to spend hundreds of thousands of kilogram-meters of work on numerous repetitions of a pole vault in order to move a few molecules of the brain that had been blocking the neural path" (essay 6).

Thus, in the traditional theory of motor development it is *assumed* that the purpose of repetition is the establishment of neural paths, an assumption that is doubly unrealistic because of the impossibility of creating precise repetitions of neural or behavioral activity in different contexts (Edelman, 1993) and because of the manifest inefficiency of this scheme. In contrast, Bernstein *hypothesized* that repetition has an ecological function. Repetition, Bernstein insisted, is characteristic of motor learning because one must repeat actions many times in order to solve a motor problem. "Repetitive solutions . . . are also necessary because, in natural conditions, external conditions never repeat themselves. . . . Consequently, it is necessary to gain experience relevant to all various modifications of a task. . . . for the animal not to be confused by future modifications of the task and external conditions" (essay 6).

This concept of motor learning implies a new definition of what is learned and a new definition of motor skill, which Bernstein provided: "Motor skill is not a movement formula and certainly not a formula of permanent muscle forces imprinted in some motor center. Motor skill is an ability to solve one or another type of motor problem" (essay 6). Motor skill is thus defined ecologically—as the ability of an organism to encounter the range of environmental variations for a given motor problem and to learn to solve them adaptively. Obviously some species (or some individuals) will be able to handle wider ranges of variability than will others, but learning any motor skill, according to this definition, implies learning to solve a motor problem in a real environment, a process that involves the animal's managing to find a solution across at least some variation in circumstances. Inspired by Bernstein, a number of psychologists began in the 1970s to define action as the ability of an animal to control its changing relationship with the environment (Fowler & Turvey, 1978; Reed, 1982; Turvey, 1977).

Nevertheless, despite all the variability and change in an animal's relation to its environment, there are patterns of repetition that are important. Moreover, as we emphasize later, human learning is especially characterized by forms of cultural organization that allow the child or other learner to repeat aspects of an activity many times. As Bernstein pointed out, however, "Adherents to the view that exercise leads to beating a trail or imprinting a certain trace onto the central nervous system, somehow, have never paid attention to an important fact. A human starts learning a movement because he or she cannot do it." At the beginning of learning a skill "there is nothing to be beaten" or, worse, "the only thing available for imprinting is wrong, clumsy movements" (essay 6).

A good example of how actions begin to be learned before humans can do them is the development of reaching. As Von Hofsten (1979) showed, children begin to reach for moving objects before they are 3 months old. Yet the movement pattern of these reaches is totally different from mature reaches and even radically different from the more mature reaches of a 6- or 9-month-old. The early reaches include many phases of acceleration–deceleration–acceleration because the child's control over the arm is very "wobbly." But repetition of these incorrect patterns by no means imprints a version of this pattern; on the contrary, all normal children reorganize their reaching so that almost the entire displacement of the hand is accomplished by a single acceleration–deceleration phase, added to which is one additional deceleration–acceleration phase to make a final adjustment of position. Moreover, this change in *movement* organization is, at least in part, the result of a reorganization and development of dynamic *postural* control, which enables the child to move his or her arm more smoothly because the potential disbalancing effects of those movements are taken into account (Rochat, 1992).

Exactly the same analysis could be applied to learning to walk. In a longitudinal study, Bril and Breniere (1992, 1993) suggested that the main problem the young toddler has to face is the mastering of dynamic disequilibrium. The solution adopted at the onset of walking is very different from that used by adults: Infants tend to use a large base of support, small steps, high frequency of stepping, negative acceleration of the center of mass at foot contact, and no heel strike. Improved postural control results in the modification of these patterns over the course of development.

We think Bernstein's insight applies to almost all important aspects of action development: What develops is never a movement pattern, and the repetition of one movement pattern is by no means a guarantee that that pattern will be imprinted or more likely to occur in future. On the contrary, in learning an action one repeats, "not the means for solving a given motor problem, but the process of its solution, the changing and improving of the means" (essay 6). This is what "repetition without repetition" means: What one learns is how to solve a motor problem or how to act. This knowledge is learned by repetition, not by repeating patterns of movement, but rather by repeating the process of solving the motor problem.

The twin assumptions that repetition *must be* repetition of movements and therefore *must* beat a pathway in the nervous system follow from theorists' treating the nervous system as a mechanical system. Traditionally, psychologists and others who have studied motor behavior have tended to treat the nervous system as an input–output mechanism. However, the nervous system is much more accurately modeled as a self-organizing, dynamic system in which alterations in the activities of a single part may cause radical reorganization of the whole (Edelman, 1993; Kugler, Kelso, & Turvey, 1982; Fogel, 1993; Reed, 1989; Thelen & Smith, 1994).

It is fascinating to note that Bernstein seemed to have anticipated even this relatively late-20th-century concept of organization. He recognized that certain patterns and processes involved in repeated activities would tend to be repeated, and others would tend not to be repeated, depending on whether or not the activities tend to contribute to the dynamic stability of the system: "Even if it were possible, at the cost of considerable effort, to perform an unstable, self-destructing movement pattern, it is certainly, absolutely unrealistic to repeat it consecutively several times" (essay 6). The very capacity to repeat a movement pattern is an *achievement* of the organism, not something one can merely assume to be the basis for learning! Furthermore, "stable forms [of action] have all the prerequisites for being easily reproducible and, therefore, should be easily memorized. The result is that bad, unsuccessful movements are not fixed in memory, whereas successful solutions to motor problems tend to be firmly remembered" (essay 6). Bernstein stated that this tendency is an instance of the behaviorists' "law of effect," but it is really a radical reinterpretation of that so-called law. As we mentioned earlier, the traditional law of effect was based on the idea that a positive affective state would be associated with certain movements and that this association would be the cause of the increased probability of those movements occurring. Bernstein's position is that there are intrinsic, dynamic properties of some solutions to motor problems (*not* movements alone) and that it is the relative stability of these dynamics that is the cause of the increased probability of that solution's being repeated. Bernstein treated learning as a change in the probability of a process's recurring and changing in efficiency, not in the probability of a movement's recurring (Kugler et al., 1982; Thelen & Smith, 1994).

We extend Bernstein's argument in one important way. We emphasize that the ability to find dynamically stable solutions to motor problems in human life is rarely an individual matter. Even such biologically basic activities as eating and walking are always and everywhere learned with at least some help from other people. Caretakers of infants always structure the environment of the infants, frequently intervening directly in the infant's action patterns. Human infants thus do not "discover" motor problems on their own, in an inanimate environment. Specific motor problems are in many cases called to the infant's attention or even thrust upon the infant by one or more caretakers in what we call a *field of promoted action*. It is because human adults promote specific motor problems for infants—often before the child is capable of solving that problem—that human action development takes the course that it does. Bernstein's account of motor learning and his revised law of effect help explain why different human cultures provide very different fields of promoted action to their children and, yet, why a number of more or less invariant human activity patterns can be found cross-culturally.

THE CULTURAL SELECTION OF ACTION, MOVEMENT, AND POSTURE

As Gibson (1979/1986) noted, the ecological niche of a species can be understood as a set of opportunities for useful or meaningful action, opportunities that he labeled *affordances* (p. 128). Those affordances that are more common or important for individuals of that species will constitute a set of motor problems that all members of that species must be capable of solving in some way. However, in social animals, such as human beings, for which explicit instruction, observational learning, and various patterns of apprenticeship are ubiquitous, the niche itself is partially structured by the activities of members of the evolving population. That is, the probability of a developing animal's encountering a given affordance can be markedly raised or lowered by the actions of its caretakers. In addition, the frequency of such encounters can also be changed by the caretakers. Finally, the functional importance of the encounter can be significantly modulated by the caretakers (e.g., the mother cat may encourage her kittens to learn how to catch mice, but she will not force them to rely entirely on their own skill for obtaining nourishment).

The description of the niche for a developing member of a social species must thus include a realistic assessment of these significant facts of the "populated environment" (Gibson, 1982, p. 411). We suggest the following analysis (a modification of Reed, 1993) for helping to track these social factors in development.

At the level of individual action and interaction there are innumerable, particular behaviors by which one individual calls the attention of another individual to an affordance or even makes a particular affordance more easily accessible to the other. With regard to human action development these individual acts of *scaffolding* (Bruner, 1983; Rogoff, 1990) are of fundamental importance. The cultural organization of human life is so pervasive that even such "biological" skills as eating and walking typically develop along the path that they do in large part because of acts of scaffolding. We believe it would be a truly exceptional case for a human being to acquire the skill of walking without some older individual's having been repeatedly involved in the infant's acquisition of an erect posture, alternate foot placement, and the maintenance of visual attention on the region to which the infant is heading.

Human infants, then, do not inhabit the complete ecological niche for our species. On the contrary, infants will be *selectively exposed* to only a subset of that niche, to certain selected opportunities for experience and action. This selected subset of the niche we call the *field of promoted action.* Although each child probably inhabits a unique field of promoted action, it is very likely that