Variability by Another Name: "Repetition Without Repetition"

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Abstract The fundamental distinction between reaction and anticipation corresponds to their respective condition. Reaction is by its nature the expression of a particular form of causality defined within Newtonian physics. Anticipation corresponds to a specific form of causality associated with the past and with possible futures. Bernstein acknowledged that motoric activity is driven by the future, i.e., by the goal pursued. The formula "repetition without repetition" captures the role that variability, as an expression of anticipation, plays in the motoric process. This study focuses on an attempt to capture the holistic expression of anticipation in quantitative descriptions, and draws a parallel between Bernstein's experimental work and that carried out in the AnticipationScope.

Keywords AnticipationScope · Causality · Motoric repetition · Variability

Anticipation is systemic in nature, and of non-deterministic condition. Bernstein, whom we mentioned already as a precursor of anticipation research [1–3] examined movement in order to obtain information on the workings of the brain (Meijer and Bruijn [4]). Feigenberg [5] considered the variety of ways in which future-driven activities can be described. He opted for the mathematics of probability, and Bernstein was quite satisfied with this option. At the antÉ—Institute for Research in Anticipatory Systems, we considered human performance in its most general terms: work, learning, leisure activities, sexuality, and reproduction. Activities (intentional or not) that trigger change or assist in adapting to change are, in my view, a better description of performance than particular motoric expressions. The goal assumed in our experiments was to characterize performance in both qualitative and quantitative ways. A simple diagram (Fig. 1) captures the working hypothesis.

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M. Nadin (ed.), *Anticipation: Learning from the Past*,
Cognitive Systems Monographs 25, DOI 10.1007/978-3-319-19446-2_19

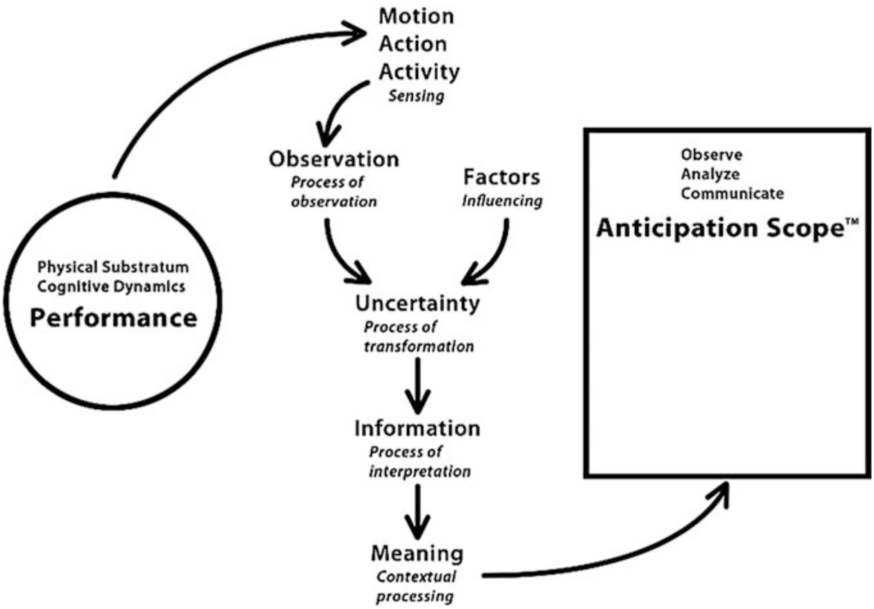

Fig. 1 Analyzing human performance

While fringe awareness of anticipation (anecdotal evidence) is ubiquitous, what has never been attempted before is quantification as a *holistic* expression. The AnticipationScope™, presented in detail (Nadin [6], among other publications), was conceived exactly for this purpose. During 2005–2006 when I designed the "scope," I was not yet aware of Bernstein's attempts at measuring motoric expression, which date back to the 1930s and 1940s. (As a matter of fact, his book, *On Construction of Movements*, published in Russian in 1947, is still untranslated. Very few scientists exploring the human motoric have ever read it. Feldman's book [7], *Central and Reflex Mechanisms of Motor Control*, also relevant to the subject, remains untranslated.) Actually, Bernstein's goals and ours overlap only partially. His goal was to describe motoric activity. We had in mind a broad integrative approach: collect data pertinent to physiology, cognitive processes, and brain and muscle activity, and provide for an integrated data-processing and data-mining platform. The goal was to integrate brain imaging, EEG data, auditory evoked potential, EKG, somatosensory evoked potentials, TMS (Transcranial Magnetic Stimulation), EOG (Electrooculogram) and eye tracking, temperature, blood pressure, respiratory rate, blood oxygen saturation, GSR (galvanic skin response), EMG (electromyography), nerve conduction, and saliva measurement (hormonal activity associated with motoric activity). In addition, physical characteristics were to be described using the classic means: accelerometer (to describe neuromuscular reflexes), force plates (for characterizing stepping, jumping, falling, etc.), dynamometer (to quantify grip strength and evaluate fatigue), etc. In defining the holistic expression of anticipation as our goal, we were aware that the list given above remains open. To map from the open-ended system to a limited model is by its nature a reductive attempt.

Theories of motor control focus on skills as integrated form movements. They ascertain that a central mechanism, an open-loop program, controls movements. This differs from Pavlov's motor control theory. The fact that the sequential model (serial order) is only an approximation becomes evident when a certain action (hammering, hitting the golf ball) involves parallel components. The action depends on the perception. The hand seems to "know" what resistance it will meet. Planning is yet another model used in order to describe how an individual performs. Planning an action such as nailing two boards, or cooking, depends on awareness of one's skills; planning in swimming is affected by the style. Planning in team activities (lifting a heavy object together), or in sports (e.g., soccer, hockey, volleyball) is a matter of coordination among many plans: those of the individual players, as well as the plans developed during training for certain situations. An orchestra (Ito [8]) embodies yet another sense of anticipation.

The AnticipationScope (Fig. 2a, b) was conceived in order to produce a representation of the living in action, not only motoric expression. Such a representation is an integrated expression across multiple systems, including sensory perception, proprioception, cognition, motor control, and affect. The basic premise of the entire design of the AnticipationScope derives from knowledge about the unity between action and goals, i.e., how anticipations are expressed. In the future, we intend to create and deploy a wearable AnticipationScope that returns an integrated stream of data that represents the Anticipatory Profile™ of the person.

As already mentioned, the knowledge we want to describe can be divided into three categories:

1. *Description of motion*: The most tangible category consists of the motions that represent the position, velocity, and acceleration of all body parts at a given time.
2. *Description of action*: Bernstein himself was very interested in this level. Actions belong to a higher-level category and refer to the basic motion sequences or to static postures. Actions are generally sequential and rather consistent. Examples include standing, moving from sitting to standing, walking, and jumping. Actions are of most interest for recognition systems since they add a temporal characteristic to the sensory observations. While actions provide more information than motions do, they lack realization of intelligent intent or of emotional drive in human behavior.
3. *Description of activity*: This role is carried out at the highest level of motion abstraction. An activity is an integrated goal-oriented group of actions. It is an integrated expression of syntax, semantics, and pragmatics. This level of description was achieved only partially in Bernstein's attempts. Bernstein was able to improvise time referencing for recording the syntax of motion, but not for providing a semantic description.

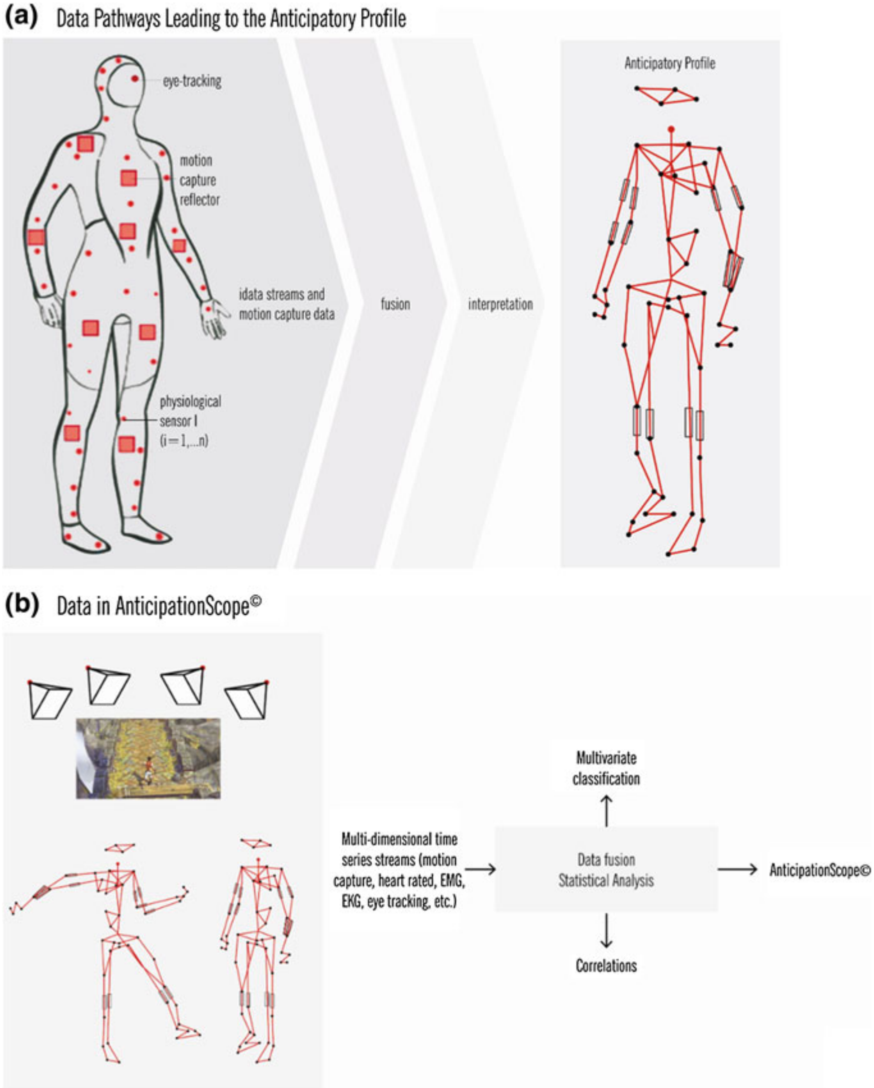

Fig. 2 **a**, **b** AnticipationScope

Our research goals are quite different from those pursued by Bernstein and those who either collaborated with him or followed in his footsteps. We were not trying to reconstruct movement kinematics. Neither were we specifically observing joint torques. However, motor redundancy soon became apparent, and we wondered if this was associated with anticipation. Evidently, since in my view anticipation, as expression in action, is always holistic, we focused on integrated motion (what Latash [9] calls *synergy*).

In retrospect, and in consideration of Bernstein's experimental work and our own, it should be noticed that we focused on the interplay between the probability distribution, corresponding to past performance, and the possibility space, corresponding to anticipation. Example: the problem of sitting and the associated problem of entering one's car without hitting the door frame involves past knowledge, as well as possibility perception, i.e., awareness of what might go wrong. Other activities subject to anticipation expression, such as ascending or descending stairs, catching a ball, and collision avoidance, were also evaluated. The experiments afforded data pertinent to a variety of measured parameters.

So far, the data suggest that high-performance perception and motoric abilities are a necessary condition for any performance—but not sufficient. Our research confirmed that through anticipation processes, data from the environment (the context) are complemented by data generated by the subject in the performance. (This goes back to research I carried out in 2013.) The concrete process of such data generation remains our major subject of inquiry at present. For reasons to be discussed below, we focused on sports performance (in addition to capturing data relevant to aging in Project Seneludens).[1]

We also continue to examine the interplay of senses, in particular how they complement each other. The community of researchers took note of the fact that in catching a fly ball (in baseball) binocular vision is correlated with the information provided by the vestibular system. But we still do not have enough experimental resolution for describing this correlation. In the next-generation AnticipationScope, in which eye movement tracking is integrated with motion capture and information from the vestibular system, the correlation in question could be better described. By extension, we could elaborate on the anticipation in returning a fast serve in tennis (sometimes as high as 180 mph), and the anticipation involved in downhill skiing. We would also start to describe the information generated by athletes on account of their experience, or as a result of dynamic somatosensory integration in cognitive processes. Moreover, sensory data—from the tongue (in the case of golfers), from nostrils, from eyelids, among other sources—affect movement. All these goals are somehow related to a fundamental observation: human performance, whether accidental or methodic, is characterized by what seems an inherent, unavoidable variability, or "repetition without repetition," Bernstein's [10] famous formulation. The "desired future," "the elimination of redundant degrees of freedom," and "the bliss of abundance" (all Bernstein formulations) were, if not specifically documented, at least acknowledged. Variability of outcome (in respect to the experiments mentioned) is captured in Fig. 3.

The functioning of a machine is characterized, of course, by perfect repetition. Every effort is made to make sure that whatever the machine "does" results in a perfect repetitive pattern. Repetition without repetition, which was documented in

[1]Project Seneludens, see (http://www.anteinstitute.org/index.php?page=seneludens) and (http://seneludens.utdallas.edu).

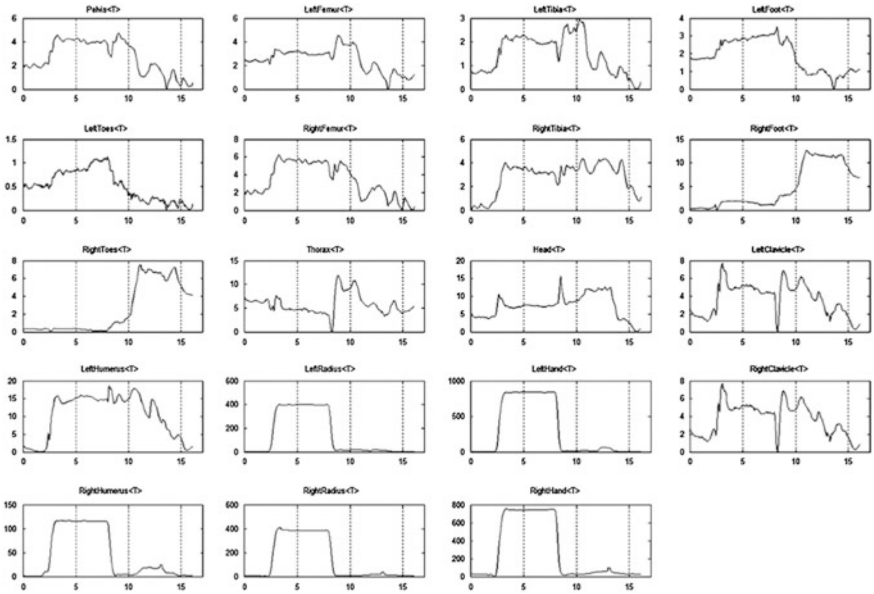

Fig. 3 Variability of outcome

the AnticipationScope, describes the fact that even gestures meant to be identical—a hand movement, gait, a dance step—are never the same. While performance in aging persons is, not surprisingly, marked by variability, that of professional performers (e.g., musicians, dancers, athletes) would have to converge to predictable monotonicity. But it does not. The motoric performance depends upon a large number of variables that continuously change. Sensors inform cognitive processes (i.e., muscles, tendons, body mass in permanent activity). Movement variability explains how virtuosity (e.g., music performance, dance, competitive sports, computer games) can be reached. The interdependence of action and perception underlies this variability.

Bernstein (see https://www.youtube.com/watch?v=yDxPJlBqWuM) was totally dedicated to recording human activity and to documenting its variability. He integrated rudimentary technology and, for all practical purposes, came up with a motion capture environment long before digital photography and computer imaging made it possible. Here I make reference to what Bernstein called "cyclogrammetry," conceived as a method for recording movement at 150–200 frames per second. This was followed by "kymocyclography," which made possible the determination of duration of movements [11]. Analysis of the recordings allowed Bernstein to discover the integrated nature of movement: every component is dependent upon all others. From here the suggestion: the central nervous system does not command a unique course of action, but rather partakes in the selection among a large variety of joint trajectories. In the framework of the conference to which this volume is dedicated, it became clear that in studying the motoric system, Bernstein chose high-performance activities (playing piano, gymnastics, and highly specialized forms of factory work, among others) exactly because of their high variability. Within all of these motoric expressions, there is a preparation component, an anticipatory component, and a reactive component.

At the time I conceived the AnticipationScope (see https://www.youtube.com/watch?v=APUQvYDyXIE), Bernstein's [12] attempts at measuring motoric activity and its variability were known to me only through a few of his writings. Of course, before Bernstein there are the "instantaneous photographs" taken by Muybridge (in the 1880s). Etienne Jules Marey (1883, a man in a black suit with striping and points predates the motion capture techniques) with his chronophotographs (of "The Human Body in Action," reported in *Scientific American* in 1914) continued in the same direction. Christian Wilhelm Braune and his student Otto Fischer (inspired by Marey) focused on the biomechanics of gait and center of gravity posture analysis. (Bernstein actually refuted their findings; Meijer and Wagenaar [13]). Georges Marinescu (Barboi et al. [14]), using a cinematographic camera, focused his studies (starting 1899) on gait disorders, locomotor ataxia, and other aspects of motoric neurological disorders. He was among the very first to recognize that film images could provide insight regarding the nature of changes in human movement. The AnticipationScope might not build upon previous work, but it certainly reflects the same interest in capturing data pertinent to motoric activity (and more).

Focus on motoric aspects peculiar to sport is a natural choice: if anticipation defines goal-oriented actions (e.g., return of a tennis serve, skiing downhill in the shortest time, scoring in ice hockey, performing gymnastics with no or only minimal errors), then competition makes it even more significant in attaining them. It comes as no surprise that Bernstein chose similar examples. Our measurements suggested that, against the expectation of "machine perfection," athletes perform under circumstances of variability. (This subject also preoccupied van Emmerik and van Wegen [15].) We produced data that take Bernstein's hypothesis a step further. There is a clearly desired variability (trying another movement in order to enhance performance), and accidental variability (affecting, positively or negatively, the outcome of an action or of a sequence of actions).

For those who study sports performance, our data is suggestive of possible changes in the practice of coaching. But there is more to this. Artistic performance (music, dance, theater, etc.) is different from sports performance insofar as one concert is not supposed to be better than the others in a three-to-four day series; a theater performance might vary from one day to another, but it will not "outperform" itself; dancers are not advised to be "champions" on one day and fail the next. Nobody wants a human-machine on the stage (equal performance regardless of context), but also not a capricious outcome. Therefore, the understanding of variability transcends the domain of the motoric. It has aesthetic significance, and it can have major medical consequences: training can help improve performance, but it can also adversely affect health. It is telling that in our days, movie-making, game

Fig. 4 Members of the USA Olympic Team in the AnticipationScope. Among the observations made: sensory data from, e.g., skin, muscles, tendons, eyelids, ears, nostrils and tongue affect motoric expression

production, and dance build upon knowledge about human movement acquired in motion capture laboratories. Meyerhold, the visionary theater director (and sometimes actor) established (1922) his Biomechanics Laboratory to help artists improve physical expression (coordination, agility, flexibility). He helped actors develop skills (for various acrobatic stunts) that in our days are usually entrusted to stuntmen. He was training their anticipation. Bernstein himself tried to describe the variability of piano playing focusing on dexterity. The aesthetic dimension of research in the AnticipatonScope has yet to be presented (Fig. 4).

I find it extremely instructive that "repetition without repetition," descriptive of variability as an outcome of anticipation, can adequately describe parallel research paths, followed at different places and at different times, by researchers dedicated to fundamental questions of science. In this sense, Rosen's research on anticipatory processes, and, more recently, Louie's [16] are no less "repetition without repetition" as my own.

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