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Verbal communication and motor control in a system-theoretical perspective

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We live in a Newtonian world of Einsteinian physics
ruled by Frankenstein logic
David Russell

Abstract

The authors outline the general bases of possible scientific development in motor control, and they argue that in this discipline it is theoretical conceptualization rather than empirical investigations, that is of crucial importance. Moreover, the bulk of motor control as a science remains an area hardly accessible to empirical researchers. The authors present three ways of anticipation: induction, abduction, and deduction. They propose taking abductive methodology and employing a systemic approach to theory development. Next, they present two important principles determining the motor behavior of human individuals: the "inverted-V principle" and the "descending firework principle". The theoretical concepts make the "abductive part" of the paper, and then the authors take the "deductive way" and show how the described principles act in three typical daily life situations.

KEYWORDS: induction, abduction, deduction, motor control, system-theoretical approach.

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What is already known on this topic?
In modern science two methods of information processing are usually distinguished: induction and deduction. However, in sciences as abstract as psychology and motor control, theoretical conceptualization, i.e. abduction, has gained the greatest significance. Unfortunately, no experimental research, even with spectacular technological successes, but without theoretical reflection, cannot lead towards progress in motor science.

Introduction

The well-known adage by Auguste Comte, founder of positivism, is "savoir pour prévoir afin de pouvoir i.e. to know in order to predict; to predict in order to control" [1]. Accordingly, one may presume that the main task of science is the creation of predictability.

There are two basic ways of predictability development: induction and abduction-deduction. The former consists of superficial observation of "real facts" underlying cause-and-effect chains and applying the discovered regularities to processes and phenomena other than those where they have been observed. However, induction does not include understanding of the processes just being observed – usually hidden deep under the "perceptible surface". The knowledge gained by way of induction is commonly termed "life knowing".

The latter is abduction, according to which processes hidden deep under the "perceptible surface" are, by definition, not directly observable and measurable, so the inductive way of their research is inefficient. The only way to get to know them is risky and unreliable reasoning that makes up the core of the abductive way of science development. Highly instructive are the following statements by evolutionist Richard Dawkins and philosophers Gilbert H. Harman and Imre Lakatos:

- "Careful inference can be more reliable than "actual observation", however strongly our intuition protests at admitting it" [2].
- "The inference to the best explanation" corresponds approximately to what others have called "abduction", "the method of hypothesis", "hypothetic inference", "the method of elimination", "eliminative induction," and "theoretical inference" [3].
- "Even science as a whole can be regarded as a huge research programme with Popper's supreme heuristic rule: "devise conjectures which have more empirical content than their predecessors" [4].

Symptomatically enough, Lakatos refers to "devising conjectures", which may seem rather suspicious to empiricists, but nevertheless without "one's head in the clouds" it is not possible to develop science.

Abduction termed "inference to the best explanation" (IBE), following Harman's methodology, is based on conjectures and it produces the noblest product of science, i.e. a theory – a specific, goal-aimed, simplified representation of reality. This is illustratively expressed by biologist Jack Cohen and mathematician Ian Stewart who wrote that: "A theory is a kind of code that transforms complicated "messages" from nature into much simpler ones" [5].

Nevertheless, abduction includes an important element not present in induction: the understanding of processes underlying the phenomena under consideration. Hence in science, the device cited by Comte may be paraphrased as: "to infer in order to explain; to explain in order to predict". The former conforms with the "inductive base", whereas the latter – with the "abductive slope" of the triangle shown in Figure 1 [6].

The problem is there are no solid signposts on the abduction slope, and thus, as Richard Schmidt aptly remarks: "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 (unlike the image on a piece of exposed film that emerges from the colors of separate molecules of pigment on it) (...)" [7]. In a more general and concise form this idea was expressed by Niels Bohr, who stated that "The opposite of a correct statement is a false statement. But the opposite of a profound truth may well be another profound truth". This is why specialists in psychology and motor control do not like the risky and swampy way of abduction in science development and – fascinated with modern technology – choose instead empirical methodology. Unfortunately, only the former – inevitably including numerous paths which are erroneous and lead to nowhere – may produce real progress (not barren development!) in science.

In motor control, while "climbing" up the abduction slope, the applicability of mathematics seems to be limited. Biologist Jack Cohen and mathematician Ian Stewart wrote that "Physics deals with an invented, simplified world. This is how it derives its strength; this is why it works so well. (…) Sciences like biology are less fortunate" [5].

It becomes therefore necessary to apply another tool for knowledge ordering, and in this respect the theory of systems seems to be promising. Janusz M. Morawski

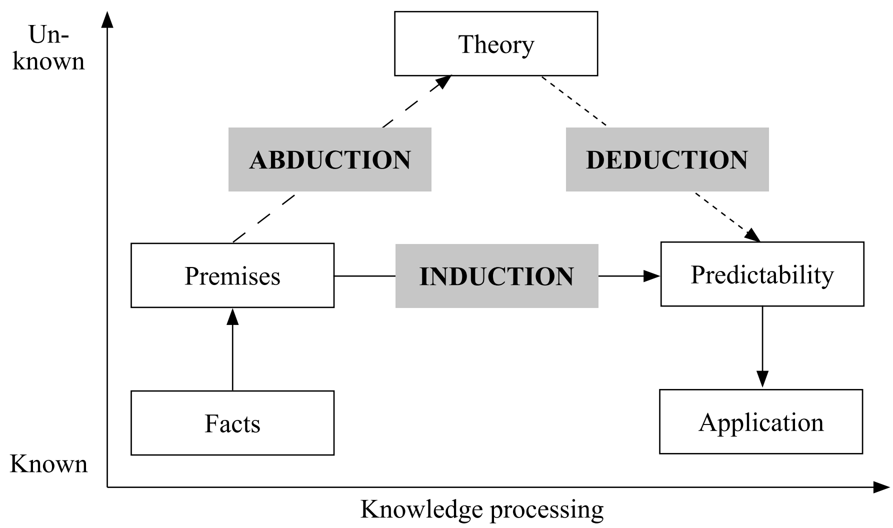

Figure 1. Induction, deduction and abduction in development of science [Petryński, Szyndera, 2013]. Inductive path – solid line; abductive slope – broken line; deductive slope – dotted line

provides three systems theory postulates as devised by Aleksandr Viktorovich Drynkov:

1. It is possible and useful to describe the functioning of various objects without analyzing their actual structure (priority of functionality).
2. The structure of a system may be discovered by external observation that includes only elements directly interacting with the environment; in other words, the conclusions concerning the internal structure of a system based on the knowledge of its functioning may only be approximate.
3. The structure of a system determines its functioning. If all these conditions are met, then it becomes possible to solve two basic tasks of the systems theory:
   a) determining the system's structure on the basis of its functioning (system analysis),
   b) determining the system's functioning on the basis of its structure (system synthesis) [8].

While the theory has already been developed, the third important procedure may be used, i.e. deduction. It applies theoretical rules to practical control of the current situation. This is why the popular adage has it that there is nothing better for practice than a good theory.

1. Abduction

1.1. Modalities ladder

The arbitrarily chosen premise for the reasoning presented in this article is Nikolai Aleksandrovich Bernstein's theory [9, 10, 11]. However, Bernstein's conceptualization based on evolutionary and neurophysiological foundations seems to be too complicated to be applied in practice. Thus, it needs some simplification. The proposal consists of "distilling" from Bernstein's five-level structure [12] the nformation processing aspects. The resulting "modalities ladder", strictly connected with Bernstein's five-level system but not identical with it, is presented in Table 1.

One of the most primeval fundamentals of the modalities ladder is the scales conformity principle by Janusz M. Morawski [13], which states that each layer has its own thinking specificity, time-space dimensionality and energy exchange range, which determine the layer's "identity" and, as a result, its potentialities.

The data in Table 1 needs an explanation that was provided by W. Wundt: "All argue for the view that voluntary actions do not come from reflexes, but that reflexes come from voluntary actions that have became mechanical. They are developed through the influences exerted by skilled voluntary actions on the existing organization of the nervous system" [14].

Thus, when the higher "rungs" of the modality ladder are fully developed, then a lower-level motor operation may become some attributes of the higher-level one. For example, automatisms do not use visual control, while habits do. However, when developed with a visually created "space map" (even if only virtually), an automatism may include some spatial and temporal attributes specific to habit. For instance, an operation with particular pedals by a skilled driver does not need visual control (thus it is a B-level operation), though the creation of that skill needs, at first, visualization – even if only imagined (C-level operation) – of the arrangement of the clutch, brake, and accelerator pedals.

The system presented in Table 1 is coherent, but not homogenous. One may observe a similar situation in physics. According to the correspondence principle,

Table 1. Selected aspects of the modality ladder in motor control

Level	Information processing code	Space dimensionality	Time perception	Motor operation pattern	Motor operation class
E	Symbolic	Abstract, three, flexible	Free representation, flexible	Vision	–
D	Verbal	Abstract, three, rigid	True representation, rigid	Program	Performance
C	Teleceptive	Three, movement in space	*Timing*	Scenario	Habit
B	Contactceptive	Two, joint rotation	This muscle earlier – that muscle later	Stereotype	Automatism
A	Proprioceptive	One, muscle contraction	Now – not now	Coupling	Reflex

on the border between classical and quantum physics the laws of both these regions coincide with each other [15]. According to conceptualization in Table 1, there are four such "border zones" in motor control. It is worth noticing that there is only limited translatability of adjacent levels – hence such a border zone may be regarded as a non-linear filter – but it seems hardly possible that a B-level code may be unambiguously expressed in, say, a D-level code. For example, it is not possible to explain verbally how to grip an egg strongly enough to prevent it from slipping while, at the same time, not crushing its shell.

1.2. The constructivist perspective: four kinds of knowledge

From the constructivist perspective knowledge does not enter the human thinking system from the environment, but it is rather created inside this system. According to Sarah-Jayne Blakemore and Uta Frith, "Most of the data on human brain development come from the human visual cortex, a large area at the back of the brain that makes sense of the visual stimuli that enter the eyes" [16].

It should be emphasized that the process of "making sense" occurs in the brain. Accordingly, one may discern four kinds of knowledge:

Data – "some quantity of not ordered knowledge about the environment, built mainly on the basis of rough sensory experiences (result of reception)".

Information – "some quantity of data, ordered and harmoniously included into a coherent system of knowledge possessed by a given individual (result of perception)".

Communiqué – "some quantity of information – produced by perception and, if necessary, complemented by intuition – which enables initiation of an action, mental or motor, by a living being" [17, 18, 19].

Releaser – "the communiqué, which in fact triggers a response production and operation execution process".

These kinds of knowledge may be also interpreted as subsequent stages in knowledge transformation, from stimulus reception (or engram retrieval) to motor operation initiation.

1.3. Inverted-V principle

The modalities ladder is built of "rungs" with more and more extensive information processing potentialities. However, the higher level, the slower information processing. Thus, some movements, when initiated, cannot be controlled any longer; they are termed "ballistic movements" and result from the phenomenon of psychological refractory period [20]. However, most real actions which take place "here and now", are slow enough to be visually controlled at C-level. On the other hand, the D-level verbal processing, reaching far beyond the existing sensory experiences, is based mainly on prediction, and is usually too slow to actively control any current situation in the environment. Hence, though information processing at D- and E-levels is much more advanced than that at B- and C-levels, in real action ("here and now"), only the C-level occupies the special position. This may underlie the phenomenon of **visual dominance** [20], i.e. the supremacy of visual stimuli over the ones of other modalities. Because of the temporal scale, the C-level may be termed "client", the A and B levels – "subordinates", and D and E levels – "contractors". In a sense, the C-level "commissions" the D or even E level to work out the solution of a specific task which then may be applied at C-level. This may underlie what may be termed "inverted-V principle", shown in Figure 2.

Summing up, in direct control of a current motor operation (excluding the ballistic one) the main role is played by the visually controlled C-level.

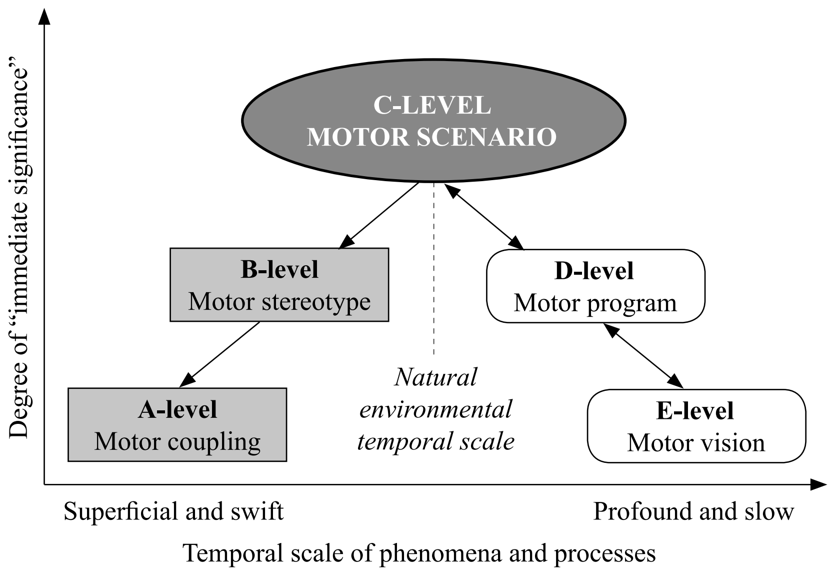

Figure 2. The inverted V-principle. To the left of C-level motor scenario ("client") there are the "subordinates", and to the right of it – the "contractors"

By the way, in this case the most important is not the kind of sense (vision), but the map of the environment that underlies operation planning. Thus, individuals deprived of vision have to prepare such a map using their other senses [21].

1.4. Descending firework principle

Probably the most important attribute of the modalities ladder is reduction of "intellectual costs" of motor operation control. To achieve it, a chunk from a higher level has to have a greater "information processing potentiality" than a chunk from a lower level. Accordingly, one may assume that one D-level chunk, say, may control many C-level chunks. This may be illustratively conceptualized with what may be termed the "descending firework principle" (Figure 3).

The limited capability of information chunks which may be processed at once was described over half a century ago by George A. Miller [22]. By the way, the specific "magical number seven, plus or minus two" was determined by Miller rather arbitrarily. On the other hand, probably the most popular achievement of Nikolai A. Bernstein is the famous freedom degrees reduction principle [9, 10, 11]. According to it in motor control "freezing" is more important of multiple unnecessary movement possibilities than using few needed ones "filtered" by Miller's concept. However, while seen from the perspective of modalities ladder, the information chunks at various levels are of different size and modality (both of these factors determine the "informational weight" of a given chunk), and are somehow associated with each other. Accordingly, one "frozen" information chunk at C-level may disable many information chunks at B-level, and, of course, still more ones at A-level. Hence, rejecting an informational chunk at the highest possible level makes the whole motor operation very economical.

Bernstein borrowed the term "degree of freedom" from theoretical mechanics (he had profound mathematical and physical education, though not confirmed with an academic diploma). However, in the modalities ladder the A-level makes the boundary between the external, physical world (where the original, physical degrees

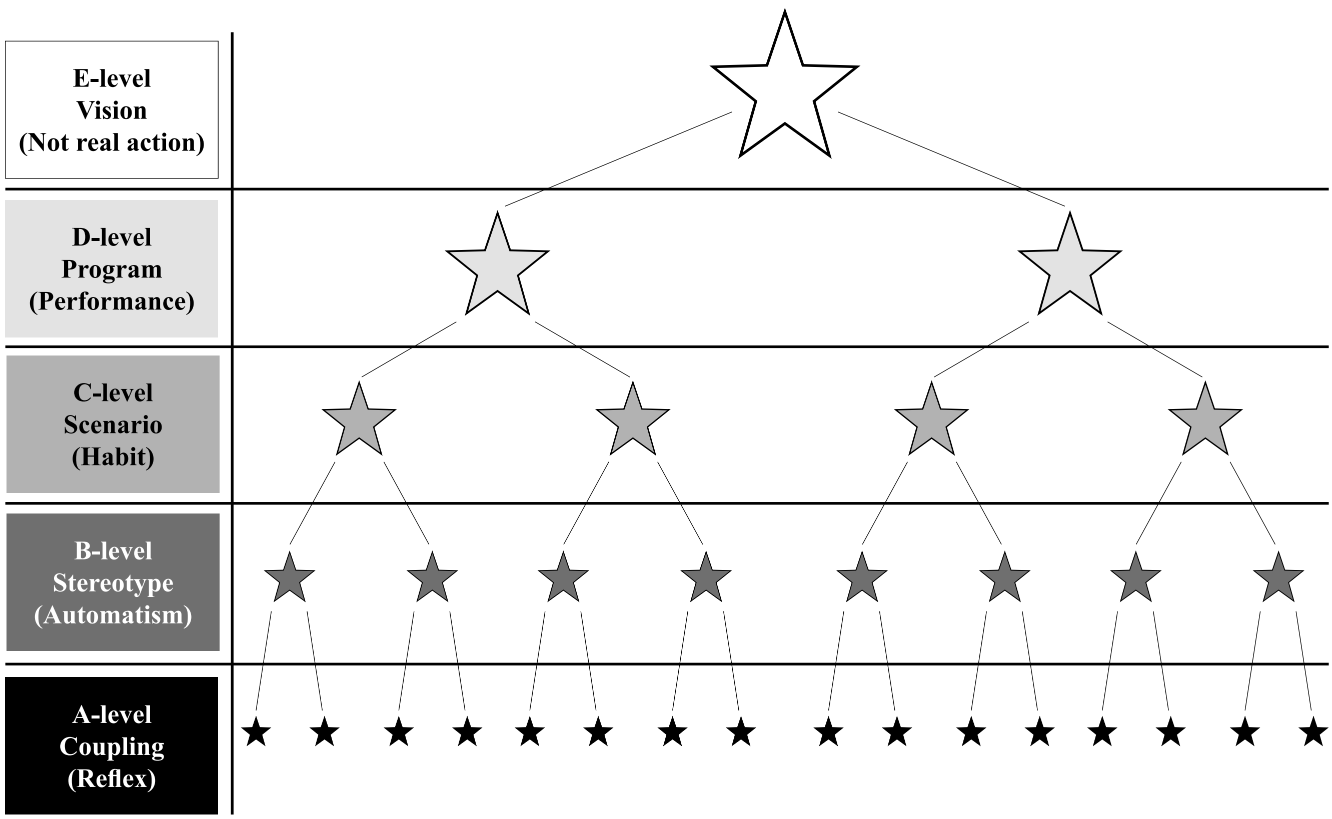

Figure 3. Multiplication of controllable information chunks while moving from higher to lower levels of modalities' ladder: the **descending firework principle**. The chunks (symbolized by stars in the diagram) differ in both size and modality at various levels (symbolic, verbal, teleceptive, contactceptive, and proprioceptive at E, D, C, B, and A-levels, respectively)

of freedom "reside") and internal psyche. Thus, while applying the idea of freedom degree to higher levels of the ladder, their general idea remains the same, but their experimental research – rooted in "tangible" physics – becomes more and more difficult (if possible at all). It is worth noticing that in this field of scientific investigation Dawkins's statement about "careful inference" becomes especially significant.

Probably the most concise résumé of the descending firework principle was given by Alfred N. Whitehead, who said that "we think in generalities, but we live in details".

2. Deduction

2.1. Instruction in sport and recreation

Each of the "rungs" of modalities' ladder has its own information processing modality. It determines the potentialities and methods of influencing the learner's behavior by a teacher.

The teacher has no access to the proprioceptive A-level. As a result, the learner has to develop one's own appropriate motor behavior patterns. At B-level the direct tactile guidance is possible; the learner will reproduce the movements and produce the necessary stereotypes. At C-level the teacher may apply demonstration; the learner will imitate the behavior and produce the relevant scenarios. At D-level the teacher may apply verbal instruction (lecture); the learner will construct the complex motor operation and produce appropriate programs. E-level does not control any real motor operation, and thus – though, in fact, it is very important and intellectually powerful – it will not be analyzed here.

Probably the most difficult teaching technique in sport or recreation is instruction. It involves the use of verbal communiqués to influence motor operations. As already stated, the verbal information processing is much slower than it is necessary at C-level (inverted-V principle). Accordingly, to make any verbal instruction useful, its information processing has to be as similar as possible to that at C-level. Thus it has to:

a) be very concise and thus easily graspable,
b) concern what is most important at the moment,
c) concern observable images rather than abstract representations [23].

Only then may the verbal information processing, rather slow by its nature, turn out to be efficient in supporting the performance of motor operations.

2.2. Verbal versus visual information in human motor operations

The popular adage has it that while somebody buttons the first button wrongly, then it will be not possible to button one's shirt properly. Such a wrong action might be associated with distraction. While seen from the modalities' ladder perspective, the level of the "wrong" button is also very important. If distraction takes place at verbal D-level, then it "tows" with it respective C-level habits, B-level automatisms, and A-level reflexes. On the other hand, rejecting a high-level chunk in the process of degrees of freedom reduction "switches off" many potential sub-operations and thus makes the whole main operation more economical in terms of information processing, physical effort, and time consumption. At low levels, where the psychological refractory period plays a crucial part, it – for example – becomes a basis for feints in sport.

In daily practice the most important is the C-level visual information ("measure-by-eye") and D-level verbal information ("common reason"). The former encompasses a three-dimensional space and a short fraction of the time axis limited by direct sensory experiences, i.e., timing. According to Hotz, "timing is the temporal punctuality towards a spatial point, and also the functional potential to be at proper time, with optimum speed and in relevant place" [24].

The price which had to be inevitably paid for extending the time axis beyond the limits marked by sensory organs potentialities was complete detachment of information processing from the current extrinsic physical stimuli. This was possible at the metasensory, verbal D-level. The time axis extension makes the development of anticipation possible, which in the course of evolution turned out to be more precious than fangs, sharp claws, brutal force, and tremendous swiftness. However, if a given "blueprint" has not been prepared in advance at D-level (specific to humans), the anticipation at C-level may include merely a short part of time axis limited by timing. By the way, this phenomenon was excellently described not by a scientist, but by a writer Jack London in his novel "White Fang" [25].

Thanks to technology, in daily practice humans move much quicker than even the quickest animals. In this respect the famous racing driver Ben Collins may provide an explanation: "What defines a good driver? What attribute is necessary, and what merely useful? The anticipation. A racing driver is a person, who does not look for solutions of the problems that occur in a race. He knows those solutions, and when the situation comes, when the reaction becomes necessary, he/she simply performs the operations leading to its successful solving" [26].

However, while comparing the visual and verbal information processing one comes across a very significant limitation: the more profound information processing, the slower. Hence, the C-level visual information processing may be usually applied "on-line", to control just the ongoing operation, while the D-level verbal processing is usually too slow (*"just a moment, please, let me ponder over this"*). In short, one may state that in daily life humans have to do mainly either with "superficial and swift" C-level visual chunks, or with "profound and clumsy" D-level verbal chunks. Usually, the former may keep up the pace with the actual run of events, whereas the latter is too slow. As a result, one may control the current operation with a C-level scenario, but if the D-level modality becomes necessary, the respective program has to be prepared in advance and applied as a ready "blueprint", reduced to the scenario level. While interpreted from the modalities' ladder perspective, just the temporal constraints constitute the basis for what is termed "visual dominance" in human motor operation, i.e. supremacy of visual stimuli over stimuli of other modalities [20].

The specificity of information processing in dynamical operations can be illustrated with an instructive metaphor by Richard A. Schmidt and Craig A. Wrisberg. They compared the limited capacity of simultaneous processing of various information chunks to a bottleneck [20]. If such a bottleneck is being choked by unnecessary, slow and clumsy verbal information, then the necessary, swift and agile, visual information has to wait for its turn. And waste time, sometimes very precious. According to Schmidt and Lee, referring to Patricia L. Trbovich and Joanne L. Harbluk, "Cell phone conversation reduces the capacity to perceive changes in the visual environment such as traffic patterns" [27].

While seen from such a perspective, it does not matter whether one has a hand-free phone or not, because the problem is the information modality and not the technological details [28]. Moreover, a higher intellectual "weight" makes the verbal information more "inert", so the temporal delay while switching from verbal to visual information processing seems to be much longer than switching "within" the purely visual modality.

What this study adds?

The present analysis is an attempt at designing a real theory of multimodal nature of wholesome mental and motor control in humans. The authors show how two system-theoretical principles can be developed on the basis of Bernstein's theory of movement creation, and how they can be used to explain important phenomena in daily life.

Conclusion

It is worth noticing that George A. Miller's classical work on the limited capacity of the human information processing system was mainly based on analyses of verbal information. As he put it, "In my opinion the most customary kind of recoding that we do all the time is to translate into a verbal code (…) In particular, the kind of linguistic recoding that people do seems to me to be the very lifeblood of the thought processes" [22]. Miller analyzed what is referred to in the present study as "words-information carriers" (data, information, communiqué). They include only one information processing modality. On the other hand, the "words-releasers" initiate a much more complicated process of multilevel and multimodal information processing. Moreover, in the process of anticipation – crucial in operations like, e.g., car driving, both of them have to cooperate with each other. Some experimental studies into this issue have been carried out [23], but they have not reached beyond the safe, inductive, but not very fertile way of reasoning, relying nearly exclusively on "hard" empirical data. The abductive slope, leading through the inevitable – "non-scientific", "daydreaming" or even "moonshine" – conjectures towards the noblest product of science, i.e. theory of multimodal information processing in motor control, is still accessible for strong, able and brave climbers.

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