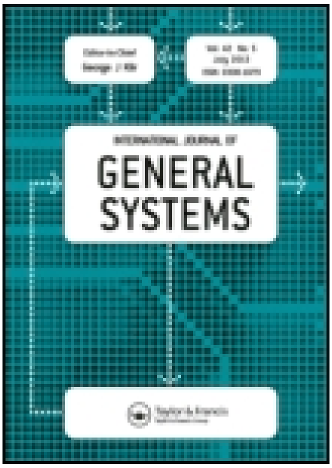

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Anticipation - the underlying science of sport. Report on research in progress

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Anticipation – the underlying science of sport. Report on research in progress

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Professional sport practitioners intuitively acknowledge anticipation. Sports researchers sometimes discuss it. Still, there is little data-based evidence to characterize the role anticipation plays in human performance. Even less documented is the distinction between reaction and anticipation. This text presents the real-time quantification environment developed as an AnticipationScope™. Based on a very large data harvest from this experimental set-up, hypotheses regarding the role of anticipation in sport are advanced. The conclusion is that while preparation and reaction play an important role in sports performance, in the final analysis anticipation distinguishes the professional from other sport practitioners. Work in progress is presented with the aim of engaging the community of researchers in the design of alternative methods for quantifying anticipation and for processing the data. Generalization from sport to human performance is one of the intended outcomes of this research.

Keywords: anticipation; holistic perspective; perception; reaction; space of possibilities; variability

Dedicated to I. M. Feigenberg

1. A context for defining the subject

Sport is primarily an expression of self-awareness. In the vast scientific literature about sport (Bingham 2000; Richmond, Begun, and Strait 2001; Bramble and Lieberman 2004; Roach et al. 2012, 2013), evolutionary aspects take precedence over any other explanation. There is, evidently, an evolutionary advantage to being faster, jumping higher, hitting harder, striking the target, swimming better, maintaining balance under difficult circumstances and in out-doing adversaries. However, sport is less an outgrowth of evolution – it is actually not the *outcome* of evolution – but more a particular way of self-constitution as human (Gibson 1979). Sport and survival of the fittest (the trivialized model of evolution theory) have little in common. Sport becomes possible in the "second nature" of human beings, i.e., in culture. In current predominantly science-and-technology based human activity, the only justification for competitive sports is its entertainment value. And, of course, the role it plays in the economy. Wolański (1999) was quite blunt in his observation: sport (he meant high-performance sport) "has nothing in common with promoting and supporting health". Chances are that some sports of the past, in which the human being competed with animals (fighting lions, e.g. in the Roman circus), will be replaced by competing with machines: the robot runner, or jumper, or swimmer,

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even sharpshooter. Computer games (sometimes known as videogames) have already triggered intense competition among their fanatics, playing against AI-driven programs or each other: 27 million daily, organized in teams of five playing against each other.

The above paragraph is a sketch for a broader context of understanding the changed meaning of sport in our days. In *The Civilization of Illiteracy* (Nadin 1997), which describes the new dynamics of post-industrial society, I dedicated a chapter to sports ("The Professional Winner"). The role played by technology was generously highlighted. Human motion (in the broad sense of the word), in gymnastics in particular, was the focus of Bernstein's (1947, 1967) early research in anticipation (a subject to which I shall return). Since 2005, anticipation expressed in action has become a focus of research in the lab of the Institute for Research in Anticipatory Systems (Pradhan et al. 2007); after 2010 it was extended to quantifying various aspects of human performance. This led to the observation that the question of why sport is not only for pleasure but also a serious subject of research suggests a new perspective. Indeed, sport is researched in order to understand better how the human being performs and thus to better understand ourselves. Knowledge of medical, psychological (Straub and Williams 1984; Senot, Prévost, and McIntyre 2003), neurocognitive (Adam et al. 2003) and technical significance is a part of this endeavour. *Human Movement Science* (a journal is dedicated to the subject) also informed the research (from Buytendijk 1956 to, more recently, Mori, Ohtani, and Imanaka 2002).

Sport is also researched from the perspective of competition: What drives human performance? Of course, those who teach sport (from physical education in school to competitive sports) want to know what it takes to shape successful practitioners – the champions. The fact that ethnic aspects, environmental issues, gender peculiarities, etc. eventually come up corresponds to the many functions that sport has acquired. It is symbolic for nations, for races, even for religions; it is political in the sense that it reflects values associated with democratic access vs. elitist models. Handicapped persons are now part of the larger sports movement – it is a "right" they fought for and enthusiastically exercise, for example, through the Special Olympics, Paralympics and Olympics for the disabled. Sport also factors into the economy, which is more important than anything else in our days. Events significant to sports figure very high in the global economy, given the interest in practicing sport for one's own benefit (health not necessarily part of it), and in the economy of entertainment (associated with supporting technology, sports medicine, rehabilitation and especially, merchandising). A full stadium, for whichever event (including the "finals" of the 67-million-participant game called League of Legends, Seoul, South Korea, October 2014, attended by 40,000) is of many orders of magnitude a more powerful economic engine than a concert hall or an art museum. Owning a successful team (basketball, hockey, football, soccer, and more recently a computer game team) is way more profitable than building a factory or housing units. Sport is big business in our time; and the science of sports became – not necessarily because researchers had this goal in mind – a means for monetizing knowledge (of physiology, anatomy, cognition, diet, etc.) leading to victory. As an expression of self-awareness, sport is addictive: the living, whether animal, bird, fish, insect, or human, wants to win. Sport turns this instinct into a characteristic of the human species shaped by forms of activity unrelated to survival and existence. For the average individual forced to a sedentary lifestyle, one additional push-up or a higher score on the steppers in the gym is a victory, no less rewarding than winning at Wimbledon or the Olympics.

2. The wager

This is the first level at which anticipation – of success – intuitively comes to mind. Anticipation means that the future appears in the causal chain as a factor impossible to sort out.

A very simple representation can help explain how the future figures into the causal sequence (Figure 1).

The deterministic cause-and-effect relation, in which the past alone determines the present, is complemented by the relation to the desired outcome in the form of feedback (the core of cybernetics). If we add here the feed-forward processes, i.e., the activity of the mind specific to sport activities, we arrive at a more suggestive representation (Figure 2).

Much has already been contributed to this understanding of anticipation (Abernethy 1987; Lacquaniti and Maioli 1987, 1989; Elsner and Hommel 2001; Nadin 2003; Hoffmann, Stoecker, and Kunde 2004, Shim et al. 2005; Borysiuk and Sadowski 2007; Huys et al. 2009). Behind the intuitive-level description associated with the outcome there is, of course, the deeper level at which not only the motivational aspect of winning plays a role. The jumper wants to reach a height that competitors are unable to match. However, no less important is the concern with not doing oneself harm. Successful expression during performance engages the totality of the entity in question. This applies to the simplest forms of the living, as well as to the most complex – the human being. While animals do not really engage in sport, their performance (in catching prey, e.g.) depends on their sensorial endowment, their brain and the associated motor control, their physiology, and their anatomy. The human being dedicated to sport, for whichever reason (even for what is expressed as "for the fun of it") is entirely engaged. This holistic understanding points not only to the eyes, ears, muscles, toes, someone's tongue or hair, but also to the molecular level, to all the cells, to the proteins, to the neurons and to the DNA. The list is open, but by necessity includes all there is to each individual. And since each organism is in continuous change, we consider a dynamic holism.

In terms of anticipation, this means synchronization processes expressed in the successful performance of the task undertaken. Indeed, time is essential in every form of sport (fast or slow). The fact that even hairs participate in the perception of time (Neisser 1976) is a good, although only partial, illustration of the holistic nature of every form of human activity. From head to toe, all is engaged. This article will not, given the context, focus on the particular role of each component; we shall also leave aside, for now, molecular and genetic aspects. But in order to understand the scientific premise – anticipation as the underlying premise of sport – one must first realize that anticipation is a holistic expression. Sport performance is a living argument in the anti-reductionist understanding of life. The reductionist viewpoint of science (dating back to Descartes and the world views of the seventeenth century) is based on the assumption that by knowing the parts we end up knowing the whole. This might be the case with physical reality (everything not living), but not with what is alive.

3. The perfect sport machine

Reductionism and determinism go hand in hand. Sport science adopted the broad view they set forth. For all practical purposes, reductionism and determinism remain the dominant view. It is embodied in the focus on the machine model: "The best-designed and built car will win

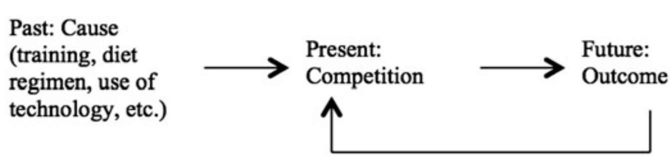

Figure 1. Past, present, and future in the causality chain.

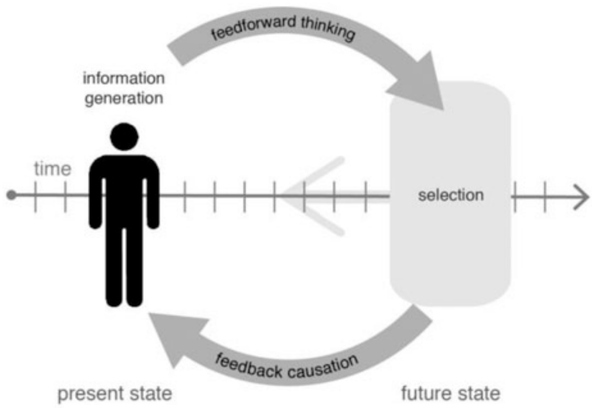

Figure 2. Feedback and feed-forward.

any competition", is the short expression of this view. Sport is performed according to this understanding, which is extended to how the sport is performed (Sternad et al. 2001; Knoblich and Flach 2002). This assessment is critical. The reductionist-deterministic model, as we shall see, describes sport performance only partially. A "human machine," such as we sometimes encounter on the tennis court and in all kinds of athletic competitions, is the outcome of such a view of sports. It is a simplified model, which in the long run is detrimental to those practicing sport and even to its public success. Within this view, the human being is reduced to a machine-state, and the machine is perfected for the goal: fastest, highest, strongest, etc. The science behind it is simple: use whatever produces the best result. In this sense, those who research sport and those who practice (athletes, coaches, consultants, physicians, etc.) focus on "the best hammer to hit the nail." For this purpose, advances in science are translated into new methods for training, new drugs, new technology – anything that leads to victory. They are methods for "squeezing" the maximum output from the individual by engaging those parts of the whole that play a more important role. In golf, training methods focus on eye-hand coordination as the "secret" to winning (Arvind and Bates 2008). Performance-enhancing drugs have been used to build up the bodies of baseball players. Anabolic steroids have also been administered in order to give the football players a way to handle pain. The famous (now infamous) Tour de France became the experimental playground for new methods of turning cyclists into "winning machines". Let others deal with the subject of the damaging consequences of this rather widespread conception originating in the reductionist-deterministic understanding of human performance.

The perfect sport machine – a machine conceived solely for performance – could of course be an emulation of the human being. Based on the knowledge that describes human sport performance, we can indeed produce synthetic sprinters, jumpers, boxers, cyclists, etc. The military is obviously interested in such high-performance machines. And although the field is still very young, I predict that the future has in store not only a world championship in computer chess – programs playing against each other – but many other competitions between "programs:" "machines" that play ping-pong, run the marathon, perform pole jumping and AI programs that play computer games (and win!). The RoboCup soccer competition (since 1997) is already quite popular.[1] Competition among machines might not really be sport, but technological confrontations. Competition among human beings is different from that among machines because the living, by its very condition, is anticipatory. Even those who conceive competition among machines realized that anticipatory features similar to those characteristic of human beings make them more engaging. Incidentally, the researchers involved in the RoboCup were also trying to emulate anticipatory aspects characteristic of playing soccer (RoboCup 2014; Veloso, Stone, and Bowling 1999).

4. Anticipation and human performance

Sport is foremost an expression of *human* performance. It is in this respect that the antÉ – Institute for Research in Anticipatory Systems (www.anteinstitute.org) dedicated research resources to examining the underlying anticipation of particular sports. Within the *AnticipationScope*™ (elaborated in the framework of Project *Seneludens*, 2005, http://seneludens.utdallas.edu/), the researchers conducted experiments (IRB approved) with members of the US Olympic team in women's gymnastics, with motorbike racers, and with golfers. Individuals trained in African dancing, Tai Chi practitioners, basketball players, etc. were also tested. While particular data (pertaining to individual test results) is confidential, the methodology and the broader implications can be shared with the sport research community. This is the purpose of the article. In time, as we continue aggregating data, we will share our findings with the scientific community. Suffice it to say that the performance of a motorbike racer and of a gymnast (to give the example of one session on the AnticipationScope) express different types of reactive and anticipatory behaviour.

Just for the sake of creating a context, let us take note that our focus on

(1) measuring reaction time
(2) measuring anticipation
(3) elaborating a possible "Anticipatory Profile"

was pursued (as of summer 2013) with 97 participants, between the ages of six to 94 years, male and female, of different ethnic, social and economic profiles. The high performance of athletes was continuously referenced to a baseline of "normal" subjects, that is, individuals who are not dedicated to sport (some exercise regularly, some do not).

4.1. Defining the concepts

An anticipatory system is a system whose current state is determined not only by some previous states but also by possible future states. This definition of anticipation – one among several (Nadin 2003) – has been adopted for this project for the following reasons:

- It integrates the knowledge accumulated by cognitive scientists, psychologists, neuroscientists and medical researchers through brain imaging and neurophysiological techniques.
- It builds upon hypotheses advanced in the study of anticipation from the systems perspective.
- It can be experimentally validated, particularly in respect to aging persons. Their life experience (previous states) is challenged (by the open set of possible states, i.e., new life situations). Their anticipatory characteristics, if properly stimulated, can help mitigate the new circumstances of their lives.

Given the extreme dynamics of current life, anticipation is relevant in many endeavours. The successful return of a fast tennis serve is the result of anticipation at work; so are successful performance in downhill skiing, or a goalkeeper's performance in soccer, as well as in piloting an airplane or a boat in a storm, or during engine failure.

Anticipation is an expression of how the living copes with change. It underlies evolution. A faster-than-real-time scanning of the environment informs someone's falling in real time (a pole vaulter for instance, or a skier). This is not unlike our own falling, when we ski downhill at high speed, or when we accidentally trip while playing some game. The information process through which this scanning, involving all the senses takes place defines the anticipation involved. When this information process is affected by reduced perception, inadequate motor control, impaired proprioperception, or short attention span, falling can become dangerous.

4.2. Quantifying anticipation

The premise for the effort of quantifying human performance is simple. We want to describe the definitory levels: motion (pretty much in the sense defined by physics), action (in which a purpose can be identified) and activity (integration of all components). While Roozbeh, Ghasemzadeh and Guenterberg (2009), Roozbeh, Ghasemzadeh, Dabiri, et al. (2009) and Roozbeh, Ghasemzadeh, and Loseu (2009) focused on these three levels, we find them to correspond to the syntax, semantics and pragmatics of all human performance (Nadin 2012).

The goal is to define the meaning of each performance. Someone can be fast without a good reason (hurried actions); others can choose to slow down the adversary (delaying a tennis serve). Successful performance is what counts. In regard to how we will observe participants, analyse the data and communicate the results, we shall proceed by first explaining the AnticipationScope (Figure 3).

The AnticipationScope produces a representation of the human being in action as an integrated expression across multiple systems, including sensory perception, proprioperception, cognition, memory, motor control and affect. The AnticipationScope is a corollary to brain imaging (the "brainscope"): knowledge gained through the AnticipationScope can be correlated to that gained through brain imagery.

The AnticipationScope quantifies the process by capturing the motion, not on a film or a video, but in the mathematical description (as a matrix) corresponding to the high-resolution

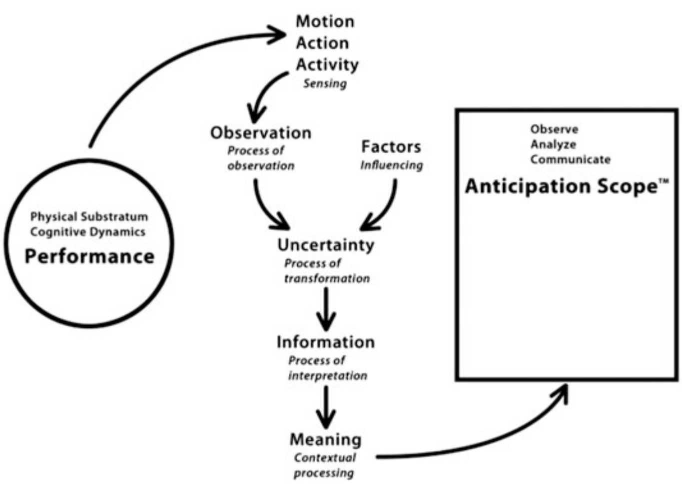

Figure 3. Analysing human performance.

motion capture technology. Such a description allows us to focus on single points on the body, and to pick up even the most evasive tremor or motion characteristics (of joints, body segments, muscles, etc.). Sensors, such as EMG, goniometry, accelerometry, blood pressure, EEG, etc. (and new sensors, to be developed as significant parameters are identified), are applied to different parts of the body in order to capture physiological expression specific to the task (Mendez-Villanueva and Bishop 2005). Such sensors capture the various *preparatory* processes, as well as the reactive components, for maintaining balance.

To describe how anticipatory characteristics, which underlie our adaptive capabilities, change over time implies the need to develop means not yet available for quantifying anticipation. With such means, the many inter-related factors involved in adaptive deficiency can be identified and eventually retraced to the molecular, neuronal, or DNA level. None of the conditions mentioned results from diminished reaction. All are expressions of affected, mainly reduced, anticipation. Diminished cognitive functions, reduced memory performance, loss in sensory acuity and discrimination, loss in motor control – all contribute to the loss of anticipation. Since anticipation is an integrated expression of each individual's characteristics across multiple systems, the goal was to conceive, design, specify, test, and implement an "anticipation scope" – the metaphoric equivalent of a microscope – that can help "see" how anticipation takes place. I conceived of the AnticipationScope as an integrated information acquisition, processing, interpretation and clinical evaluation unit (Figure 4).

It is currently impossible to study the complex dynamics of human actions – such as walking – and complex motor sequences – such as catching a ball, aiming, or executing a golf swing – that involve anticipation by using brain recording and imaging techniques. The AnticipationScope was designed to collect physiological data synchronized to a movement. Preliminary results show that we can quantify the dynamics on very short time scales (milliseconds). The methods we employ – high-resolution motion capture synchronized with biosensor recordings, such as EMG (electromyography), EDA (electrodermal activity), EKG (electrocardiogram) allow us to capture the dynamics and timing of anticipatory behaviour in real time. More simply put: as actions unfold (e.g. ascend/descend stairs of variable configuration), they can be described through motion capture data (Figure 5).

The integration of data is not trivial. Just for the sake of providing a simple example: illustrate integration of motion capture and EMG data. The experiment focused on how the change of the centre of gravity characteristic of catching a ball is expressed physiologically (toe movement, gastrocnemius and tibialis anterior) (Figure 6).

Let me summarize what has been learned so far and what we are looking for. Project *Seneludens* was the pilot for the AnticipationScope and the Anticipatory Profile™. In this project, we interacted with physicians. In using imaging and measurement, medicine acts upon *representations*. Data describing the body in action is a good representation for defining how well integration over many systems (neuronal, motoric, sensory, affective, etc.) takes place.

Data acquisition is necessary, but *not* sufficient. Data sets were acquired from performance athletes (the Olympic women's gymnastics team, golf players, motorbike riders, etc.). The need to develop a processing and interpretation framework was recognized early on. Accordingly, we focused on algorithms for data interpretation; data integration; design and implementation of the Anticipatory Profile.

5. Time and anticipation

The integration of motion capture and sensor-based data systems (EMG, EDA, EKG, and others) is, from the viewpoint of knowledge acquisition of sport performance, probably the

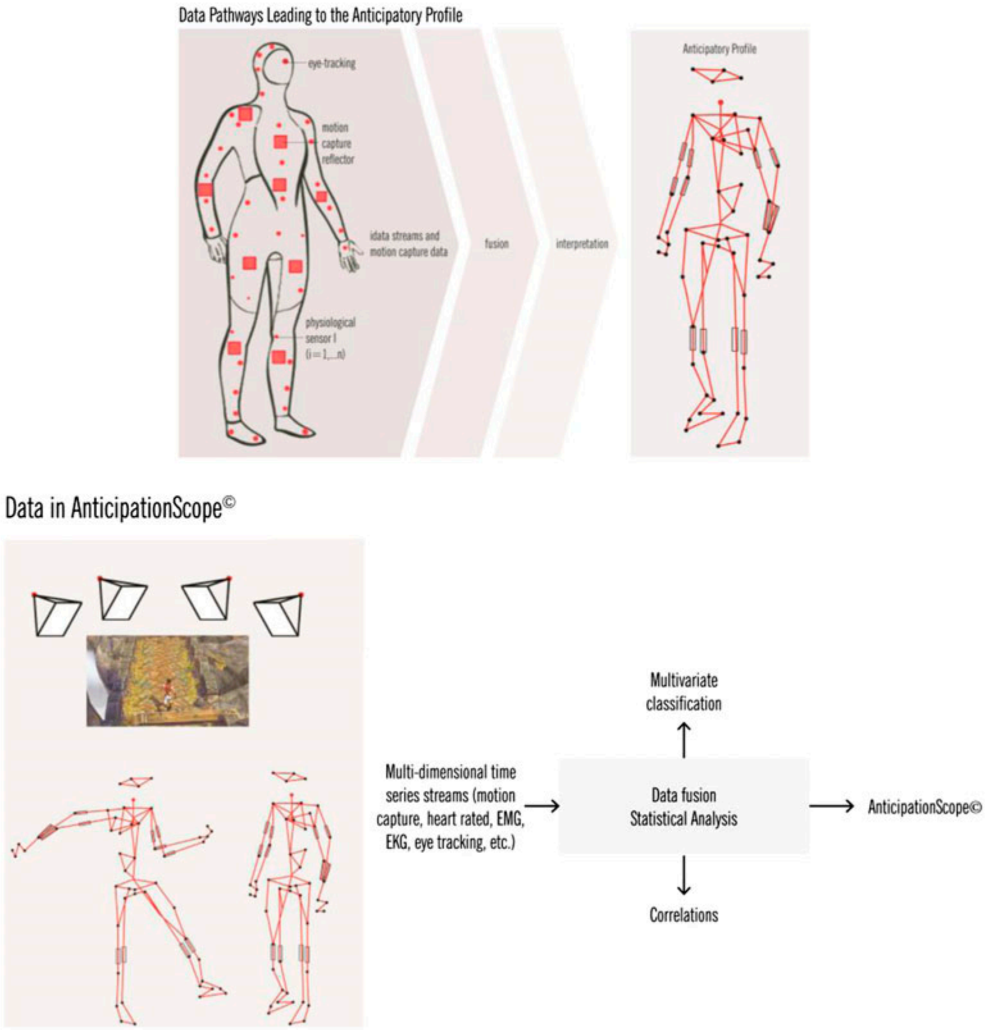

Figure 4. A and B: AnticipationScope.

most challenging part. This is where cognitive science, computer science and the theory of anticipation effectively meet. The task is simple:

- to associate to each captured movement signals previous to, concomitant with, and following the athlete's movement;
- to create a map of alternatives.

Let me use an example: a tennis player returning a serve. Motion capture delivers the "movie" of the player's actions. This "movie" is precisely indexed; that is, the system returns a timeline of every partial movement of the entire body. Ideally, we should also have a "movie" of the eye movement. But this is not yet possible, mainly because the integration of eye movement tracking and motion capture is not trivial. Parallel streams of data from the

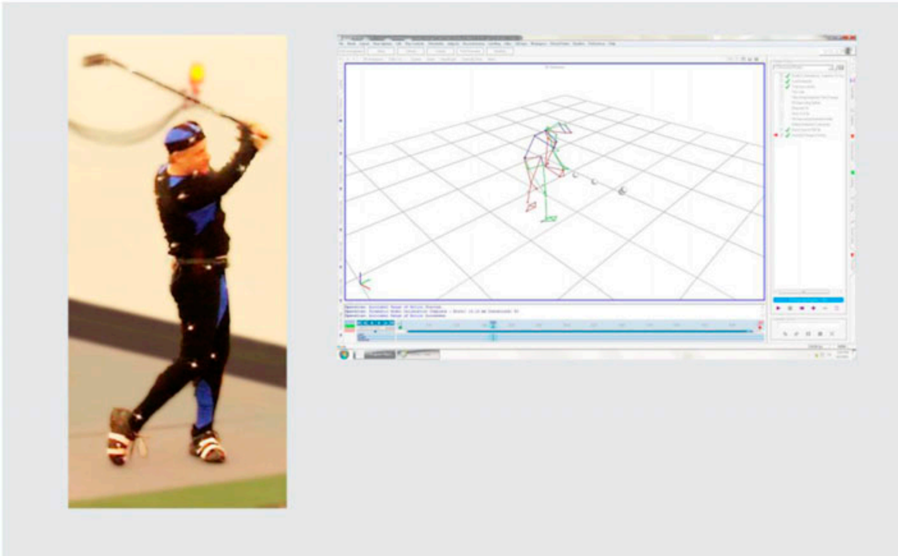

Figure 5. Golf session in the AnticipationScope.

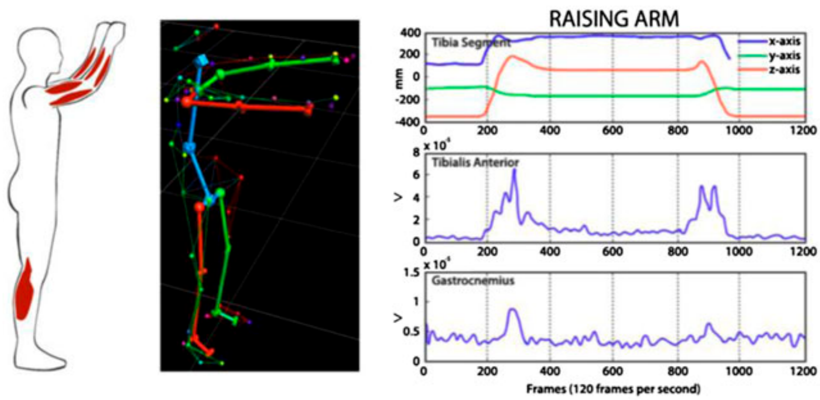

Figure 6. Integration of motion capture data and physiological sensors.

physiological sensors are synchronized with the motion capture. As a result, the researcher can identify how minute changes (in posture, hand and arm position, wrist, head, feet, legs, etc.) are reflected in the successful or failed return (Knuf, Aschersleben, and Prinz 2001; Nattkemper and Ziessler 2004).

This kind of detailed knowledge is equally important to coaches and players. But let's be clear: The goal is not to "fine tune" a "machine," but rather to make learning possible. Learning is the final source of anticipation. Schuber (1980) studied the preparedness of athletes and noticed that to know your opponent is important, but can sometimes be less than useful (what is called *the open-endedness of anticipatory processes*). As an autonomic function, anticipation results in the acquisition of knowledge within the athlete's cognitive and motoric system (Nadin 2013).

Let's attempt a suggestive diagram for the idea articulated above (Figure 7). Each movement an athlete performs is the result of many factors: experience, intuition, inspiration, guidance (in forms of real-time cues), training, etc. The space of possible variations is extremely large. Selection is guided by some factors that can be controlled, and by many that are not subject to conscious decisions. If we consider only a small subset, we can imagine variations as parallel streams (Figure 8). Based on the data acquired, we can run simulations. The constraint we impose is that the interval between start of action (move one leg in front, or jump, or lift arm) is the same. Thus we generate alternative paths.

One has to realize that all these alternatives (represented as data streams) represent a space of choices. Indeed, within the athlete (mind and body) multiple scenarios run simultaneously. Anecdotal evidence from a variety of sport performances will attest that this is usually the case. To anticipate often means to choose from among conflicting models of the future (Nadin 2003), as it relates to the sport performance. Observations made in the AnticipationScope show that for decisions made under time pressure, the athlete has no time to mentally simulate the entire action. Often, an athlete finishes an action before the mind has finished the entire virtual action (a rehearsal). Downhill skiing is a good example of such a situation. Golf affords all the time for virtually "rehearsing" the final movement and virtually "executing" it (Craig et al. 2000).

6. Intuition

Tennis players often speculate when returning a serve or in an exchange of balls from the baseline or near the set. So do hockey players, football players, and soccer players. When sport performance is actually a confrontation, the player's anticipation plays out against that of the adversaries.

"Follow your nose" (a good expression for describing intuition) corresponds to an anticipation expressed under tight processing constraints. In comparing motion capture timelines (the "movie" of the action), EMG, EDA, and EKG data streams, we can locate where (which point in time) and how situations requiring choices occur. In the AnticipationScope, movements that appear as incoherent, or successful beyond anyone's expectation, can be analysed in detail. As a matter of fact, we analysed such movements with the goal of understanding why an athlete settles for one choice from among many, and when such decisions are made.

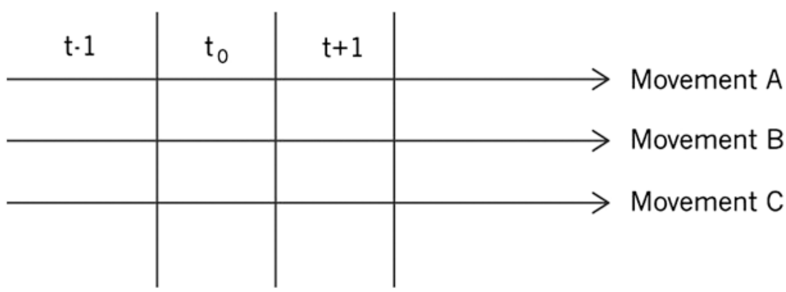

Figure 7. Composition of movements along the timeline of action.

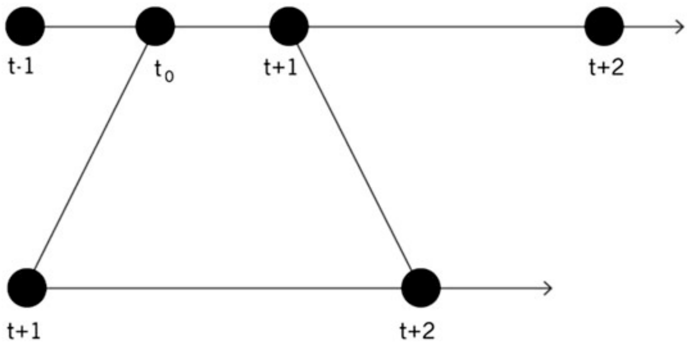

Figure 8. Possible parallel streams.

7. Expected knowledge

Since the living is not reducible to a machine, our best chance to understand our own knowledge regarding sport performance, and thus provide for effective anticipation, are hybrid systems that integrate the human being. Of course, hybrid creatures (such as the unity between a race car and a driver, a yacht team and the yacht designed for high performance in races where the weather conditions play an important role) assume that the machine part functions perfectly, and the human contribution is one of adaptive performance.

The simple diagram presenting the space of alternative paths (Figure 9) suggests that even under normal circumstances (no reason to hurry, select the path by trial-and-error), the information density might at times exceed our ability to figure out, i.e., anticipate, which path from among a few is better suited. To use a variable environment, in which the virtual scenery changes at a speed we can control, will allow us to infer to the discrimination processes involved in anticipation. It is clear that the human being simulates events in faster than real

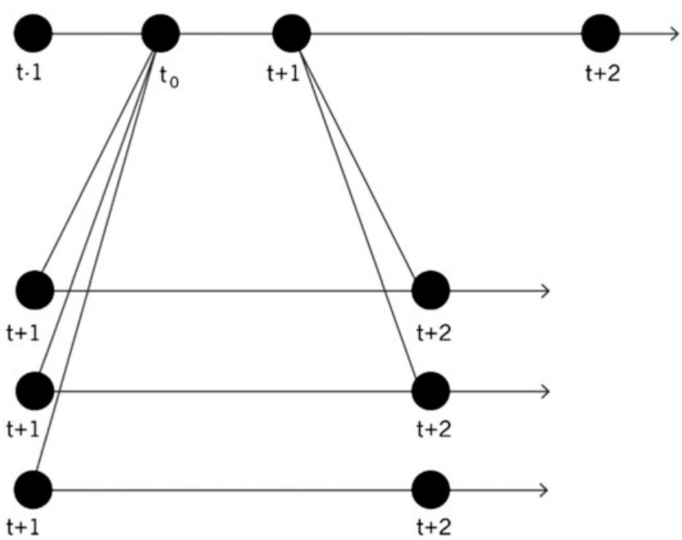

Figure 9. The space of alternative paths.

time (e.g. in fast downhill skiing, returning a fast tennis serve, avoiding danger, etc.). We anticipate before we are conscious of anticipating (Gallese 2000) and even before being prompted to act. To increase our knowledge about what it takes to reach such an anticipatory expression and to eventually increase it through training and learning, is the long-term goal of this investigation. The people who learned, against their desire, how to cope with an extreme event (such as earthquakes, tornados, hurricanes) are extremely important "witnesses" to processes upon which individual lives depend.

The unity between the various components of the sports performance is achieved through learning. As already stated, the source of anticipation is learning. The living is not born with anticipation, and loses anticipation with aging. Those involved in sport activities realize this quite well. Sport performance traditionally invites the study of cognitive and motoric skills. Empirical research has evinced a variety of factors, ranging from emotional factors to the perception of time and to communication aspects. The fact that more and more people are involved in some sport activity is, of course, testimony to an awareness of the advantages of such endeavours. But, sport is also consumed in a variety of contexts: amateur and professional competitions, junior sports in schools or communities, local teams, national teams, up to international competitions. Not everyone is given to the same sport. Fans of football or hockey, the passionate tennis public, admirers of gymnastics and television viewers of skiing competitions form groups of shared interests. Interest in sport is quite different from an interest in music (classic, pop, improvisational, etc.), but there are also some commonalities. In every form of partaking, cognitive science identifies the mirror-neurons effect (Gallese and Goldman 1998). To watch a game of soccer is to "live" the game, similar to watching a dancer or a soloist. Viewing sport, even after many years of dedication to a sports club and sport performance are connected. However, you do not need the knowledge an athlete has in order to enjoy a successful performance.

A variety of research perspectives guides the science of sports performance; and the technology developed aids such performance. Theories of motor control (Lashley 1951; Bernstein 1967, 1975) focus on skills. They ascertain that a central mechanism, an open-loop programme, controls movements. Of course, this is different from Pavlov's motor control theory. The fact that the sequential model (serial order) is only an approximation becomes evident when a certain action (hitting the golf ball) involves parallel components. The action depends on the perception. Planning is yet another model used in order to describe how an athlete performs: planning in swimming is affected by the style; planning in team sports is a matter of coordination among many plans.

The AnticipationScope produces a representation of the living in action, as 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. As already mentioned, this knowledge can be divided into three categories based on the level of abstraction of the conclusion:

Motion: The most tangible category consists the motions that represent the position, velocity and acceleration of all body parts at a given time.

Action: Actions belong to a higher-level category and refer to the basic motion sequences or static postures. Actions are generally sequential and rather consistent; examples include standing, moving from sitting to standing, walking and jumping. Actions present the most interest for recognition systems since they add a temporal characteristic to the sensor observations. While actions provide more information than motions, they lack realization of intelligent intent in human behaviour.

Activity: This role is filled with the highest level of motion abstraction. An activity is a goal-oriented group of actions.

8. On the fringes of anticipation awareness

John McCrone (www.dichotomistic.com) provides a useful narrative to anticipatory sports expression. Like many others, he is aware of the fact that the sensory input needs no longer than 20 milliseconds to reach the brain. He makes reference to Benjamin Libet's research (which informed some of my work, Nadin 1991), which suggests that becoming aware of an event (such as in sport activity) takes 400 to 500 milliseconds to be understood. In other words, a fast tennis serve would never be returned on account of reaction – yes, even when reaction is swift, it is way too slow. Of course, hockey, basketball, soccer and squash, to name a few sports, would never coalesce in a game if they were based on a reactive awareness of situations. As the mantra goes, a good hockey player does not run after the puck; he is where the puck will be. The goalkeeper acts, sometimes successfully, on a variety of cues. There is less system in his (or her) defending a penalty kick, but there is a lot of anticipation – sometimes unsuccessful (since anticipatory processes are basically non-deterministic in nature).

Let us take note that in terms of reaction characteristics, the difference between the average individual and the high-performance athlete is relatively modest – less than 15 per cent. The real difference is in the anticipation. Abernethy (1990, 1991) and quite a number of others (such as Abernethy and Sparrow 1992; Reed, McLeod, and Dienes 2010) speak of action directed by "gut feeling." While he is predisposed to associate this with a subconscious recognition of cues, he concedes, "You cannot teach people anticipation […] It just has to come with practice and players may never really know what they are reacting to" (quoted in McCrone 2006).

Indeed, top performers in a broad variety of sports (boxing, judo, ping-pong, cricket, slalom skiing, baseball, etc.) are admired for what seems to be an almost instantaneous action. There does not seem to be any reaction gap. This is how anticipation, as an autonomic function, is expressed. Dedicated research (Tanaka et al. 1991; Tanaka 1993; Wang, Tanaka, and Tanifuji 1996; Riehle et al. 1997; Velmans 1991, among others) has focused on such details as the coding of visual images associated with sports performance, synchronization mechanisms, preparation, etc. Although we do not intend to specifically test their ideas, or, for that matter, other valuable hypotheses (Rowe and McKenna 2001; Savelsbergh et al. 2002), it is clear that the AnticipationScope could serve as a validation environment. It allows for descriptions of actions, qualification of a variety of parameters and data-mining of the big data generated within each human performance.

9. Open questions

While fringe awareness of anticipation (or "anecdotal evidence," as it is sometimes referred to) is ubiquitous, what never has been attempted before is quantification. The AnticipationScope, presented in detail in other publications (Nadin 2013, among others) was conceived exactly for this purpose. 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 (Figure 10).

Anticipation is systemic in nature. Bernstein, whom we mentioned already as a precursor of anticipation research (cf. 1947, 1990, 1991), examined movement in order to obtain information on the workings of the brain (Meijer and Bruijn 2007). Feigenberg (2004, 2014) considered the variety of ways in which future-driven activities (sport is outcome-driven) can be

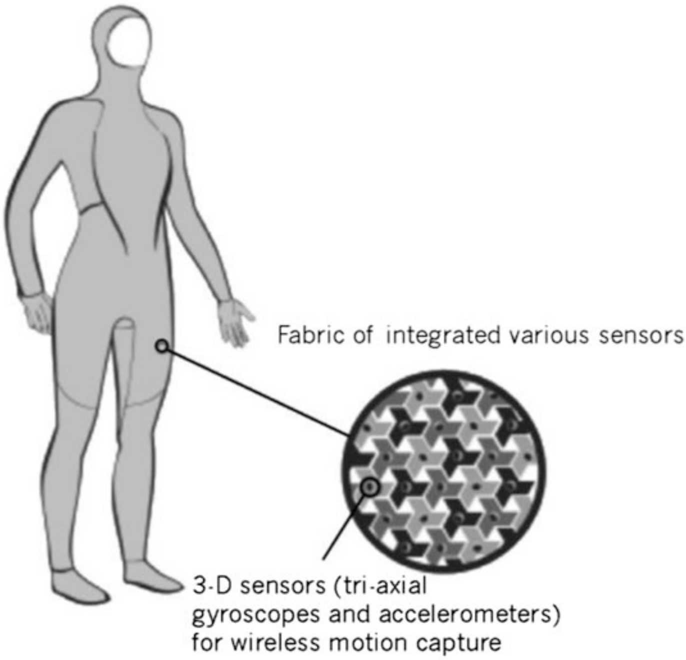

Figure 10. Wearable integrated AnticipationScope.

described. He opted for the mathematics of probability (Feigenberg 2008). Aglioti et al. (2008) investigated the underlying neural correlates of professional basketball performance. Transcranial magnetic stimulation (TMS) and psychophysical intervention informed their investigation.

In contradistinction to them, we focused on the interplay between the probability distribution, corresponding to past performance and the possibility space, corresponding to anticipation. So far, we've acquired data that suggests that high-performance perception and motoric abilities are a necessary condition to sports success – but not sufficient. Our research confirmed that through anticipation processes, data from the environment (the sports context) is complemented by data generated in the act of sports performance. (This goes back to research by Nadin 2013.) The concrete process of such data generation remains our major subject of inquiry for the time being.

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 better describe the anticipation in returning a fast serve in tennis (sometimes close to 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.

10. "Repetition without repetition"

This formulation comes from Bernstein (1967). The functioning of a machine is characterized by perfect repetition. Effort is made to make sure that whatever the machine "does" results in a perfect repetitive pattern. Repetition without repetition, which was documented in the AnticipationScope, describes the fact that even gestures meant to be identical – a hand movement, gait, a dance step – are never the same. The motoric performance depends upon a large number of variables that continuously change. Sensors inform cognitive processes; muscles, tendons, body mass, etc. are in permanent activity. Movement variability explains how virtuosity (music performance, dance, competitive sports, computer games, etc.) can be reached. The interdependence of action and perception underlies this variability (Figure 11).

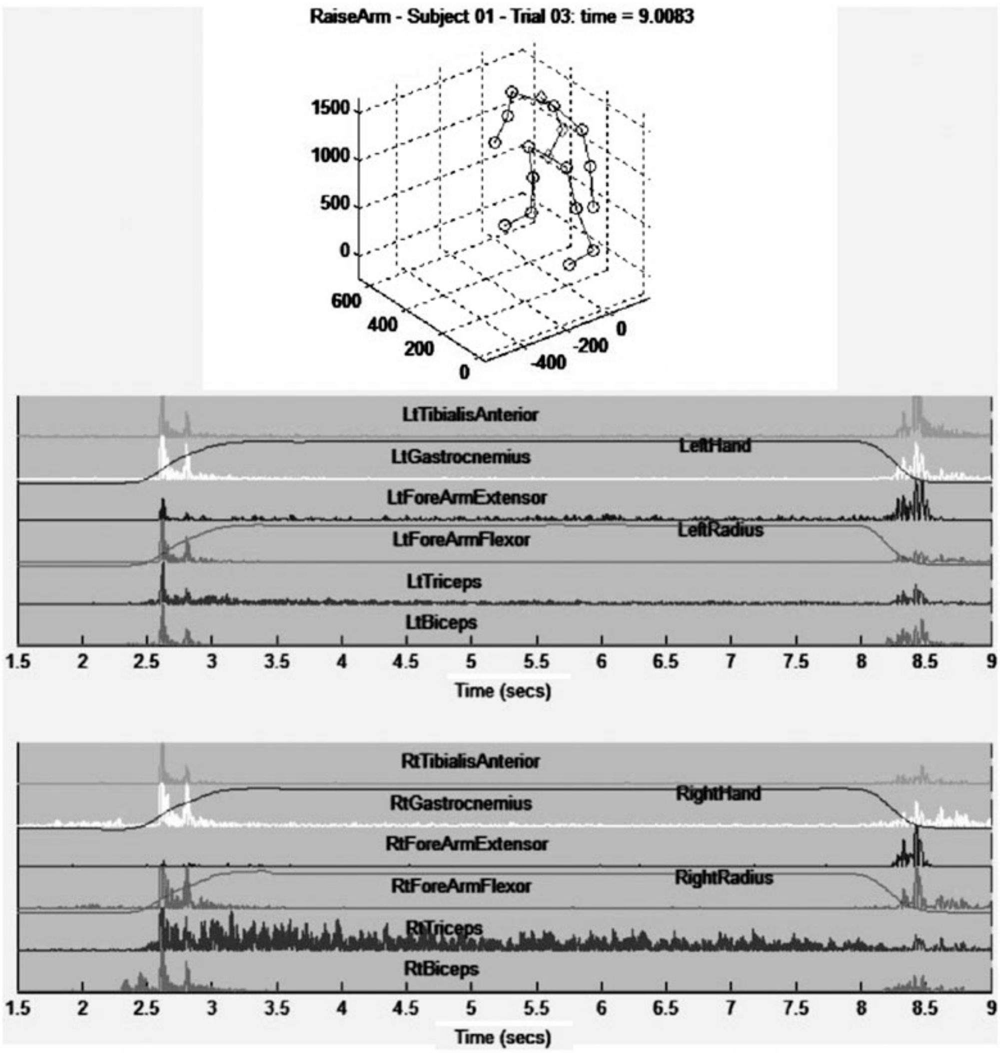

Figure 11. Action and perception of raising arms.

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 he called "cyclogrammetry," conceived as a method for recording movement at 150 to 200 frames per second. 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 *Anticipation: Learning from the Past. Rediscovering the Pioneering Work of Scientists from the Former Soviet Union* (Delmenhorst, Germany, 1–3 September 2014), it became clear that in studying the motoric system, Bernstein chose high-performance activities (playing piano, gymnastics, 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&feature=youtu.be), Bernstein's attempts at measuring motoric activity and its variability were known to me only through his writings. Our focus on motoric aspects peculiar to sport is a natural choice: if anticipation defines goal-oriented actions (return of a tennis serve, skiing downhill in the shortest time, scoring in ice hockey, performing gymnastics with no or only minimal errors, etc.), 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. (The subject also preoccupied van Emmerick and van Wegen 2002.) We produced data that takes Bernstein's hypothesis a step further (Figure 12).

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

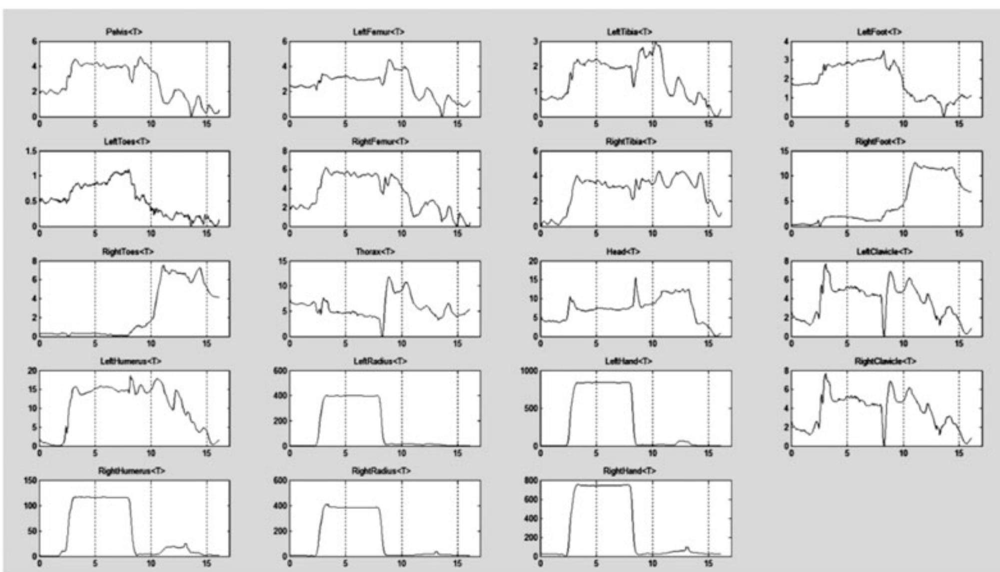

Figure 12. Variability of outcome.

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 (2014) are no less "repetition without repetition" than my own.

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AnticipationScope™ and Anticipatory Profile™ are trademarks belonging to Mihai Nadin.

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Note

1. RoboCup is a robotics competition founded in 1997. The aim is to promote robotics and AI research by offering a publicly appealing, but formidable challenge. The name RoboCup is a contraction of the competition's full name, "Robot Soccer World Cup." By the mid-21st century, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official rules of FIFA, against the winner of the most recent World Cup.

Notes on contributor

Mihai Nadin's interests and professional life combine engineering, mathematics, digital technology, semiotics, mind theory and anticipatory systems. He holds advanced degrees in Electrical Engineering and Computer Science and a postdoctoral degree in Philosophy, Logic and the Theory of Science. Since 1985, he has dedicated his research to anticipation/anticipatory systems. His book *Mind – Anticipation and Chaos* (1991) advanced a dynamic systems perspective of anticipatory processes. Research in dynamic systems at Stanford University and UC–Berkeley led Nadin to further probe anticipatory systems: "Anticipation – A Spooky Computation", "Anticipating Extreme Events: the need for faster-than-real-time models" and the book, *Anticipation – The End Is Where We Start From* (which set a foundation for the field in lay terms). He established the antÉ – Institute for Research in Anticipatory Systems (2002) as a research "think tank", and consulting entity (for technical innovation, business, policy development, game-based simulations, defence). It became part of the University of Texas at Dallas (2004) when Dr Nadin accepted its invitation to become Ashbel Smith University Professor. Recent publications on anticipation include: "Quantifying Anticipatory Characteristics" (2013); "The Intractable and the Undecidable – Computation and Anticipatory Processes" (2013); "G-Complexity, Quantum Computation and Anticipatory Processes" (2014). He was named Honorary Fellow of the Hanse Institute for Advanced Study (Germany), where he initiated *Anticipation Across Disciplines*. This study group (with support from the Thyssen Foundation and the German Science Foundation/DFG) organized two international conferences in 2014. The third, "Anticipation and Medicine", will take place in September 2015. For more information, see http://www.nadin.ws, http://www.anteinstitute.org, http://www.nadin.ws/ante-study/.

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