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Original Article

MOTOR ABILITIES IN HUMANS FROM BERNSTEIN'S AND FLEISHMAN'S PERSPECTIVE

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Motto

A theory is a kind of code that transforms complicated „messages" from nature into much simpler ones.
J. Cohen, I. Stewart

Abstract

The basic goal of science is to produce the predictability that enables intentional shaping of environment and efficacious influence the future events. To achieve this goal, three methods of information processing may be adopted: induction, abduction and deduction. The former bases on observation of simple cause-effect chains and the premise that the same causes will evoke the same results. It enables production of predictability "rooted" in reality. Abduction includes abstract processing of the observed reality and creation of generalized theories. Theory enables production of predictability "rooted" in formal representations of reality (and not in sensory experiences) by means of deduction. In motor science, being probably the greatest challenge to the whole contemporary science, production of predictability is especially difficult. The elementary conditions for performing any motor act make the motor abilities. They may be identified either experimentally, or theoretically. The former way, basing on superficial parameters of motor performances, is being initiated by E.A. Fleishman. The latter, founded on neurophysiological and physiological rationale, has been developed by N.A. Bernstein. In the paper both these approaches of identifying and defining particular motor abilities have been presented with special emphasis on the latter.

Key words: motor ability, motor performance, motor science.

Introduction

The basic task of science is to create the predictability. This was aptly expressed by founder of positivism, A. Comte, who stated "*savoir pour prévoir afin de pouvoir"* (Comte, 1852, p. 91). In this adage "*to know*" means the abstract representation in human mind of the world image, i.e. objects, phenomena and processes. "*To anticipate*" needs perception of time as a factor determining sequence of events in the temporal scale that reaches beyond direct availability by sense organs; thus, it has to be abstract.

The future events are burdened with much uncertainty, so the anticipation is nearly always of probabilistic nature [Feigenberg, 2008]. Accordingly, the process of developing the predictability has to go far beyond the bases determined by positivist or behaviourist paradigms. The main task of science is to build predictability, and this is why – as it aptly stated M. Heller – "*the science sees the world through theories*" [Heller, 2011, p. 44]. So, to achieve a scientific predictability it is necessary to create its basis, i.e. abstract theory.

The positivist and behaviourist paradigms were based on so called "real facts". However, A. Einstein remarked that already at the level of sensory experiences an image of reality becomes somehow distorted because of specificity of human sense organs [Einstein, 1936]. So, the bases of perception are not the facts, but their sensory representations that may be termed "afferentations". Moreover, it is worth noticing that the afferentations always include a share of subjective interpretation; hence, there is no something like "objective fact" or "bare fact". Nevertheless, just the afferentations make a basis for creation of more and more abstract representations of reality in individual's mind, finally leading to creation of a hypothesis, from which may originate the highest advanced product of science i.e. theory. Such a series of representations of increasing "abstractness" might be termed "Einstein's spiral" (figure 1). Figure 1. Reality and abstraction in information processing in humans – the Einstein's spiral.It is to be emphasized that "*the development of science is a creative process, so the complete elimination of subjective elements from it is not possible*" (Heller, 2011, p. 82). Accordingly, the abstract representation of reality, being the fundamentals of theory creation, may take various shapes and it results – all the more – with different theories basing on the same facts. This was expressed by R. Schmidt as follows:

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> *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 (...)* (Schmidt, 1988, p. 29).

More general is the statement by P. Lenartowicz:

> *The "science" is a historically variable, rough vision of reality, connected not only with observation and researching the Nature itself, but also with some historical philosophical tendencies* (Lenartowicz, 2010, p. 39).

Consequently, according to nonlinear theory of science evolution (Heller, 2011, p. 68), the process of development consists of stationary phases and bifurcation phases. In stationary phase the current paradigm enables achieving valuable results, so the scientists are glad to follow it. However, when such a paradigm becomes infertile, a new way of researches and reasoning has to be developed and this makes the essence of bifurcation phase. Such a bifurcation results with creation of two streams and usually, in a long temporal perspective, only the more effective one survives.

1. Predictability creation methods

Already Aristotle defined two ways of reasoning: inductive and deductive one (Reale, 1990, p. 361). In short, the former bases on facts, and the latter on ideas.

However, one may ask, where the ideas, necessary for deduction, come from? It is to be noted that – roughly – the facts are rooted in reality, whereas the ideas are fully abstract. So, to create the ideas, the observations have to be transformed, expressed in abstract form and generalized, i.e. the theory has to be developed. To achieve this, it is necessary to "ascend" into higher levels of abstraction. According to C.S. Peirce, such a transformation is termed "abduction" [Harris, Hoover, 1980; Sowa, 1990; Sowa, Majumdar, 2003]. The relations between induction, abduction and deduction are presented in figure. 2. Induction, abduction and deduction

Accordingly, the following definitions may be formulated:

Induction – *«Information processing consisting in joining the observations into cause-effect chains at the same level of abstraction».*

Deduction – *«Information processing consisting in transformation of abstract, generalized knowledge, translating it into code understandable at "working" level of given task solution and producing a pattern of such a solution realizable in practice».*

Abduction – *«The process of reasoning including transformation of perceived reality into more abstract form and generalizing the idea obtained in such a way».*

Accordingly, the **induction** may be regarded as intellectual operation at low levels of Einstein's spiral, where only simple cause-effect connections may be discovered; the **abduction** – as risky climbing up it, towards the elusive and unambiguous regions where the scientific conclusions and hypotheses may be invented; and the **deduction** – as descending down the Einstein's spiral, from the regions of theories, to the sphere of reality, where the (possible) usefulness of abstract theories – measure of which is the highly practical predictability – is being observed (or not). It is worth noticing that the bottom of Einstein's spiral is intellectually "safe" – so, just this region is beloved by so called "empirical sciences" – but enable only extensive development of science. On the other hand, the peak of the spiral is intellectually quite risky, but only here the real progress may arise. Paradoxically enough, only creation of formal representations and then processing them at a level of higher abstraction enables unveiling such phenomena and processes which are not detectable at the level of direct observation. A. Einstein wrote:

> *I have learned something else from the theory of gravitation: no collection of empirical facts however comprehensive can ever lead to the setting up of such complicated equations. A theory can be tested* (not proved! – WP) *by experience, but there is no way from experience to the construction of a theory. Equations of such complexity as are the equations of the gravitational field can be found only through the discovery of a logically simple mathematical condition that determines the equations completely or almost completely*. (Einstein, 1996, p. 85).

Similar idea expressed R. Dawkins, who wrote:

> *Careful inference can be more reliable than "actual observation", however strongly our intuition protests at admitting it* [Dawkins, 2009, p. 15].

Accordingly, in motor science, dealing with probably most challenging issues in whole contemporary science, the "new, original experimental data" cannot any longer result with valuable discoveries "by themselves".

2. Inductive paradigm in motor abilities identification in humans; The Fleishman's legacy

At first let us define the term "motor ability" as follows:

> ***Motor ability –*** *«the specific current primeval potentiality of using the biological energetic and informational resources by a living being in order to bring about desirable physical phenomena and/or processes in the environment».*

Here it is to be emphasized that the term "motor ability" is somewhat misleading, because even in the most primitive of them, i.e. the strength, also the informational components make its inseparable parts.

The empirical method enables adoption of induction only. Consequently, it may give rise to a THEORY THAT (it has been observed **that**...). It bases on observations and determines the superficial associations of causes and effects (at the bottom of

Einstein's spiral), but it lacks in deep theoretical reflection (at the peak of Einstein's spiral). Such a "theory" – termed by R. Dawkins "theorum" – enables prediction only in the field of knowledge acquired empirically; it might be compared to mathematical interpolation. The theory THAT might be identified with what G. Gigerenzer termed "surrogate for theory" [Gigerenzer, 2009].

The inductive method of motor abilities identification might be associated with works by E.A. Fleishman [Schmidt, Wrisberg, 2008; Schmidt, Lee, 2011]. He adopted statistical factor analysis in the study of perceptual-motor abilities. R.A. Schmidt and C.A. Wrisberg wrote:

> *So far, scientists have identified around 20 to 30 cognitive and motor abilities, and they anticipate discovering more in the future* (Schmidt & Wrisberg, 2008, p. 165).

While looking at figure 2 one learns what is the most important trait of this way of research. Whole the process of induction happens close to reality (as a rule, at the level not higher than that defined by arithmetic average, standard deviation or correlation coefficient). So, it is quite immune to false interpretations, because of close relations to "hard facts". On the other hand, such a way of reasoning it is quite immune to any interpretations at all, so it makes no basis for generalizations and thus developing the universal theories. A really creative process needs more abstract (and intellectually more risky) information processing and even change of information modality (e.g. construction of mathematical model).

Statistics eliminates some observational noise and makes the image of reality more sharp, indeed, but – unfortunately – it does not explain "by itself", what namely such a sharpened image presents. So, Schmidt and Lee wrote:

> *Fleishman's work leaves a legacy for future efforts on solving problems of prediction*. (Schmidt, Lee, 2011, p. 309).

It is worth noticing that they wrote not about "*solving problems of prediction*", but about "*future efforts on solving problems of prediction*". By now, this stream of researching has no significant successes and evidently cannot make a reliable basis for "strong" predictability. Schmidt and Wrisberg wrote:

> *Thus it appears that predicting future performance on the basis of people's abilities alone is, at best, an imperfect science* (Schmidt, Wrisberg, 2008, p. 182).

3. Abductive paradigm in motor abilities identification in humans; The Bernstein's ladder

The abductive method enables more universal generalizations than the inductive method, and supports formulation of a THEORY BECAUSE. It takes the real facts, at low part of Einstein's spiral, then forms the abstract premises, and creates the abstract mechanisms, at high part of Einstein's spiral, which produce the model relations between causes and effects (it has been achieved a given effect, **because**...). Such a theory enables prediction also outside the field of knowledge acquired empirically; it might be compared to mathematical extrapolation.

The abductive way of motor abilities categorization might be traced in the works by N.A. Bernstein (Bernstein, 1947; Bernstein, 1991; Bernstein, 1996). He followed the evolution of vertebrates and joined the development of their central nervous system (CNS) and movement potentialities. So, in this case the rationale was not a superficial observation, supported by statistical calculations, but the evolving structure of the CNS. At this point the inductive method of reasoning would be infertile, so it became necessary to apply the abduction.

The abduction is no doubt intellectually riskier than induction because the conclusions association with reality is indirect. Nevertheless, it is the only way for creation of theories BECAUSE. As a matter of fact, only such a mental structure deserves the title of genuine theory. However, to develop a theory BECAUSE it is necessary not only to discover the superficial regularities, but also to figure out the mechanisms underlying them

Summing up, the "prediction giving mental construct" based on induction R. Dawkins termed "**theorum**"; the one based on abduction – "**theory**"; and the one completely detached from reality (e.g. of purely mathematical nature) – "**theorem**.In this paper, the basis for abduction makes the five-level Bernstein's pattern of motor control in humans. It bases on anatomical and functional division of the central nervous system. Level A controls muscle tonus and level B – muscle synergies. Both they are being controlled by sub-cortical structures.Level C is divided into two sub-levels: C1 and C2. The former controls the movement of a whole body in environment (great motoricity), whereas the latter manages the precise movements of working organs and other objects (small motoricity). C-level makes a specific bridge between sub-cortical and cortical control centres, because C1 level is being regulated by sub-cortical centres, whereas the C2 – by cortical ones.Two highest levels, D and E, are fully cortical and purely intellectual, i.e. they are not directly "connected" to sensory organs. The former manages the real motor programmes embedded in "stiff" time-space continuum, whereas the latter deals with fantastic, often not realizable representations of motor performances enveloped in "flexible" time-space continuum.The A, B and C levels may be termed "sensory levels", because they are somehow connected to reality perceivable by sense organs. The A level reacts to stimuli from inside the organism. The higher B and C levels make "sensory gates" to environment: the former a "contact gate", the latter a "remote gate". The D and E levels have no their "own" sense organs and they may influence the lower ones only by the agency of memory, i.e. abstract representations of reality.

The simplified diagram of motor control system in humans is shown in figure 3.The simplified diagram of information processing paths in human movements' management system; the codes' ladder.

The original theory by Bernstein bases on evolutionary and neurophysiological data, so it is too complicated to be adopted in practice in its "rough" form. In the course of evolution, as a result of encephalization, the motor functions of particular elements of the CNS become more and more "fuzzy" distributed among spinal cord, cerebellum, basal ganglia and cortex. Thus, the problem, to what extent say, globus pallidus is responsible for this or that part of a human motor operation may be compared to the question, to what extent the exhaust valve in third cylinder contributes to maximum speed of a car. Accordingly, on the basis of Bernstein's theory much simpler (and more abstract) structure has to be developed to enable creation of a theory that might turn to be useful in practice. In this paper such an intellectual structure includes only two elements "distilled" from Bernstein's theory and coupled with particular Bernstein's levels, i.e. the codes varieties and the spatial-temporal dimensionality specific to particular levels [Petryński, 2008; Petryński, 2010]. Both these factors determine the potentialities of motor performance control. The sequence of codes may be termed the "**codes ladder**" (CL). It has been shown in the middle column in figure 3.The CL seems to be a promising base for building a THEORY BECAUSE concerning human motor behaviour.

3.1. Codes' ladder; time as events' ordering factor

The potentialities of information processing at particular "rungs" of the CL determine the class of motor and intellectual behaviour being controlled at each of the levels.At A-level muscle tonus may control one-dimensional muscle contraction. While taking into account the specificity of motor units action in a skeletal muscle (**all or nothing**), the time function is very simple: now-not now. At "sensory side" of A-level there are intrinsic stimuli, and the information processing capabilities of the code applied at this level enable the control of the intensity of muscle contraction, i.e. the strength at "action side".At B-level muscle synergy controls the two-dimensional joint bend and has to synchronize the action of at least two muscles: extensor and flexor. Here necessary is the more complex synchronization of type: **this one earlier – that one later**. At "sensory side" of B-level one may place the contact stimuli (including inertial ones, perceived as "apparent contact stimuli"), whereas at "action side" of it – the control of speed.At C-level an organism has to control intricate, three-dimensional net of joint bends. The three-dimensional space makes the environment where the events happen, so it cannot be separated from the time. Here a living being comes across time-space continuum. However, the time is being perceived only to the extent limited by sense organs capabilities (in humans mainly vision). Accordingly, one should not speak about four-dimensional time-space continuum, but about "three and fraction-dimensional" C-level environment.The division of C-level into two sub-levels, C1 and C2, enables differentiation and identifying of two motor abilities associated with this level. The C1 whole body movements may be described as "agility", whereas the C2 working organs movements – as "dexterity".Summing up, at "sensory side" of C-level one may place the remote stimuli, whereas at "action side" of it – the control of complex movements structure in space along with its proper timing.In the CL the C-level is the highest one connected directly to reality by means of sensory organs. Here very important is also ability to join sensory inputs coming from various sensory organs to create a complete image of reality. For instance, a snake is able to use only one sensory modality at once, whereas a cat may use at the same time stimuli of various modality to recognize the environment [Gärdenfors, 2003, p. 39].The sequence of three-dimensional nets of joint bends constituting a complex motor performance at D-level is commonly termed "motor programme". It needs designing of a performance reaching into the future beyond the limits set by sensory organs; accordingly, they are not directly useful at this level. Here it becomes necessary to enter the region of abstraction. The price that has to be paid for extending the temporal scale far into past and far into future is switching off the sensory experiences. So, employing the abstract representations instead of sensory perceptions enables using full four-dimensional time-space continuum. It is to be emphasized that it is fully abstract, i.e. the D-level has no its "own" sensory organs. The motor programmes are representations of real (and usually realizable) motor performances, so they have to take into account real conditions. At this level the time-space continuum makes a "stiff frame" for events being programmed. This "stiff frame" mirrors the reality truly, and embedding realizable performances in it is termed "common reason". Here the ability being controlled may be termed "expertise".

The highest E-level is also of fully abstract nature. However, here the "stiff" is the event, and "flexible" is the time-space continuum. The ability being controlled at this level – sometimes not constrained by reality – may be termed "invention" or "fantasy".Neither D-level, nor E-level has its "own" sensory organs, so the only "fuel" for information processing at both of them is an abstract representation of reality.The E-level with it "rubber time-space dimensionality" with "rigid" events embedded in it cannot control any real motor operation, even indirectly. The D-level, with realizable motor programme, firmly embedded in reality, with "flexible" events that have to be adjusted to it, may indirectly control even a very complex motor operation. However, the highest level able to control directly any real motor activity is the C-level. Otherwise, it is fascinating level. According to Bernstein, from the neurophysiological and evolutionary perspective, in humans just here one may observe the "evolution at work", i.e. the process of transferring the motor control functions from the sub-cortical to cortical CNS structures. From the point of view of information processing its appearance in the course of evolution may be compared to Copernican revolution. At A (intrinsic) and B (tactile) levels the one's own organism was the whole universe for a living being. Along with appearance of the telereceptors, specific to C-level, the one's own body may be perceived as an element of much more extensive environment. A very important transformation of time perception happened at C-level, too.The visual experience is the reality representation which lasts only as long as a stimulus that evokes it. The word is fully resistive to time lapse. Somewhere in between there is what psychologists termed "object permanence". P. Gärdenfors described it as follows:

The cat has object permanence and can therefore predict that a mouse that runs under one side of an armchair will come out the other side. A snake could never manage that. The cat can "think" of the mouse even when it is receiving no signals from its senses (…) [Gärdenfors, p. 39].

Summing up, A-level may be associated with one-dimensional muscle contraction and time perception "now-not now"; B-level – with two-dimensional muscle synergy and time perception "flexor first-extensor later"; C-level – with three-dimensional agility and/or dexterity and time perception at the level of object permanence (i.e. three-and-fraction dimensionality of time-space continuum); D-level – with full, rigid time-space continuum, completely detached from sensory experiences; and, finally, E-level – with full, flexible time-space continuum also completely detached from sensory experiences.

3.2. Codes' ladder; time as duration measure

The other function of time, as a duration measure, is by far less complicated, even boring. Because of fatigue, each of the already listed abilities may be executed in a limited period of time only that determines a specific kind of **endurance**. Accordingly, one may distinguish:

- At A-level – strength endurance,
- At B-level – speed endurance,
- At C-level – agility/dexterity endurance,
- At D-level – expertise endurance (ability to design realizable, goal-aimed motor programmes),
- At E-level – invention endurance (ability to invent fantastic performance, sometimes bordering on daydreaming).

4. Final remarks

As shown in this paper, the CL makes rationale for the motor abilities as presented in table 1. Motor abilities according to codes' ladder.

All the listed abilities make a continuous system. At lower levels it is of sensory-motor nature, whereas the higher ones are more and more "soaked" with intellectual element and at the same time deprived of somatic one. Moreover, in the CL the borders between particular levels – though much more clear and distinctive than those in original Bernstein's theory – are quite fuzzy. Nevertheless, all they make a system in terms of systems theory [Petryński, 2008; Petryński, 2010; Petryński, Feigenberg, 2011].

While comparing the "rationale" resulting from the "Bernstein's paradigm" with the "experimentale" resulting from the "Fleishman's paradigm", it seems very probable that the observable movements' effects, making the basis for Fleishman's categorization, result from mixed Bernstein's abilities. The Bernstein's model is a system in terms of systems theory, so the results of its action are system effects. By definition, they are not predictable on the basis of their components' traits (Jervis, 1997; Morawski, 2005). Summing up, the "Fleishman's paradigm" may probably produce the "theories THAT", whereas the "Bernstein's paradigm" – and the CL concept, resulting from it – is likely to create the "theories BECAUSE".

It is worth noticing that the formulation "not predictable" bases on current state of science. May be some day in the future it will be possible to use the great legacy of contemporary experimenters and "re-forge" it into useful theory. This makes a basis for the "anything goes" principle by philosopher P. Feyerabend [Feyerabend, 2002, p. 23]. Nevertheless, by now the science has no intellectual tools strong enough to solve the problems of motor control in humans basing on statistical data.

The presented considerations are reflected in practice. As a matter of fact, the sport coaches take as a basis the Bernstein's structure rather, and not the Fleishman's one. So, while training athletes they shape usually strength, speed and endurance (Bompa, Haff, 2009), and not the multitude of abilities identified with statistical methods by Fleishmann and his followers.

Contemporary science tends sometimes to make divisions of what in practice is inseparable. Such is the categorization of reality exploration methods into "phenomenological" and "rational". As a matter of fact, the rational (abductive) way of thinking has to correspond somehow to reality – otherwise the subsequent deduction would be probably directed to nowhere – and the phenomenological (inductive) way inevitably has to run at a higher or lower level (rather the latter) of abstraction. Nevertheless, while taking this division (commonly adopted in science) as a rough approximation, one may conclude that the rational (abductive) ordering of motor abilities seems to have greater "predicting power" than that erected on phenomenological (inductive) fundamentals. Accordingly, one may paraphrase the dialogue between Buddha and Shepherd [Kazantzakis, 2008, p. 19] and say:

> *While looking from codes' ladder, we were able to find rationale for only four motor abilities (strength, speed, agility and dexterity), two their extensions into the purely mental sphere (expertise and invention), and*

six kinds of endurance, corresponding to them. And you, Phenomenologist, can experimentally find as much new, original motor abilities as you please!

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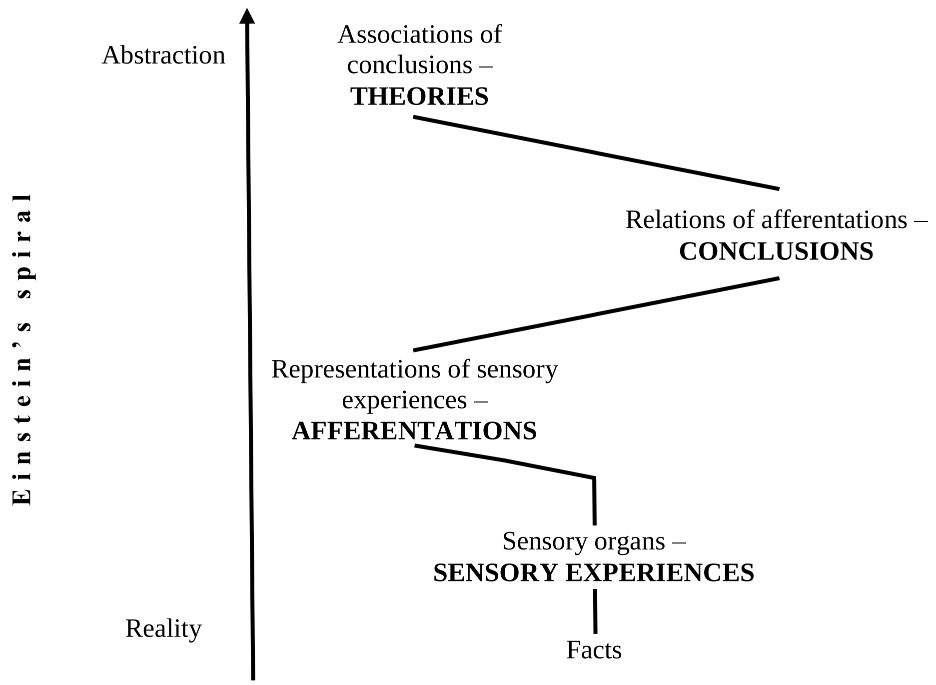

Figure 1. Reality and abstraction in information processing in humans – the Einstein's spiral.

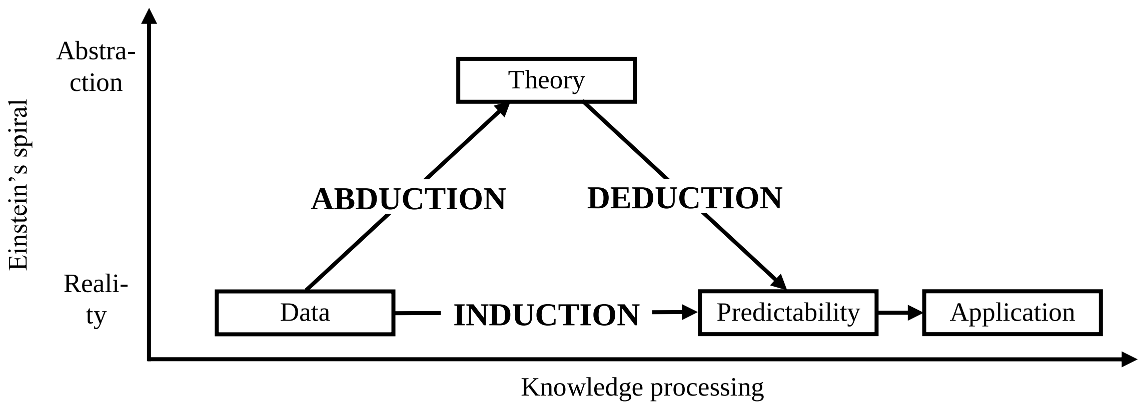

Figure 2. Induction, abduction and deduction.

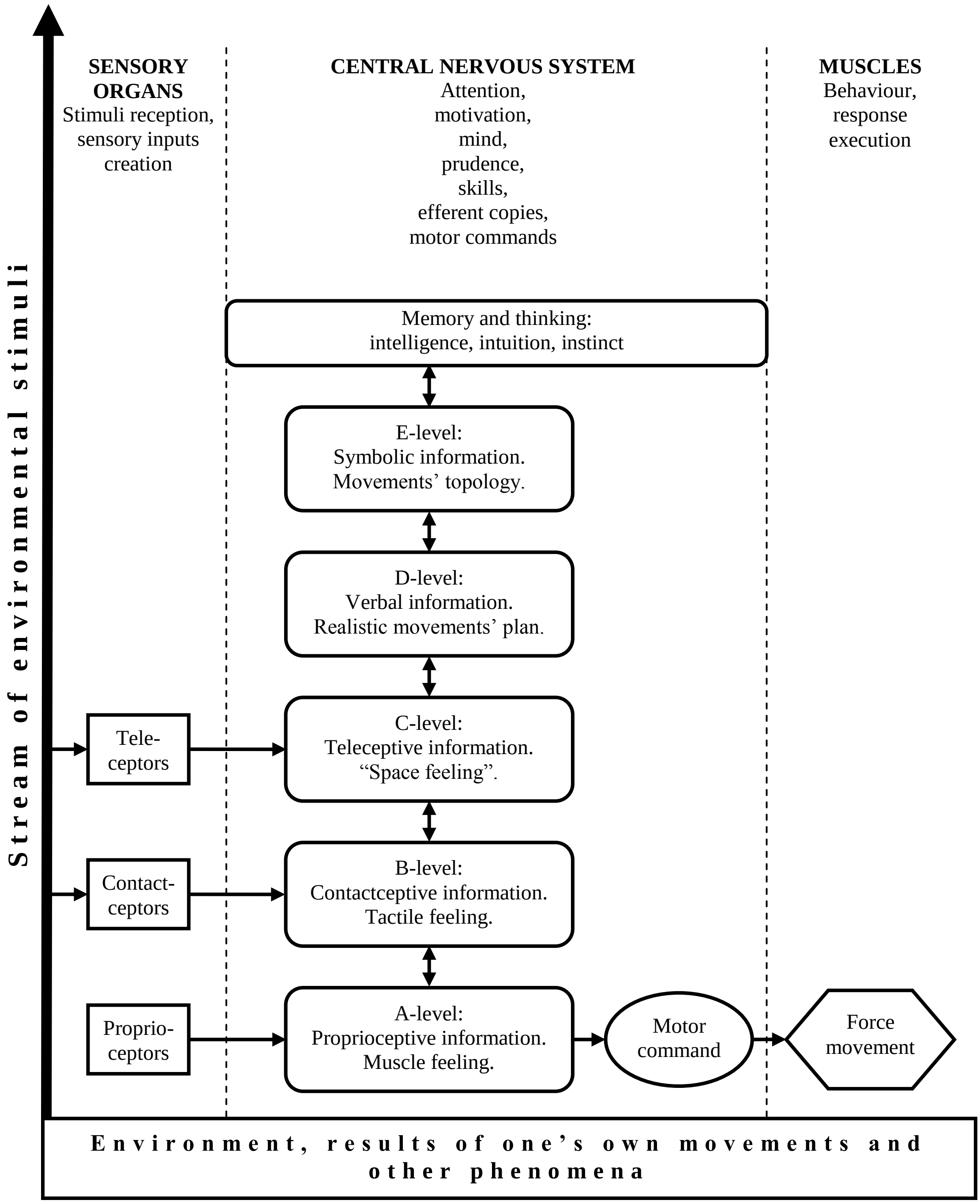

Figure 3. The simplified diagram of information processing paths in human movements' management system; the Bernstein's theory.

Table 1. Motor abilities according to codes' ladder.

Bernstein's level	Time as events' ordering factor	Time as duration measure
E	Invention	Invention endurance
D	Expertise	Expertise endurance
C (C1/C2)	Agility/Dexterity	Agility/dexterity endurance
B	Speed	Speed endurance
A	Strength	Strength endurance