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System Description of Human Motor Performance: The Movements' Construction Matrix

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ABSTRACT

In contemporary science about human motor behaviour, the theoretical description of motor activities learning and performing becomes more and more necessary. There is a lot of experimental data, which in its "rough" form is not useful, both for scientific and especially for practical purposes. In this paper a theoretical approach termed Movement Construction Matrix (MCM) has been presented. Its coordinates are: Bernstein's five-level motor control system and the succession of consecutive information processing events: attention, motivation, mind, and prudence. The MCM includes also dynamical movement patterns and efferent copies.

Keywords: Bernstein's ladder, Motor Performance, Movement

INTRODUCTION

From among achievements of N.A. Bernstein, his five-level model of movement construction seems to deserve more attention than it actually receives (Bernstein 1947, Bernstein 1991). It is one of very few comprehensive system descriptions of motor performance production in humans, including harmoniously joined neurophysiologic, motor and cybernetic elements, which make together one inseparable system. It may be perceived as a set of "empty containers" for various patterns of human motor activities. A human fills these "empty containers" with theoretical knowledge and practical skills during whole his/her life. In this process, he/she produces dynamical movement patterns, enabling quick using in typical situation with flexibility enough to be adapted to current environmental demands.

Broadly speaking, a human motor performance has a typical general structure (Schmidt, Lee 2005). Usually it starts with physical factor (a stimulus) reception by sensory organ (receptor) from environment. The stimuli are not "understandable" for the central nervous system (CNS), but receptors produce then sensory inputs. Only the sensory inputs may be later processed in the CNS.

First main processing "device" in the CNS is the attention. It ascribes some specific information (retrieved from memory) to the sensory input and gives some specific "weight" to it. When the weight turns to be insufficient, the information is rejected. In other words, the attention identifies the information and makes a hierarchy of it. The hierarchy determines the sequence and importance of further information processing in mind.

Next process is incentive motivation. It integrates information of various modalities from various receptors, differently evaluated by attention, and decides about processing it – as a whole – in mind.

The mind is the next link in information processing chain. It includes three main tools: intelligence, intuition and instinct. Its function is to process the data delivered by attention and filtered by incentive motivation, and then to develop a response.

While the response is already being worked out, the next link of information processing is the prudence. Basing on previous experiences it decides, whether the response being produced by mind should be realized or not. Important element of the prudence is the performance motivation.

Next link in the chain of information processing is selection of a proper dynamical movement pattern (DMP). It is a pre-prepared performance "blueprint" which enables to perform a given performance with highest available efficiency, using previously collected experience. Just the properly developed and well used DMPs make what is termed "skill".

Along with the performance execution, there runs still one more important process: the recording of efferent copies. Their role is twofold: firstly, they enable differentiation of results of one's own actions from the events independent of these actions. Secondly, they play important role in learning, developing and perfecting the sensory-motor performances.

1. Five-level pattern of movements' construction in humans: the Bernstein's ladder

Basing on detailed analyses of evolutionary development of living beings, great Russian scientist N.A. Bernstein invented a five-level model of motor activities construction in humans (Fig. 1). He associated the particular elements of the human CNS with corresponding classes of movements and arranged it into one system built according to the principles of cybernetics. It has to be noted that he has done it in 1947, when neither systems theory, nor cybernetics did exist yet as independent branches of science.

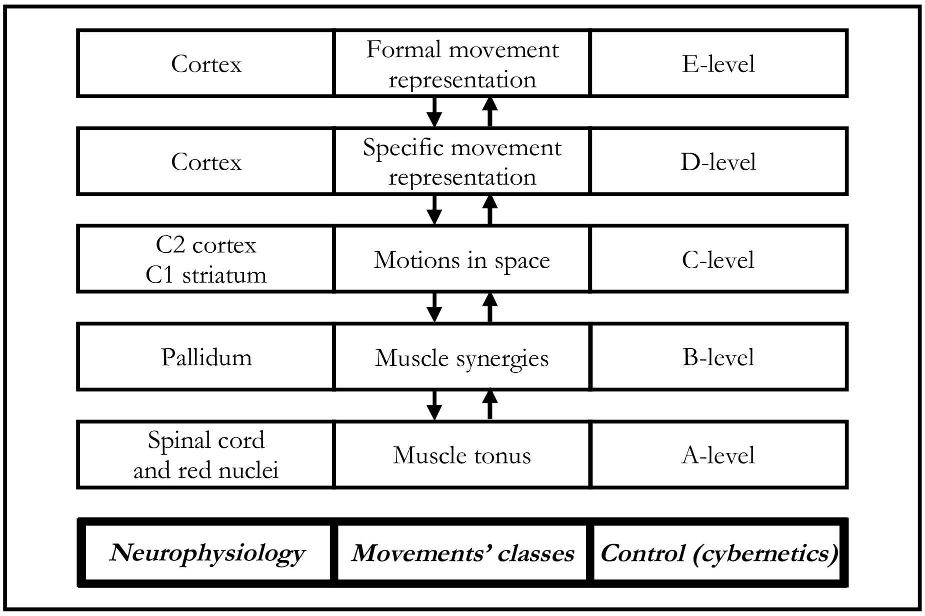

Fig. 1. Movements' construction system in humans: the Bernstein's ladder (Petryński, 2010).

The middle column in Fig. 1 makes the "drawers" or "empty containers" for dynamical movements patterns: automatisms (A-level), routines (B-level), schemes (C-level), specific motor programmes (D-level) and generalized motor programmes (E-level).

It is worthy to notice that apart from Bernstein, many other authors followed the same way of thinking and divided the CNS into two parts: pyramidal and extrapyramidal system (Abernethy et al. 2005). Nevertheless, the five-level Bernstein's ladder is much more detailed than two-level division into pyramidal and extrapyramidal part of the CNS.

Motor control structure in humans: A system description

The system is a layered structure of information and energy exchange built according to three general principles:

1. Layers hierarchy principle,
2. Layers autonomy principle,
3. Scales conformity principle (Morawski, 2005).

According to layers hierarchy principle, in a system there exist a main layer ("master") and the other ones are auxiliary layers ("slaves").

According to layers autonomy principle, each layer performs its tasks independently and does not need any additional information.

According to scales conformity principle, each layer has its own, specific code of information processing and information storing, as well as temporal phenomena and energy flows scale.

Noteworthy enough is that the system is specific to a task, and not to its own structure. In other words, its configuration depends on its current function, and not on the "independent" properties of particular layers. So, the same layer of a given system in one task may be the "master", and in another task – a "slave".

Let us adopt the system theory principles to describe the processes and phenomena forming the human sensory-motor performance.

At A-level the source of stimuli is one's own body, and receptors producing the sensory inputs are (roughly) proprioceptors. The process of ascribing the information to a given sensory input at this level may be termed **proprioception**.

At B-level stimuli come from environment, but they may be received only by direct contact with body surface (skin). Here the "producers" of sensory inputs are contactceptors, and information recognition at B-level is the **contactception**.

At C-level teleceptors receive stimuli from outside the body, but – unlike contactceptors – from the space much more extensive than the size of one's own body only. Thus, the sensory inputs coming from teleceptors may evoke much more detailed information than the ones of B- or A-level. The information recognition at C-level is termed **teleception**.

The D- and E-level have no their "own" sensory organs. They process the information delivered by lower layers, being identified by human attention, processed by human mind and stored by human memory. Information identification at D- and E-level may be termed **perception** and **ideation**, respectively.

The first "device" in information processing chain in a human is the attention. It has two main tasks to fulfil:

- To identify information evoked by a sensory input,
- To arrange an information hierarchy to be processed later in mind.

Identification of information is made at A, B, C, D and E-level (proprioception, contactception, teleception, perception and ideation, respectively).

Arrangement of information, which has been already identified, is made by emotional factors. Broadly speaking, they are results of generalized previous experience. They are: arousal, sensation, impression, emotion and attitude at A, B, C, D and E level, respectively. Thus, emotional factors are "responsible" for selective amplification of information at each level of Bernstein's ladder separately.

The attention capacity is limited, thus some information, placed lower in a hierarchy, may be rejected or omitted because of lack of time. Which information will be processed first in mind, and which be eventually lost, depends on attention and its emotional factors.

The information delivered by particular levels may not be homogenous. For example attitude may demand to rescue a sinking man, but emotion – fear – may prevent a human from doing it. Thus, the next element in the information processing chain is the **incentive motivation**, which determines the initial intensity of work in the next element of information processing chain: the mind. In other words, the incentive motivation is "responsible" for overall amplification of information delivered to the mind.

The mind has three mechanisms to its disposal: intelligence, intuition and instinct. The science as a whole does not provide us with clear and unambiguous definitions of these mechanisms. However, they are very important in the processes of shaping the sensory-motor behaviour of a human; hence, in kinesiology it is necessary to formulate such definitions. My suggestions, basing on "system way of thinking", are as follows:

Intelligence *– ability to solve a given task having whole necessary information about a given task and knowing all the rules of its processing.*

Unfortunately, very rarely we face so luxurious situation that we have full knowledge about the task and methods of its solving. Usually we have incomplete information, thus it becomes necessary to guess the lacking part of it. The mechanism enabling us to do it is **intuition**. Only when intuition rounds up our knowledge, it becomes possible to activate the main information processing mechanism, i.e. intelligence. If intuition provides a human with right information, the intelligence may lead him/her to proper solution. If, however, the intuition gives false cues, then even the best intelligence will lead a human to the false solution. The intuition may be then defined as follows:

Intuition *– ability of living beings to guess the lacking information, when it is incomplete for solving a given task; after rounding up the information, it becomes possible to use the intelligence to develop the response.*

Instinct is in fact no mechanism of information processing, but a tendency to look for lacking information in particular directions. It is partly inherited, and partly acquired. The instinct may be defined as follows:

Instinct *– partly inborn, partly acquired tendency to look in specific directions for lacking information, necessary for solving a given task, by intuition, or for methods of response developing by intelligence.*

Summing up, it may be said that the intelligence is analogous to mathematical interpolation, the intuition – to mathematical extrapolation, and the instinct determines the courses, the intelligence and intuition will sail.

All three mechanisms – intelligence, intuition and instinct – act simultaneously at each of the Bernstein's ladder levels. Their capabilities and mutual shares depend, of course, on character of the task and capabilities of information processing code used at given level. So, different is a C-level intelligence of a boxer, D-level intelligence of a sailor, and E-level intelligence of a mathematician.

The mind, using intelligence, intuition and instinct, develops a response, which is then transferred to the **prudence**. Here the response is subject to selective amplification by **emotional factors**: attitude, emotion, impression, sensation and arousal, at E, D, C, B and A level, respectively. Here, again, the amplification at each of the levels may be different, so it arises the necessity of "reducing it to the common denominator" to work out a homogenous will of performing the invented activity. This is the task of **performance motivation**.

If it is already decided that the response should be executed, the next step is to use a proper **dynamical movement pattern**. At A-level it is automatism, at B-level – routine, at C-level – scheme, at D-level – specific motor programme, and at E-level – generalized motor programme. If such movement patterns have been previously shaped, there is no necessity to develop them "on line", i.e. during the performance. Proper dynamical movement patterns protect the CNS from being overloaded with information, enable efficacious use of already acquired experiences and efficient execution of the motor performance.

Along with executing a given movement pattern, the appropriate **efferent copies** are created. They are copies of "products" (usually DMPs) of particular levels, which were sent to realization. Such copy enables creation of an image of expected result of the just being performed action in real environment. Thus, it enables the differentiation in environment the results of one's own actions and events independent of such actions (Petryński 2008). Moreover, such efferent copy may be identified with the "memory trace" as described by Adams, thus it plays great role in learning sensory-motor performances. By the way: the set of information delivered by proprioception, contactception, teleception, perception and ideation after execution of a given action may be identified with Adams' "perceptual trace".

Motor control matrix

In mathematics very commonly used way of bringing order into apparently quite chaotic data is to present them in form of a matrix. It is a mathematical object build of rows and columns. The crossing of each row and column makes a "drawer" for number or information. The meaning of it depends both on its value and the place in the matrix. In the system description of motor control mechanisms in humans the presentation of main factors in the form of a matrix seems to be very illustrative and instructive (Table 1).

It has to be noted that just graphical presentations are common ways of ideas explaining in mathematics, physics and technology. This is why the graph or table is not only a passive tool for presenting the ideas with a code other than verbal, but also a creative component of theory building process. Often logical errors – if any – are clearly visible only at graphical presentation of the idea.

It is also to be noted that such representations have great didactical value. Taking into account that there are many elements of a human motor performance, the matrix presentation seems to be very valuable way of ordering these elements.

Very important MCM feature seems to be better visible in Fig. 2. There are only two "input gates" from environment into human information processing system: contact one at B-level and remote one at C-level, and only one "output gate": the movement at A-level. Just at A-level a product of even most sophisticated information processing at D- or E-level (reason and soul) may be "exported" to environment. In such sense the movement is inseparably associated with mind and emotions; all these elements make one coherent system (as understood in systems theory). These facts have important consequences for motor control scientists. Directly may be observed only contact and remote stimuli, and then a movement. All processes involving information transformation are not clearly visible and may be analyzed only indirectly, i.e. hypothetically.

Thus, a scientist is forced to build theoretical models. This is common way in natural sciences, which led to great successes e.g. in physics. No one physicist saw directly an electron or any other elementary particle, but nevertheless the scientists were able to describe their properties precisely enough to enable construction of electron microscope, picture tube, processor or nuclear reactor. Also the motor science, being the most theoretical among all physical education sciences, has to enter the world of hypotheses and theories. However, the matter of motor science is much more complicated than that of physics. Biologist J. Cohen and mathematician I. Stewart wrote:

> *Physics takes very pragmatic and critical position. It focuses its attention on simple systems, easy to strict control. In turn, it expects the flawless conformity of theory to experiment. Physics has to do with the imagined and simplified world; this is the source of its power, this is why it functions so good (…)*
>
> *The sciences such as biology are not so lucky* (Cohen, Stewart 2005).

Unfortunately, it seems that Cohen and Stewart are absolutely right. In the same conditions all elementary particles behave – at least in statistical sense – identically. On the other hand, the knowledge structure of each human being is different, thus information processing (which in humans, unlike in purely physical objects, is a multilevel process) is specific to a given person.

	Level	Receptors	Attention		Motivation	Mind: intelligence, intuition, instinct	Prudence				Result
			Recognition	Selective amplification	Overall amplification		Selective amplification	Overall amplification	Dynamical movement patterns	Efferent copies	
			M e m o r y								
S t i m u l i	E		Ideation	Attitude	Incentive motivation	Movement topology	Attitude	Performance motivation	GMP	EC_E	
	D		Perception	Emotion		Movement plan	Emotion		SMP	EC_D	
	C	Teleceptors	Teleception	Impression		"Space feeling"	Impression		Scheme	EC_C	
	B	Contact-ceptors	Contact-ception	Sensation		Tactile feeling	Sensation		Routine	EC_B	
	A	Proprioceptors	Proprio-ception	Arousal		Muscle feeling	Arousal		Automatism	EC_A	Movement
	E n v i r o n m e n t										

Table 1. Motor control matrix. SMP – specific motor programme; GMP – generalized motor programme. EC – efferent copy.

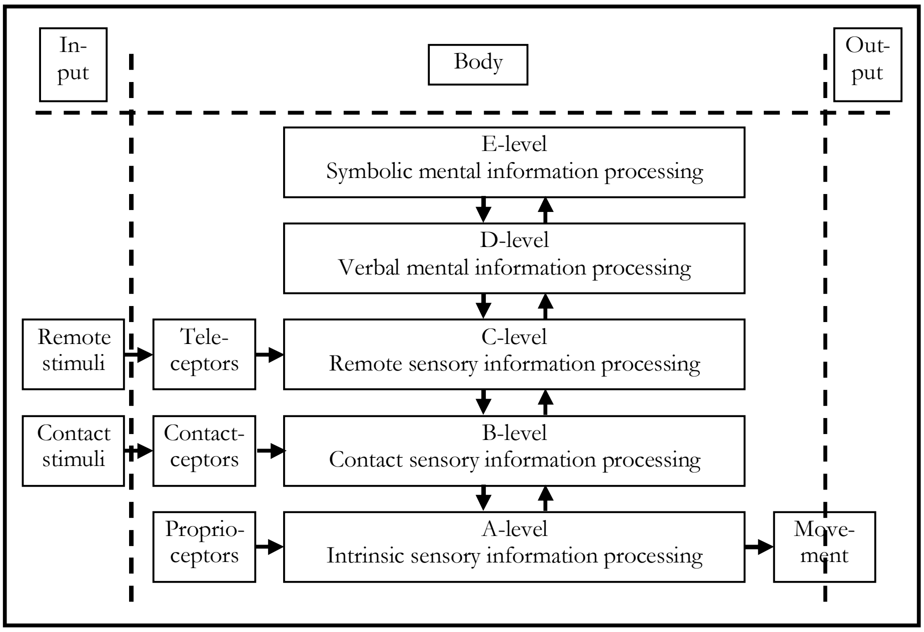

Fig. 2. Input (environmental influences), body (internal information processing and energy flows control) and output (effect on environment) in human information processing system.

CONCLUSION

The adoption of matrix description to information processing in humans enables bringing some kind of order into otherwise very complicated matter of human behaviour. The splitting information system in humans into five levels (Bernstein's ladder) enables analyzing each of the level separately, what makes the analyses simpler. Nevertheless, it has to be remembered that all these layers make together one inseparable system, thus such a splitting is justified only for analysis purposes.

However, the MCM is a system description and this fact has its important consequences. From the scales conformity principle it results, that each of Bernstein ladder levels has to possess its own emotional factor. This results in differentiation between arousal (A-level), sensation (B-level), impression (C-level), emotion (D-level) and attitude (E-level). Very important are also different codes being used at each of the levels (symbols, words, generalized images, contactceptive information and proprioceptive information at E, D, C, B and A levels, respectively). The higher the level of Bernstein's ladder, the more complicated and sophisticated the code. Unfortunately, the growth of its information processing capabilities is inevitably accompanied by slowing down the speed of this process. So, the five-level movement construction system makes some "gearbox", enabling selection of the "gear" most efficient for a given sensory-motor task. However, there is a great difference between gearbox and human information processing system. The gearbox "speaks" to driven wheels always with the same "language": rotational speed and torque. On the other hand, each "gear" in human information processing system has its own, specific "language" according to scales conformity principle. This makes the analyses of processes and phenomena associated with movement production in humans extremely difficult. It seems that this is by now most challenging task in the whole contemporary science. Old research paradigms adopted in kinesiology, basing mainly on superficial observations and statistical processing, seem to be not only outdated, but – above all – inefficacious. For many years we had no significant scientific achievement in this branch of science. Thus, it is more and more evident that the change of main scientific paradigms in kinesiology becomes absolutely necessary. In motor science the era of absolute domination of simple statistical tools is obviously over. They may contribute mainly to dynamical growth of already high piles of "original experimental data". Even today nobody is able to control these piles and it is hardly possible that in this respect the sheer quantity of knowledge will "by itself" transform into quality of it. Unfortunately, production and processing of "original experimental data" in laboratories equipped with computers is easy and tempting to scientists. In physics the theory overtook the experiment in XVII century (thanks to Sir Isaac Newton) and just this is why physicists achieve such brilliant successes. The matter of human behaviour is much more complicated than that of physics, indeed, but nevertheless the way marked out by physicists seems to be most promising. R.A. Schmidt and T.D. Lee wrote:

> *The processes that underlie changes of capability (…) are rarely directly observable and one must infer their existence from changes in motor behavior* (Schmidt. Lee 2005).

The sooner contemporary physical education and sport scientists will understand this, the less intellectual and scientific energy (and money as well) will be wasted in vain.

The paper may be also regarded as presentation of a systematic "Bernstein's ladder philosophy" of motor theories. Let the main theoretical pillar of various analyses be the Bernstein's ladder, symbolized by the ordinate ("y"-axis). In this paper, the abscissa ("x"-axis) represents the sequence of events in a human sensory-motor performance. Both ordinate and abscissa make coordinates for a two-dimensional matrix, which enables describing in ordered way the specific relations between Bernstein's ladder and chosen other factor of human motor capabilities construction

REFERENCES

1. Abernethy B., Hanrahan S.J., Kippers V., Mackinnon L.T., Pandy M.G. (2005). The Biophysical Foundations of Human Movement. Second Edition, Human Kinetics, Champaign, IL.
2. Bernstein N.A. (1947). O postroyenii dvizheniy, Medgiz, Moskva.
3. Bernstein N.A. (1991). O lovkosti i yeyo razvitii, Fizkultura i Sport, Moskva.
4. Cohen J., Stewart I. (2005). Załamanie chaosu. Odkrywanie prostoty w złożonym świecie, Prószyński i S-ka, Warszawa.
5. Morawski J. (2005). Człowiek i technologia. Tajniki wzajemnych uwarunkowań, Wyższa Szkoła Humanistyczna, Pułtusk.
6. Petryński W. (2008). Współczesne teorie uczenia się ruchów i sterowania nimi przez człowieka, Górnośląska Wyższa Szkoła Handlowa, Katowice.
7. Petryński W. (2010). Feedforward, feedback and UCM in motor control in humans, 10th Scientific Conference "Perspectives in Physical Education and Sport", Konstanta, Roumania, 21-23 May 2010.
8. Schmidt R.A., Lee T.D. (2005). Motor Control and Learning. A Behavioral Emphasis, Human Kinetics, Champaign, Ill.