Bernstein's rejection of Braune and Fischer: Studies on the physiology and pathology of movements (1936)

Meijer, O.G.; Wagenaar, R.C.

published in
Motor control
1998

DOI (link to publisher)
10.1123/mcj.2.2.95

document version
Publisher's PDF, also known as Version of record

Motor Control, 1998, **2**, 95-100

Bernstein's Rejection of Braune and Fischer: Studies on the Physiology and Pathology of Movements (1936)

Onno G. Meijer and Robert C. Wagenaar

In 1936, on the eve of the great purges, Nikolai Bernstein no longer worked in the Central Labor Institute, where he had started his career. The Labor Institute was to be closed and its director, Gastev, would be killed in Siberia in 1938 (Bongaardt, 1996; Bongaardt & Meijer, in press). Since the beginning of his career, Bernstein had built networks of cooperation, and in the late 1930s he continued his work without problems at the Laboratory for Biomechanics of the Central Scientific Institute of Physical Culture, later as director of the movement laboratory of the Institute of Neurology. Bernstein's survival can be understood from both his own theoretical development and his practical involvement.

In the early 1920s, Bernstein was very much under the spell of Braune and Fischer's "Der Gang des Menschen" ("Human Gait") (1895–1904), which was at the time state-of-the-art. Braune and Fischer disagreed with the Weber brothers' idea (1836/1894) that the human walker should exploit the free fall of the swinging leg. According to Braune and Fischer, there is no such thing as a free fall in normal walking because muscles are continuously controlled by the will. By filming movements, they argued, one can first infer force from acceleration and then infer central nervous activity from force. These mechanistic assumptions led Bernstein to refine filming techniques, resulting in his kymo-cyclography of the 1920s (cf. Bernstein, 1936). Looking at his first results, he was struck by the detailed regularity of the kinematics of human movement.

In 1929, however, he used the term *biodynamics* instead of *biomechanics* in the title of a paper on piano playing (Bernstein & Popova, 1929), and he emphasized that the same movement can be produced by different constellations of forces. The simplicity of Braune and Fischer's mechanicism started to crumble. When mechanicism fell from grace in the Soviet Union in 1930, it was quite natural for Bernstein to switch his focus to the dynamics of movement. And in his 1935 paper on coordination and localization (1935/1967), he also rejected the second premise of Braune and Fischer: There is no univocal relationship between central impulse and peripheral force. Thus, force and kinematics became separate entities in the

Onno G. Meijer is with the Faculty of Human Movement Sciences, Vrije Universiteit, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands. Robert C. Wagenaar is with the Department of Physical Therapy, University Hospital, Vrije Universiteit, P.O. Box 7057, 1007 MB Amsterdam, The Netherlands.

study of biological movement. In 1935, inspired by German Gestalt theory, Bernstein emphasized the topological integrity of movements, while the microscopic details were now supposed to vary from repetition to repetition.

Politically, Bernstein had nothing to fear in the late 1930s because of his emphasis on dynamics and organized wholes. Moreover, he always had a strong interest in practical applications, and the practical application of science was highly regarded in Stalin's Soviet Union. From the start of his career, Bernstein had studied industrial labor. He always had a keen eye for sports, which is beautifully illustrated in his popular *On Dexterity and Its Development* (1947/1996). After the war, he was involved in training cosmonauts, and throughout his career he was engaged in the pathology of movement, not only because it posed an intellectual challenge but also because he wanted to help patients.

Bernstein's Approach to the Pathology of Movement

So far, Bernstein's ideas on the pathology of movement have been relatively inaccessible to the international community. However, Mark Latash has translated several of Bernstein's papers on the pathology of movement, and these translations will appear in the Bernstein's Heritage section of *Motor Control*. It is a pleasure to introduce the first of these translations, a 1936 paper entitled "Studies on the Physiology and Pathology of Movements."

As is so often the case with Bernstein's work, the paper reads with difficulty. Endnotes have been provided to clarify particular points in the text. The structure of the paper is that of a conference presentation, with numbered sections summarizing rather than elaborating arguments. In his introduction, Bernstein emphasized the importance of technical developments in filming movements (Section 1). He then explicitly departed from mechanicism to focus on the morphology of movement in terms of German Gestalt theory (Section 2) and restated his 1935 theory of coordination as the structured interaction between the central impulse and the external force field (Section 3). Many experiments had been performed on human gait, in both health and pathology (Section 4).

The central argument of the paper (Sections 5–9) starts off close to the work of Braune and Fischer, with Bernstein focusing on the regular nature of ground reaction forces (Section 5) and the evidence from these forces that central impulses are prestructured in time (Section 6). From the viewpoint of Bernstein's 1935 paper on coordination (1935/1967), this is somewhat puzzling. Wasn't he convinced by now that one cannot infer the central impulse from force? Yes, because of the external forces. In this 1936 paper he appeared to first subtract the external forces from the ground reaction forces in order to still arrive at the central impulse. In part, this may have been tactical—Bernstein wanting to bring the audience to familiar grounds before breaking the news. In part, however, the argument is also in agreement with the 1935 paper on coordination, where Bernstein emphasized the Gestalt nature of the spatial organization of movement, at the same time understanding the temporal organization of movement in terms of a prestructured program. It is the nature of these programs that is amazing: Running may be based upon a very similar "series of central impulses" (Section 7) as walking, but the interrelations between force waves are different. In other words, and this is where the paradox resolves, there indeed exists a nonunivocal relationship between the central program and the final output of forces.

Such nonunivocality is clearly illustrated in the ontogeny of walking, where the kinematics may appear to be "flawless" (Section 8) while the pattern of force waves is still underdeveloped. Thus, there is a very clear difference between kinematics and forces. They are united through proprioception, and so the rejection of Braune and Fischer's mechanicism becomes complete. The control of equilibrium offers a good example (Section 9): The Gestalt structure of the kinematics remains the same, while actual forces are changing all the time in order, one would say now, to allow for this invariance of the kinematics.

Having presented his distinction between kinematics and forces, Bernstein proceeded to apply this idea to the pathology of movement. Peripheral problems lead to changes in actual force production (Section 10), while the central program tends to remain the same. In problems with proprioception, the pattern of force waves remains the same while the actual kinematics start to fluctuate wildly (Section 11). Finally, central nervous problems lead to completely different patterns of force production (Section 12). Clearly, this is an inspiring scheme, driven much more by his enthusiasm for the rejection of mechanicism than by data. Nevertheless, this scheme shaped the development of Bernstein's understanding of the pathology of movement as the pathology of coordination.

Studies on the Physiology and Pathology of Movements[1]

N.A. Bernstein

1. Our studies are presently performed using the method of cyclogrammetry, which has been refined to a very high level of precision. The most important recent technical innovations are kymo-cyclo-apparatuses of the newest models (Pavlenko) and tuning-fork/tone-row synchronizers[2] (Bernstein & Pavlenko).

2. Movement studies by earlier authors (the Weber brothers, Vierordt, Braune, and Fischer) were focused on a mechanical analysis[3] of motor processes. At present we emphasize the descriptive morphology of movement, considering it as an organically complex structure and performing its microscopic analysis in health and pathology.

3. Movement is an external manifestation of the cyclic interaction between the central nervous system and the external force field, which contributes to the reactions of passive elements of the peripheral motor apparatus and the external forces acting upon it. What is called movement coordination is the structure of this interaction, which is anatomically reflected in the localized structure[4] of the central nervous system. The general localized and coordinated regularity of the interactions between the motor apparatus and the environment is the motor field[5]. Studying its development and pathological changes is an urgent task for motor physiology.

4. We performed a very detailed analysis of one of the most interesting groups of motor structures, namely human locomotions. Hundreds of experiments have been performed on tens of subjects to study walking patterns of healthy adults without an additional load (Bernstein) and with a load (Popova)[6], and with and

without fatigue (Spielberg); running patterns of elite athletes (Bernstein); the development of walking in early childhood (Popova) and its involution with age (Spielberg); and the pathology of walking in organic disorders of the central nervous system (Bernstein, Farfel) and in disorders of the peripheral motor apparatus (Farfel, Zaltsgeber).

5. The main characteristics of locomotion dynamics are revealed in the curve of ground reaction forces, which is equivalent to the pattern of forces at the body's center of mass. During normal walking, this curve contains three dynamic waves, which I originally described. Its relative amplitude, A (i.e., amplitude divided by body weight[7]), is less than unity during walking and shows a close proportional relation to the square of stepping frequency: $A = Qn^2$, where n is the number of steps per minute and Q is a constant whose normal value is between 0.09 and 0.1 s^2. Load is characterized by an inequality $A \geq 1$ and by ground reaction curves with a single prominent peak.

6. We have for the first time discovered that force curves in links and systems during walking have precisely defined and universal structures characterized by a strict order and by spatial[8] relations among the waves. One of these waves represents mechanical reactive effects that depend on the anatomy of the peripheral motor apparatus. Other waves are reflections of central neural impulses representing waves of muscle contractions that cannot be reduced to an interplay of external, mechanical forces. These waves are the first documented case of multistage innervation of a rhythmic movement outside the visceral system.

7. The dynamical structure of running is dramatically different from the structure of walking, but it is based on a series of central impulses that are very similar to the series of impulses during walking. This series is inherent to many cases of running that I have studied, and it repeats in a regular fashion all the major impulse waves of walking, although with changes in their interrelations.[9]

8. Studies of the evolution of locomotor structures at very early stages (Popova) have shown that the mentioned series of impulses are not present at the beginning of ontogenesis. Walking patterns of children 1 to 2 years of age reveal an innervational primitive,[10] with only single-stage reciprocal impulses and a few waves of mechanical origin. Many basic force waves emerge much later (at 6 to 7 years) than the seemingly flawless patterns of child walking and, in particular, much later than children master equilibrium. That is why these basic force waves cannot be viewed as identical to the dynamical mechanisms of postural equilibrium.

9. Mechanisms of the control of equilibrium cannot, by their very nature, manifest themselves as stable, ubiquitous waves. These mechanisms manifest themselves as quantitative rhythmic differences between successive locomotor cycles. During normal walking, as a rule, differences among the kinematics (trajectories) of individual cycles progressively disappear; these differences are much more pronounced among force curves (a symptom of healthy proprioception).[11]

10. Pathology of motor structures manifests itself differently in different cases. Peripheral abnormalities (e.g., hypotonus in tabes dorsalis, antalgic symptoms in knee joint pain, etc.) result primarily in changes in the mechanical waves. Central pathologies lead to disorders of central, neural waves which, however, display high resistance.[12]

11. Pathological changes of proprioceptive mechanisms (tabes dorsalis) manifest themselves as an inversion of healthy proprioception: Differences among

kinematic patterns (trajectories) of individual cycles not only become visible but start to exceed the differences among corresponding force curves (a symptom of a proprioceptive disorder).[13]

12. The basic structure of the ground reaction curve shows dramatic changes in organic disorders of the central nervous system. In particular, in tabes dorsalis, there is an obvious dominance of the single-peak type with isolated, short-lasting vertical waves (Farfel). This symptom can be seen at very early stages when the walking pattern does not show any discernible differences from normal walking.[14]

Notes

[1]At the time this paper was written, Bernstein was with the Section of Movement Physiology, The All-Union Institute of Experimental Medicine, Moscow. The original paper was published in the *Physiological Journal of the USSR*, Volume 21, No. 5/6, pp. 1017-1019, 1936.

[2]The shutters of Bernstein's cameras consisted of a rotating wheel with holes in it. In order to determine shutter speed, he blew air through the holes, established the tone with tuning forks, and then calculated shutter speed (Bongaardt, 1996).

[3]Bernstein missed the dynamical inspiration of the Weber brothers (Mary Flesher, personal communication), apparently by relying too heavily on Braune and Fischer. The work of the Weber brothers as well as Vierordt, and for instance Marey, is discussed in some detail in the introduction of Braune and Fischer's "Human Gait" (1895-1904).

[4]This localization is a localized organization (a localized set of relationships) rather than one-to-one relationships between cortical cells and motor functions (cf. Meijer & Bongaardt, 1998).

[5]Bernstein's notion of "field" derives from Gestalt theory. Its physical definition adds to the dimensions of position and velocity a partial differential equation for each point in the field. In other words, each point in the field has its own tendency to change like water drops in a flowing river. To Bernstein, biological movement reveals this phenomenon in the ubiquitous possibility of adapting to perturbations while retaining the overall morphology.

[6]Currently, the Bernstein Heritage section focuses on Bernstein's own publications. In later issues, the focus will be widened to include his co-workers.

[7]*A* is dimensionless because both force amplitude and weight are expressed in newtons.

[8]These "spatial relations" are properties of the time structure and have no direct relationship to the kinematics of the movement.

[9]Bernstein may well have been the first to claim that the basic structure of running and walking is the same, notwithstanding the vast differences in their phenomenology.

[10] It seems that here Bernstein used the mathematical notion of a "primitive," that is, a root function from which other functions can be derived. Later, he wrote that the problems of an older child walking may be different in principle from those of a younger child (1947/1988).

[11]This is a central point in Bernstein's theory from 1935 onward: That the spatial topology remains invariant is made possible by the variance of other factors.

[12]This appears to be inconsistent with Section 12, where Bernstein emphasized that disorders of the central nervous system lead to very different force waves. Maybe Bernstein envisaged the central programs as dynamically stable, that is, resistant to change unless there is a transition to a completely different form of organization.

[13]Bernstein appears to be saying that the diagnostics of pathology should include both force production and changes in kinematics. Even to date, such a viewpoint is still in its infancy.

[14]We apologize that the length of our introduction plus endnotes exceeds the length of the original paper. To us, this paper reads like a piece of art: The more one studies it, the richer it becomes. Here one sees a man entering a completely new territory but still showing signs of the old. Contrary to what many believe, paradigm shifts take much longer than a split-second (cf. Gombrich, 1950/1972).

References

Bernstein, N.A. (1936). Die kymocyclographische Methode der Bewegungsuntersuchung [The kymocyclographic method of movement analysis]. In E. Abderhalden (Ed.), *Handbuch der biologischen Arbeitsmethoden* (Vol. 5, pp. 629-680). Berlin: Urban und Schwarzenberg.

Bernstein, N.A. (1967). The problem of the interrelation of coordination and localization. In N.A. Bernstein, *The co-ordination and regulation of movements* (pp. 15-59). Oxford, UK: Pergamon Press. (Original work published 1935)

Bernstein, N.A. (1988). Die Koordination der Bewegungen in der Ontogenese [The coordination of movements in ontogenesis]. In L. Pickenhain & G. Schnabel (Eds.), *Bewegungsphysiologie von N.A. Bernstein* (2nd ed., pp. 97-137). Leipzig, Germany: Johann Ambrosius Barth. (Original work published 1947)

Bernstein, N.A. (1996). On dexterity and its development. In M.L. Latash & M.T. Turvey (Eds.), *Dexterity and its development* (pp. 3-244). Mahwah, NJ: Erlbaum. (Original work written 1947 and published 1991; translated by M.L. Latash)

Bernstein, N.A. & Popova, T. (1929). Untersuchung über die Biodynamik des Klaviranschlags [Study of the biodynamics of piano playing]. *Arbeitsphysiologie*, **1**, 396-432.

Bongaardt, R. (1996). *Shifting focus: The Bernstein tradition in movement science.* Unpublished doctoral dissertation, Vrije Universiteit, Amsterdam.

Bongaardt, R., & Meijer, O.G. (in press). Bernstein's theory of movement behavior: Historical development and contemporary relevance. *Journal of Motor Behavior.*

Braune, W., & Fischer, O. (1895-1904). Der Gang des Menschen [Human gait]. *Abhandlungen der Könichlich Sächsischen Gesellschaft der Wissenschaften*, **21**, **25**, **26**, & **28** (6 volumes).

Gombrich, E.H. (1972). *The story of art.* Oxford, UK: Phaidon. (Original work published 1950)

Meijer, O.G., & Bongaardt, R. (1998). Bernstein's last paper: The immediate tasks of neurophysiology in the light of the modern theory of biological activity. *Motor Control*, **2**, 2-9.

Weber, W., & Weber, E. (1894). *Wilhelm Weber's Werke, Band 5: Mechanik der menschlichen Gehwerkzeuge* [Wilhelm Weber's works, Volume 5: Mechanics of the human walking apparatus]. Berlin: Springer. (Original work published 1836)

Acknowledgments

We gratefully acknowledge Rob Bongaardt, Mary M. Flesher, and Mark Latash for stimulating discussions about the content and historical background of this paper. For our introduction, we heavily relied on Bongaardt (1996).

Accepted for publication: December 12, 1997