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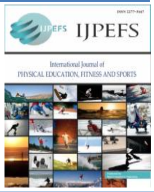

Formation of the sensorimotor operation pattern from a system-theoretical perspective

In memory of
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Abstract: The starting point to the analyzes presented in this paper is the fact that the primary task for the nervous system – both central and peripheral – of living creatures is the control of movements. The only result of any mental process, the only way to influence the environment, aimed at producing desired results in environment, is the movement. These issues make the subject of the discipline of science termed motor control. In this field, the efficiency of mathematics is highly disputable. On the other hand, the promising tool for knowledge ordering seems to be the systems theory. For its invention Ludwig von Bertalanffy is credited (1968). However, already in late 1940s such an approach has been presented by Nikolai A. Bernstein. His theory is commonly regarded as a cornerstone of modern motor control. Basing on evolutionary and neurophysiological knowledge, he invented a systemic model termed "brain skyscraper", structural in its essence. It was possible to invent the slightly simplified, parallel model of functional nature, termed "modalities' ladder", founding upon information processing. The practical application of the ladder in teaching of motor operations, presented in this paper, is termed "one level higher" principle. An important outcome of the modalities' ladder is also its specific, function oriented, systemic ordering of motor control terminology.

Key Words: sensorimotor, nervous system, neurophysiological, motor control

Wacław Petryński, *M.Sc. Eng. (Mechanics), PhD (Physical education). Currently, he serves as dean in Katowice School of Economics, Bielsko-Biała camp, Poland. His main field of scientific activity is the psycho-kinesiology (motor control, movement science). In 2007-2011, he served as general secretary of International Association of Sport Kinetics. He claims that in researches into processes underlying human motor behavior mathematics is hardly useful. In this respect, promising seems to be a system-theoretical perspective. Petryński traced the roots of such a perspective in the works of N.A. Bernstein and P.D. MacLean, and the essence of a system as such – in the works of J.M. Morawski. Recently he presented his views in detail in the book, Motor Control in Humans. A System-Theoretical Approach" (Nova Science Publishers, Hauppauge, NY, 2016). His hobby is sailing; he is ocean yacht skipper and former vice-president of the Polish Yachting Association.*

1 Introduction

In contemporary world the biomechanical analyzes – both qualitative and quantitative – are no doubt very important elements of the motor activities improvement. The central subject of such analyzes is the movement, especially in sport. Nevertheless, as it aptly philosopher Andrzej Wohl remarked, "*whole human history is the history of human activities; all that we dispose of, all what constitutes the resource of our culture, all the pieces of art, science and technology – all that results from motor activities*" [1]. In this respect, very instructively sound also the words by psychologist James W. Kalat, who stated:

> *A great brain without muscles would be like a computer without a monitor, printer, or other output. No matter how powerful the internal processing, it would be useless. Nevertheless, most psychology texts ignore movement (my emphasis – WP), and journals have few articles about it* [2].

Therefore, the movement makes a final link of a complex, cause-effect chain, in living beings encompassing physical, physiological and psychological phenomena and processes. It seems hardly possible that the researches into merely final link of such a long and complex chain will enable creation of useful explanations and yield productive results.

While taking into account the advice by mathematicians and physicists Alan Sokal and Jean Bricmont that "*it's a good idea to know, what one is talking about"*[3], let us take an assumption that we will focus our attention not on every motor activity, but only on such, which is intentionally deliberated to induce desirable changes in environment. Let us term such a motor phenomenon **motor operation**. It occurs in reality and may be observed with biological senses and/or measured with physical and technical gauges. However, to appear in reality, it has to be prepared in advance in mind. To reduce intellectual costs of such an operation, living beings store in memory operation patterns already worked out previously, due to process of learning. They are ready to immediate use. Let us term them **skills**. A skill being performed as a corollary to reception of a current extrinsic stimulus is a **motor response**.

At that moment, we come across a fundamental difference between physical reaction and biological response. The former does not include any information processing. It results from "stiff" physical laws. Therefore, it is easily describable mathematically and thus – predictable

On the contrary, the motor operations and motor responses include information processing. Therefore, in any motor operation, the intellectual and motor elements are inseparably intertwined with each other, what makes its mathematical description hardly possible.

In addition, categorization in advance of any mental-motor operation as more or less "intellectually noble" is at least risky. For example, development of unusual, original solution of a specific situation in soccer, basketball or boxing needs by far more **intellectual** work than solving a trivial differential equation.

Nevertheless, abstract reasoning has its roots in reality and sensory experiences. This idea may be traced already in the concepts by Aristotle (4th century B.C.), then formulated in 13th century by Thomas Aquinas: "*Nihil est in intellectu quod non prius in sensu" ("nothing is in intellect that was not first in senses")* [4]. This statement is known as the peripatetic axiom. In 17th century Gottfried Leibniz supplemented it with the words: *"excipe: nisi ipse intellectus" ("except the understanding itself")* [5]. As a result, a human mind is able to create great spaces of reasoning completely detached from reality. Nevertheless, the roots of reasoning itself – however abstract it may be – reside in the "tangible" reality. This is why mathematician Ian Stewart and biologist Jack Cohen termed the mental representations of both real and imagined world – separate, yet not completely independent of each other – "*figments of reality*". Real movements and abstract thoughts are, then, not separate phenomena, but they make a consistent, continuous (yet not homogenous) system, from simple knee jerk through invention of general theory of relativity. This may be instructively illustrated with the following quotation from Ian Stewart and Jack Cohen:

> *Mind is not immaterial transcendence: it is the response of an evolving brain to the need to survive in a complex environment. And with evolution of culture, that environment has become self-modifying and self-referential, and human mind done the same* [6].

In human mind, one has to do with both the external environment – world of objects, phenomena and processes – and non-linearly coupled with it an internal environment – world of words, notions and thoughts, i.e., the figments of reality. One of such figments is the science.

All this needs a comment. The reasoning and definitions presented in this paper differ from other models in science. However, reality is too complex to be fully described scientifically. As a result, each theory is inevitably a simplification [7-8]. As it Richard A. Schmidt remarked, *"since laws are the product of human creativity, different laws can be formulated by two different individuals who are examining the same observations; laws do not automatically spring forth from the facts* [9].

This may be illustrated with Fig. 1 [10]. Let the central body symbolize reality, and the particular shadows – its simplified representations, or branches of science. All the three shadows come from the same body; none is more or less true than another one; but nevertheless each differs distinctly from the two others.

In this respect highly instructively sound the following words by philosopher Charles S. Peirce about three methods of reasoning: induction, deduction and abduction.

> *Abduction is the process of forming an explanatory hypothesis.* ***It is the only logical operation, which introduces any new idea*** *(my emphasis – WP); for induction does nothing but determine a value, and deduction*

merely evolves the necessary consequences of a pure hypothesis.

Deduction proves that something ***must be****; Induction shows that something* ***actually is*** *operative; Abduction merely suggests that something* ***may be*** *[11-12].*

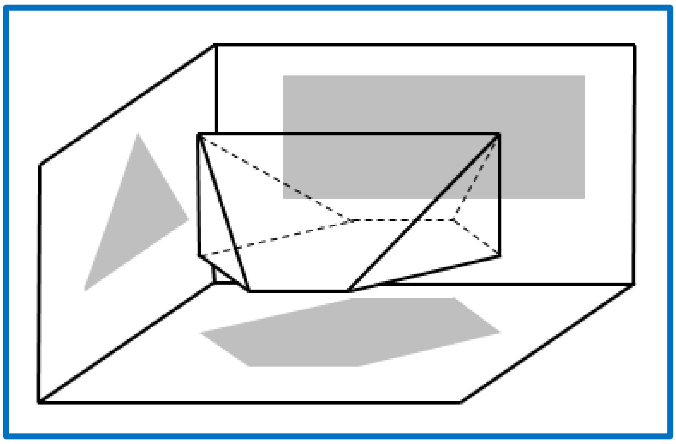

Figure 1. Complex reality and its simplified scientific "shadows" [10].

Unfortunately, abduction is the riskiest way of reasoning. There are no any "rails for thinking", which would make it light and easy, yet acceptably reliable.

2. Sciences on human movements: pre-motor sciences and motor sciences

According to engineer and biomechanist Janusz Morawski, three cornerstones of motor behavior of every living creature, including human, are energy, structure and control [13]. Important is that they make not a sum, but a system, i.e., "*a goal-aimed, multilayered, organized set of ideas, biological structure or technical device which is able to generate a qualitatively new ability (emergent), not resulting directly from traits of any of components of the system*" [10].

Let us take, then, an assumption – consistent with the already cited statement by Wohl – that in a living being the final link of a cause-effect chain, initiated with reception of an extrinsic stimulus, is a motor operation. While paraphrasing old, Latin adage, "*all roads lead to movement*". Let us start, however, from the statement of polymath Mihai Nadin that "*philosophy remains a science of sciences*" [14]. In other words, just the philosophy is the main and potentially most productive figment of reality. In general, a system of "meta-motor sciences" might be designed as in Tab. 1.

However, it is possible to arrange the set of sciences – let us term them "motor sciences" – describing a motor operation production slightly differently, or to show another scientific "shadow" of the phenomena and processes joined with it. Let us focus our attention on the science directly joined with the motor operation production, i.e., the kinesiology. Its internal structure might be designed as shown in Table 2.

Accordingly, one might state that psycho-kinesiology is inseparably associated with biomechanics; without biomechanics, psycho-kinesiology would be unproductive, but without psycho-kinesiology biomechanics would be senseless. Together they make inseparably joined "counties" in a single, general "empire" of kinesiology.

3. Mathematics and system

The sciences on sport, exercises and other motor operations in humans are by far less ordered than, say, physics or technology. One may take an assumption that this is because the effectiveness and efficiency of mathematics in description of human motor behavior is by far smaller than in so-called exact sciences, and its possible contribution to the explanation of phenomena and processes underlying human behavior is next to zero.

Mathematics – allegedly, "Queen of Sciences" – is the science on relations [15]. It does not care about the essence of what it describes. In the equation 2 + 2 = 4, it is not important, whether we speak about two chairs and two kangaroos, professor and hedgehog and smartphone and airplane. Important is only possibly "stiff" relation.

Accordingly, in mathematics functions what might be termed "dictatorship of equal sign". What is on the left side of it has to occur also on the right side. Even more, on either side of equation cannot appear something what was not on the other side. According to mathematician Ian Stewart and biologist Jack Cohen [2000, p. 234], mathematics does not give birth to anything new [8].

However, such a categorical statement seems to be too harsh. Mathematics is able to unveil new relations, and their interpretations may be intellectually fruitful not only in the sphere of mathematical "pure nonsense". Nevertheless, the interpretations – which endow the mathematical relations with a "tangible" meaningfulness – however fruitful they may be, remain beyond the "main body" of mathematics (or "pure" mathematics). Accordingly, direct application of mathematics in biology, and –

even more – in psychology and kinesiology seems to be hardly reasonable.

Interpretations include some freedom of concluding. Here there are no "stiff rails" for thinking (as, e.g., the mathematical formalism). More freedom means more inventiveness, indeed, but also more dead ends. Therefore, for a scientist, the mental interpretations are by far more risky than, say, light and easy production "new, original experimental data" in laboratory.

However, just the freedom of thinking enables fully abstract reasoning and creation of intellectual worlds not directly joined with reality. In other words, only the reasoning methodology termed by Peirce "abduction" enables invention of theories and science as a whole [11].

Table 1. A general system of "meta-motor sciences".

PHILOSOPHY		
ENERGY	**STRUCTURE**	**CONTROL**
Biochemistry Energy transformations	**Anatomy** Body construction	**Psychology** Information management
Biophysics Movements' power supply	**Physiology** Movements' production	**Psycho-kinesiology** Movements' control
MOVEMENT		
Pedagogy, training theory, kinesiotherapy etc.		

Table 2. A specific system of "motor sciences".

KINESIOLOGY	**PSYCHO-KINESIOLOGY (MOTOR SCIENCE)**	**Psychology**	Mind
		Neurophysiology	Nervous system
	BIOMECHANICS	**Physiology**	Musculoskeletal system
		Physics	Environment

In mathematics, the subjects of analyses do not influence the relations described with equations. In biology they do. In this field of natural phenomena and processes, a non-linearity of living creatures' responses to extrinsic stimuli has been shaped evolutionary. A living being cannot control this non-linearity. For example, the cell membrane "knows" what it may allow into the cell, and what it should pump out. Such an ability – nonlinear in its essence – destroys the "stiffness" of relations, typical for mathematical descriptions and makes the effectiveness of "Queen of Sciences" by far less than that in physics or technology; in biology, it is marginal. A scientist may use it for ordering the superficial phenomena, but for explanation of their bases, the interpretations are necessary. Let us add that also in physics and technology useful is not the creative, full of fantasy and novelty mathematics, but boring, deprived of panache, yet reliable calculations.

Still more difficult is the situation in psycho-kinesiology, where the nonlinearities, which remain beyond the reach of mathematics, are not a relatively stable product of evolution, but are on-line created by a living being. In such a situation, the mathematical description is virtually impossible, because the relations are deprived of any "stiffness".

Because only the ordered body of knowledge deserves the noble title "science", and in this respect, mathematics is hardly effective in psycho-kinesiology, it is necessary to use another ordering tool. Promising seems to be the systems theory. Though nowadays it is often associated with technology, it was born in the field of biology [16]. According to Morawski, system is a layered structure of transferring and transformation of energy and information, being built according to the following rules:

1. Layers' hierarchy rule.
2. Layers' autonomy rule,
3. Scales' conformity rule [17].

The first rule says that in a system exists a main layer. It shapes the run of processes being analyzed, and other layers are auxiliary to it.

The second rule says that each layer is able to perform its task without any additional information.

The third rule says that each of the layers has its own code and methods of information processing, i.e., the modality. It determines depth and time demand of information processing. In fact, both these factors make a specific "identity" of a system's layer.

Probably the most elusive – and most creative as well – process in a system is the communication between particular layers [18]. A system is able to produce a new, unpredictable, qualitatively new, emergent system effect. Just this makes a fundamental difference between systems and the objects describable mathematically. In biology, thanks to a system effect, the evolution was possible. Its most advanced product is life, and in psycho-kinesiology – the ability to learn and acquiring qualitatively new knowledge and skills.

By the way: if one applies the system principles by Morawski to a system of motor sciences (scales' conformity rule), one might discover that it seems hardly possible to achieve any significant scientific successes in the region of psycho-kinesiology as a result of researches into biomechanical issues, because each of the "floors" of motor sciences system (Tab. 2) has its own modality of information processing, not fully "translatable" into modality of another floor [10].

3.1. Systemic patterns in the science on human motor behavior

As already stated, for creation of general theory of systems biologist Ludwig von Bertalanffy is credited [16]. However, already two decades earlier the concept of neurophysiologist Nikolai A. Bernstein [Bernstein, 1947] was fully consistent with the system concept invented by von Bertalanffy [19].

In science on human motor operations, one might to seek the roots of such an approach already in achievements by Aristotle and Descartes, but in fact, for systemic way of reasoning in motor control in humans the neurologist John Huglings-Jackson should be credited [20]. His papers, describing three-level mechanism of human movements' control – as well as the achievements by Ivan P. Pavlov – inspired Bernstein, probably the most outstanding author of human movements' construction theory in 20th century. He has built his theory on evolutionary and neurophysiological knowledge and termed it "the physiology of activity" [21]. Its simplified and easily accessible representation he termed "brain skyscraper" [22-23]. It consisted – roughly – of five "floors": A through E. The rubrospinal A-level (paleokinetic regulation), the thalamo-pallidar B-level (synergies), the pyramidal-striatal C-level (subdivided into striatal C1 level, controlling movements of the whole body in space, and cortical C2-level, which controls the movements of working organs), cortical parietal-premotor D-level (level of actions) and cortical E-level (level of motor fantasy). In fact, Bernstein regarded the latter not as a single level, but as a group of levels [19, 24]. By the way: in his no doubt greatest work, "*On construction of movements*", Bernstein only once termed C-level – very aptly – "half-cortical".

Independently of Bernstein, physician and neuroscientist Paul D. MacLean [MacLean, 1985] has developed an analogous system description of movements' control in humans [25]. His "*triune brain*" consisted of a reptile brain (*arch pallium*), paleo mammalian brain (*paleo pallium*) and neomammalian brain (*neopallium*) [25-26]. The ways of reasoning, both Bernstein's and MacLean's, were similar, indeed, but Bernstein's theory was more detailed and invented 20 years earlier. Unfortunately, though Bernstein spoke eight languages, his main work [Bernstein, 1947] has been published only in Russian [19]. The other, more accessible book has been in 1947 withdrawn from publication because of political reasons and published no sooner than in 1991, 25 years after Bernstein's death [22-23].

Bernstein analyzed the progress in motor potentialities in living creatures in the context of development of their sensory organs and central nervous system (CNS). Successive, more and more complex sensorimotor tasks which appeared in environment and evolutionary struggle for life forced the development of more and more sophisticated nervous structure, which were able to control more and more complex motor operations. According to Bernstein, in a motor control in humans (and other living beings) there is a main level, which controls the general run of a motor operation just being realized, and the lower one(s), which make what Bernstein termed "background". In short, main level is responsible for what to do, whereas background level(s) – for how to do it (control and coordination).

Moreover, the profound knowledge of neurophysiology is not necessary for motor control specialist. For instance, a good driver does not need to know the details of dynamics of fuel-air mix combustion in, say, third cylinder of the engine. Moreover, the excess of knowledge is in some situations a harmful ballast, which reduces efficiency of a given motor operation. This is why philosopher Andy Clark has formulated the "007 principle" that "*one needs to know only as much as you need to know to get the job done*" [27]. Consequently, having in mind the Bernstein's evolutionary and neurophysiological roots of human motor behavior, I propose another approach towards these problems, or creation of another "shadow" of the motor control (Fig. 1). The Bernstein's "brain skyscraper" is in fact of a structural nature. So, let us try to invent a functional model, symmetrical to it. It may be termed "modalities' ladder" [10]. Its essence is "distilling" from Bernstein's theory only the codes and methods – i.e., the modalities – of information processing. While using it, the "towing" of whole neurophysiological knowledge – in itself valuable, indeed – through reasoning being focused on motor operation control becomes superfluous. In short, while comparing with car driving; one does not need to know details of fuel combustion in cylinders, but s/he has merely to push the accelerator. It is by far simpler, yet in practice equally (in fact, even more) efficient.

3.2. The "brain skyscraper" and the "modalities' ladder"

Construction of the modalities' ladder (ML), symmetrical to brain skyscraper (BS), needs some modifications in original Bernstein's theory. The A-level, which controls contractions of particular muscles, should be divided into two sub-levels: A0, which controls the basic muscle tonus responsible for posture maintaining, and A1, which controls particular muscles' contractions, aimed at solving a specific task in environment [10].

To each of the ML "rungs" may be assigned particular basic skill patterns. Roughly, they are mental structures, controlling specific motor sub-operations (or a whole motor operation), with which the modality of that "rung" is able to deal efficiently enough. At A-level, it is coupling, at B-level – template, at C-level – scenario, at D-level – program. The E-level does not control any real motor operation, hence it has no its "own" basic skill pattern. The mental representation at this level, the idea, is not directly joined with reality.

While looking at structure of the BS, at first glance one might term the three lower levels – A, B and C – "sensory levels", whereas the two higher ones, D and E, "abstract levels". However, one should have in mind that also sensory experiences are being recorded in memory as abstract engrams. Roughly, one might associate E-level with a specific spatial-temporal topology, D-level – with spatial-temporal geometry, both C1 and C2 levels – with kinematics, B-level – with kinetics, and A-level – with dynamics. From slightly different perspective – yet fully coherent with the already presented one – one might join D-level with common sense, and E-level – with "daydreaming", sometimes scientifically highly fruitful. While associating the D-level common sense with spatial-temporal geometry, then the E-level fantasy might be joined with spatial-temporal topology. Jean Piaget and Bärbel Inhelder very illustratively termed topology "*rubber-sheet geometry*" [28].

While using the poetics by Stewart and Cohen, one might state that D-level includes the "figments of reality", whereas E-level – the "figments of figments of reality" (i.e., the first derivative of figments of reality or second derivative of reality).

Moreover, it should be once more emphasized that in fact there are no "pure" motor abilities, because each of them has to include a mental element, with modality specific to its "rung" in the ML.

In the BS, the "background of all backgrounds" is the A0 muscle tonus. Its equivalent in the ML is the A0 consciousness. Let us define it as follows:

> ***Consciousness*** *– a dynamically changing part of quasi-static whole, multimodal knowledge of an individual, activated at given moment by perception being directed by attention, aimed at dealing with the task just being solved* [29].

Let us notice that this definition makes the notion of "sub-consciousness" superfluous. The A- or B-level information processing modalities, though not translatable into D-level verbal code, produce the fully-fledged consciousness at A- and B-levels, respectively.

While trying to embed the BS and ML in the system of motor sciences (Tab. 2), one might, roughly, assign the ML to psychology (motor operation invention), the BS – to neurophysiology (motor operation control), the movements' production by a biological organism – to physiology (motor operation execution), and the external constraints imposed on such a production – to physics (implanting the biological motor operation into the observable environment). In short, the BS includes potential mental-motor abilities, the ML – functional motor skill patterns, and the elements joining the particular floors of BS with respective rungs of ML are motor operation types and control mechanisms.

It seems worth noticing, too, that such an approach enables a systemic ordering of motor control terminology. Just in the lack of coherent, ordered terminology, some scientist seek the lack of intellectual successes in this field of science [30].

3.3. Motor operation teaching: the "one level higher" principle

In the ML, particular "rungs" have been associated with specific classes of extrinsic sensory stimuli and/or intrinsic engrams [10].

What is most important for reasoning presented in this paper, the higher level, the more profound, but at the same time the more time-consuming information processing. It is very important in motor operations, in which just the temporal physical constraints are decisive.

Teacher cannot influence the proprioceptive A-level motor operation (reflex) pattern in learners; each trainee has to work out such a pattern individually.

Table 3. The Bernstein's brain skyscraper and the modalities' ladder [10].

<table>
<tr><th colspan="2">Brain skyscraper,
mental-motor ability</th><th>Operation type,
control
mechanism</th><th colspan="2">Modalities' ladder;
basic skill patterns</th></tr>
<tr><td colspan="2">E
Fantazy
Topological representation of reality</td><td>No motor
operation,
Politics</td><td>E
Symbolic modality
Idea</td><td rowspan="6">A0
Multimodal consciousness</td></tr>
<tr><td colspan="2">D
Common sense
Geometrical representation of reality</td><td>Motor
performance,
Strategy</td><td>D
Verbal modality
Program</td></tr>
<tr><td rowspan="4">A0
Muscle tonus, posture maintaining</td><td>C2
Net of muscle synergies,
working organs,
dexterity</td><td rowspan="2">Motor habit,
Tactics</td><td rowspan="2">C
Teleceptive modality
Scenario</td></tr>
<tr><td>C1
Net of muscle synergies,
whole body, agility</td></tr>
<tr><td>B
Two muscles' synergy,
Movements' harmony</td><td>Motor
automatism,
Technique</td><td>B
Contactceptive modality
Template</td></tr>
<tr><td>A
Single muscle contraction
Strength</td><td>Motor reflex,
Strength
control</td><td>A
Proprioceptive modality
Coupling</td></tr>
</table>

At the contactceptive B-level (automatism), a teaching method is the guidance, active or passive [31]. It is applied mainly in rehabilitation. The B-level teacher's action enables creation A-level muscle contractions pattern (coupling) in trainee.

At the teleceptive C-level (habit), teaching method is the demonstration. It is applied very widely. The C-level demonstration enables creation of B-level synergies (templates) and A-level muscle contractions (couplings) pattern in trainee.

By the way: already in 1852 physician William Carpenter observed that intense imagination of a motor operation results with slight muscle contractions [Carpenter, 1852; Czabański, 1986], For example, in a sleeping dog the paws and nostrils start to tremble, as if our four-legged friend was chasing something [32-33]. In sport this phenomenon underlies the mental training [31, 34].

It is worth emphasizing that Bernstein noticed the specific function of the C-level in the whole structure of movements' production. In 1980s (two decades after Bernstein's death) very "fashionable" scientific issue was the topic of mirror neurons [35-36]. In short, one might state that some living creatures (including humans) have the "hardwired" ability to imitate of what they are just seeing. It is no doubt extremely important mechanism of learning, e.g., in children. Probably, it has significantly accelerated the run of evolution. In the ML, the sense of eyesight is being assigned to C-level.

At the verbal D-level, not joined directly with any extrinsic stimulus, a teaching method is a description of a given motor operation. The trainee has to work out independently the C-level scenarios, B-level templates and A-level couplings.

One might notice that creation of a motor control pattern at a given level is being realized under "management" modality specific to an adjacent higher level. This phenomenon explains the function of the E-level, which does not control any real motor operation. However, the abstract patterns of such operations, i.e., programs, are being formed under guidance of E-level, apparently "daydreaming".

Let us take as an example the flop technique in high jump. In no everyday activity, a human or an animal performs such a series of movements. Its abstract pattern had to be born at E-level (fantasy, "daydreaming"), its applicability analyzed at D-level (common sense), and finally realized at "sensory" levels – teleceptive C, contactceptive B, and proprioceptive A. In short, E-level endows a motor operation with a novelty, D-level – with an applicability, and the lower ones – with realizability.

3.4. The "one level higher" principle example

The "one level higher" principle may be regarded as a development of Bernstein's rule that appearance of a new, higher level in the BS induces the development of lower levels' motor control potentialities, and, more generally, the information processing power [22-23]. In short, the formation of a higher level activates such potentialities of a lower one, which cannot work without presence of a higher one. Further, it results with a specific phase of motor habit formation, i.e., distribution of basic skill patterns among particular levels. While shaping a general structure of a habit, such basic skills patterns (templates, couplings) are being "pushed down" to such a level, which is able to deal with a given sub-operation efficiently enough. Bernstein termed such process "automation" [22-23].

By the way, it seems worth noticing that the word "automation" has completely different meanings in science on living creatures' movements and in technology. In technology, it bases on strict control with specific measuring gauges, whereas in motor control it means the action with "sleeping" or even completely switched-off attention. Just the decreasing the attention load (thus making the whole motor operation "cheaper" in terms of information processing) poses the main goal of automation in living beings.

Accordingly, the "one level higher" principle makes a specific elaboration of the Bernstein's ideas. It includes assumption that "matured" basic skill patterns – A-level coupling, B-level template, C-level scenario or D-level program – appear at first at next higher level than that, where they function in daily life; this is coherent with the hypothetical adjacent levels transcoding axiom [10]. The main mechanism of their creation is the feedback, not without reason regarded as being one of the greatest "inventions" of evolution.

Let us look at the Fig. 2. If an internal movements' pattern, being evoked from memory with a stimulus, is wrong, then it will not produce desired changes in environment. Therefore, the error appears. It is identified with senses and the process of its correction begins with a feedback mechanism. Unfortunately, the feedback loop makes the whole motor operation by far more time-consuming. Nevertheless, the timing, necessary to produce any B-level template (and, as a result, automatism), "resides" at C-level. Therefore, the correction of a given template needs engagement of this level.

According to "one level higher" principle, such a slowing down results not only from "pure" existence of the loop, but also because it uses information processing modality from a higher level, which is more time-consuming. Nevertheless, final aim of such a process is complete elimination of the feedback loop. If it finally disappears, the informational link with a higher level – slower and "cleverer", indeed, yet more "clumsy" – is being broken and whole information processing occurs efficiently enough with a modality characteristic for lower, swifter – yet able to deal effectively with the specific task – level in feedforward mode (Fig. 3).

In short, elimination of the feedback loop means transformation of the open skill into a closed skill–by far much swifter, and "cheaper" in information processing terms [31, 37]. It is worth noticing that the senses responsible for possible error identification are usually not switched-off completely; they remain not at the state "stop", but at "stand by".

The feed forward motor operation pattern functions with the best efficiency, i.e., optimum speed and precision. If it makes a slave-pattern of a greater master-pattern, it integrates smoothly into the latter and its timing. The final motor operation is then quick, smooth and successful, i.e., efficient.

While looking at such a process from the perspective of ML, and having in mind the already cited words by Mandelstam, one had to add that the "working power" of the word resides at D-level, but its "creative power" – at E-level. In other words, the "full power" of D-level may reveal itself only in the presence of the E-level. This may be illustrated with the observation of child development by psychologists Piaget and Inhelder [28]. In the pre-operational stage (2-7 years), a child describes verbally only the items just being observed (C-level). In the specific operations stage (7-11 years), a child begins to think about reality, i.e., to produce logical, abstract representations of the observable world (D-level). In the formal operations stage (over 11 years), a young man begins to think about thinking, i.e., to create in mind intellectual structures completely detached from sensory experiences, specific to E-level [10].

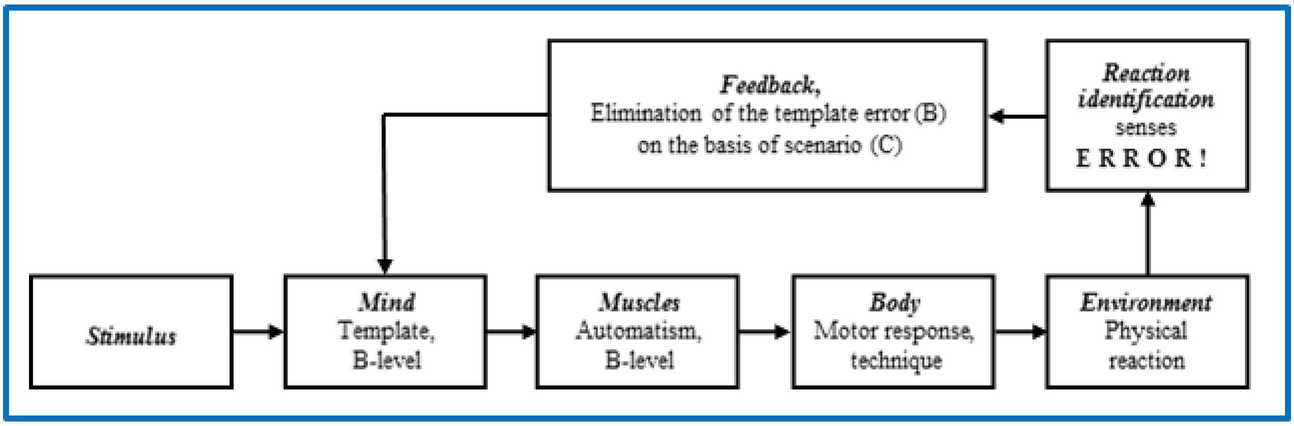

Figure 2. The feedback and the "one level higher" principle; correction of the abstract template and real automatism at B-level needs information processing at C-level.

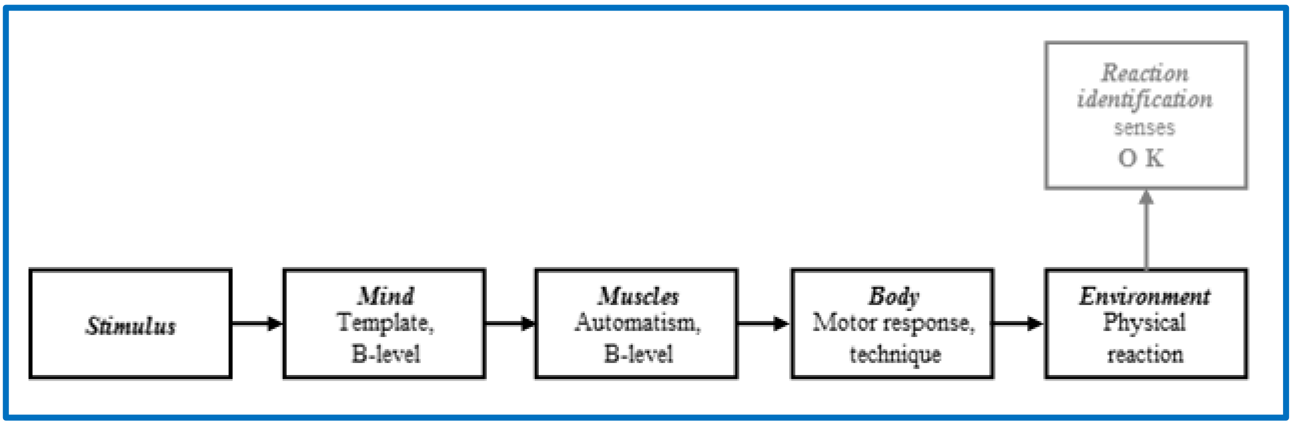

Figure 3. The feedforward in the B-level automatism. The gray "Reaction identification" box symbolizes that it is at "stand by" state, i.e., it neither needs full attention engagement, nor initiates a feedback loop; as a result, it does not slow down the whole motor operation.

However, when human experiences increased stress level, the feedback mode may be activated even if previously the proper feed forward motor control pattern has been already worked out. Even if it happens in merely one of several slave-patterns, it destroys the whole temporal structure – and efficiency – of a given master-pattern, sometimes highly complex and sophisticated.

In sport, such a phenomenon is termed "choking". For example, in 1993 Wimbledon Final (Jana Novotna vs. Steffi Graf) Novotna nearly won the match. However, she begun to control her movements very precisely, afraid of making any error. In motor control language, she switched on the slow and clumsy feedback control mode, and the winner became Graf [38].

Symptomatic is also the statement of 2007 of outstanding ski jumper Adam Małysz:

> *I have to switch off thinking (my emphasis – WP)… Before each jump I wonder, what should be improved. In team contest, I have focused my attention on preventing the delay of take-off. As a result, I skied too passively and did not take off dynamically enough – admits the World Cup holder* [39].

In system-theoretical language, it means: *Let the habits, automatisms and reflexes do their job freely and swiftly! In ski jumping, when the speed by take-off reaches 100 km/h, the real competition is not a place for slow by its nature D-level thinking. The respective motor operation patterns have to be prepared in advance and executed swiftly*.

Outstanding racing driver Ben Collins (mysterious Stig, "*Top Gear*") stated:

> **What defines a good driver? What attribute is necessary, and what merely useful?**
>
> *The anticipation. Racing driver is a person, who does not look for solutions of the problems that occur in a race. S/he knows those solutions, and when the situation comes, when the reaction becomes necessary, s/he simply performs the operations leading to its successful solving* [40].

After defeat by Tyson Fury, world-boxing champion Vladimir Klitschko stated:

> *I was in the best physical shape of my life. But no physical form will help unless it's combined with a good psychological condition. It was not an injury. (…) I felt the distance. I was thinking too much … about counting. I had to work on instinct (my emphasis – WP), that killer instinct. I kept waiting for something and the opportunity to fix things. I got uncomfortable, and all of this has caused some fatigue, discouragement, even confusion* [41].

In this context, the statement "*work on instinct*" means no doubt "*to let automatisms do their job*". The "*thinking on counting*" impaired the action of the automatisms.

A concise and interesting description of this problem comes from outstanding musician Adina Mornell, who maintained:

> *The countless individual actions involved in each and every phrase are simply not readily available to cognition. Without automation of motor programs, this would be not possible. That is why experts learn to let go in order to achieve, and why the desire to control can be so dangerous* [42].

In this statement, the term "*let go*" may be identified with the feedforward control mode. However, from the perspective of ML, the statement "*not readily available to cognition*" sounds like a slight dissonance, because in the ML each of the "rungs" has its own memory, consciousness and cognition; the lower level, the swifter its operation. Accordingly, there are no "unconscious motor operations", because each of them has to be embedded in a consciousness and an information processing specific to its respective "rung" of the ML, not always possible to express in the verbal code. Therefore, the ML model eliminates some quasi-scientific "black boxes", which have no strictly defined meaning in the science on motor control in humans (*"somehow", "in a sense", "unconsciously", "subconsciously"* etc.).

Interestingly, Bernstein refers to an example from the novel "Anna Karenina", by famous writer Lev N. Tolstoy. He presents two mowers: an old peasant Tit, and "nonprofessional" landowner Levin. Tolstoy describes the activities of Levin as follows:

> *In the midst of his toil there were moments during which he forgot what he was doing, and it came all easy to him, and at those same moments his row was almost as smooth and well cut as Tit's. But so soon as he recollected what he was doing, and began trying to do better, he was at once conscious of all the difficulty of his task, and the row was badly mown [43].*

It seems especially worth emphasizing that Tolstoy was not a motor control specialist. Therefore, his observations are not "underpinned" by any scientific "ideology". Nevertheless, they correspond perfectly to the case of Novotna and Graf.

It seems worth noticing that such an interpretation of "choking" is coherent with Clark's "007 principle" [27].

3.5. Terminology in science on human movement operations: ordering and pigeonholing

The importance of language in science is visible not only from the psychological and physiological perspective of kinesiology, but also from mathematical perspective of physics [30]. In this respect highly instructively sound the following statement by Niels Bohr: *What is that we human beings ultimately depend on? We depend on our words.*

We are suspended in language. Our task is to communicate experience and ideas to others [44].

The issue of thought-language connections has been thoroughly investigated by psychologist Lev S. Vygotsky [45]. Symptomatic is the following fragment of the poem by Osip E. Mandelstam "Swallow", cited by Vygotsky:

The word I forgot
Which once I wished to say.
And voiceless thought
Returns to shadows' chamber.

However, while looking from the ML perspective, such a phenomenon is possible only when a living being has fully developed D-level, i.e., it is able to use language. Among living creatures, only the species Homo sapiens mastered this ability efficiently enough.

The problem of terminology ordering is by no means a by-product in the process of science creation (including motor control). In fact, it is extremely important, because in the process of science creation, the words at first describe reality, but then they make a "basic stuff" for abstract scientific theories and whole science disciplines. In short, reality consists of observable things, phenomena and processes, whereas science is "woven" of abstract words, notions and theories. Therefore, the value of science directly depends on the quality of terminology. Moreover, along with the development of our understanding of the world, which is accompanied by the progress in science, the terminology has to evolve ceaselessly. Therefore, modifying and perfecting the language that mirrors our knowledge of the world is in fact a "never ending story". Moreover, it is the basic, and not merely subsidiary, process in science creation.

As already stated, just in the lack of a proper language, some scientists seek the source of too slow progress in movements' science [30]. It is no doubt right, simply evident. It is worth noticing that the Bernstein's BS bases on neurophysiological and evolutionary knowledge, whereas the ML has been founded on the abstract, logical – verbal – development of Bernstein's achievements. One has to emphasize that abstract concepts and hypotheses are full-fledged "citizens" of science. Even more, just in this region reside the sources of science. Let us remind that only properly ordered knowledge deserves the noble title of "science". Therefore, some ordering is necessary, indeed, but if a scientist crosses the elusive and hardly discernible border, it transforms into pigeonholing. The former is genuine scientific work, whereas the latter – quasi-scientific "wishful thinking". This makes a difference between ordering and harnessing the science and making it unmovable and intellectually clumsy. The former marks out the way towards progress, whereas the latter leads to petrification and paralysis of any mental methodology. Nevertheless, scientists usually strive for classification of their ideas according to an already existing system, and not to look for novelty and discoveries, both real and mental (what is by far more intellectually risky). If something does not match the already existing scientific pigeonholes, is in advance rejected as "moonwalking" or "daydreaming". In this context, let us remind that such "daydreamers" as, say, Isaac Newton, Max Planck, Erwin Schrödinger, Werner Heisenberg, Niels Bohr, Albert Einstein or Peter Higgs – to name only some of Giants in physics – took their intellectual power just from their "daydreaming". Consequently, just this thinking mode made physics the main engine of the whole science in the course of recent nearly four centuries. In this context highly instructively sound also the words by physician and biologist Thomas H. Huxley, who stated that "*every great advance in natural knowledge has involved the absolute rejection of authority*". No wonder that the scientific authorities – often dignified and powerful – do not like it.

It is worth noticing that one of the basic rules of very fruitful methodology of intellectual work, the brainstorming, consists in avoiding any evaluation of new ideas at the stage of their creation.

In motor control, it was often disputed, whether Bernstein's theory is of motor, or rather action nature. Such disputes obscured his greatest achievements. While looking from such a perspective one might – roughly – say that the "sensory" levels, A, B, and C, are of action (ecological), whereas the "purely mental" levels, D (common sense) and E ("daydreaming") – rather of motor (programming) nature. One might say that here a scientist comes across the problem analogous to physical wave-particle duality in the nature of light. In this respect, it is worth emphasizing that the matter of movements' control in living creatures is by far more complex than that of physics. By the way: the fierce disputes about open loop and closed loop motor control, about motor approach and action approach – in fact, aimed at science harnessing rather, and not at ordering it – needed much work and effort of many scientists all over the world. Even if useful at a specific stage of science development, they had later to be broken – according to advice by Huxley – to enable a real progress. It shows, how risky and treacherous is the only way towards theory (and science as a whole) production – the elusive, hazardous, mysterious, bumpy abduction path, lined with cadavers of those, who had no scientific luck enough.

4. Conclusion

The presented paper follows the way marked out by Bernstein. His "starting point" was also biomechanics, but his way towards explanation of the mechanisms underlying different motor operations led through the "county of evolution and neurophysiology". It resulted with creation of physiology of activity, which may be symbolized by the brain skyscraper. On the other hand, the way towards similar explanation presented in this paper leads through the "shire of information processing". It resulted with invention of the modalities' ladder, parallel to the brain skyscraper, indeed, yet unveiling another scientific perspective. Both these mental structures might be regarded as being two different "shadows" of the same science on motor operations development and control in humans (Fig. 1).

According to the "one level higher" principle, one might try to solve the problem presented by Vygotsky, who stated:

> *In animals, even in anthropoids whose speech is phonetically like human speech and whose intellect is akin to man's, speech and thinking are not interrelated [45].*

Why? While looking from the ML perspective, and the Bernstein's lower levels' development principle, the answer sounds: Because the ape has no E-level developed in its BS (and, consequently, in its ML). As a result, its D-level does not include the abilities, which occur only in the presence of the higher, E-level. Accordingly, its "word" has merely a "working power", and not a "creative power". On the other hand, in humans, who have quite good developed E-level, just the creative power of language enabled invention of, e.g., culture and science.

The concepts presented in this paper may be regarded as a supplement to biomechanical qualitative analysis. It deals with the observable outcomes of the psychological processes, which cannot be directly followed. However, only both observable physical and unobservable psychological processes may explain the fascinating phenomenon of human motor operations creation and control. The operations themselves are quite easily observable and measurable experimentally, whereas towards the psychological processes leads only a narrow, treacherous, full of traps and dead ends path of abduction. Therefore, the contemporary motor control needs "daydreamers" to make new inventions, and the functional, logical terminology – to order them and to incorporate smoothly into the already existing system of knowledge, i.e., the science. In short – to protect the valuable scientific thought from the fate described by Mandelstam. If it really deserves it…

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