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Apraxia research: Russian and modern neurocognitive traditions

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SUMMARY

Three scientific traditions of apraxia research are examined in this article: Luria's theory of the systemic structure and dynamic localization of higher mental functions, Bernstein's level theory of motor acts, and the neurocognitive approach. The apraxia classification developed by Luria, the classification of movements widely discussed in neurocognitive tradition, and Bernstein's level structure of the motor act are presented schematically. The strengths and limitations of each of these scientific schools are discussed. The principles of apraxia assessment in Luria's and the neurocognitive framework are analyzed. We conclude that Luria's approach and the neurocognitive tradition of apraxia investigation are quite similar. Bernstein's ideas were formed more than fifty years ago, but seem insightful and fruitful today. According to Bernstein, voluntary movements have some essential features that are not currently taken under consideration. From his point of view, movements are meaningful (determined by a motor task), holistic, hierarchic, dynamic and creative. These postulates were discussed in many of his now-classic works. At the same time we must confess that they are not widely known among clinicians. That is why we believe that Bernstein's concepts can significantly enrich our knowledge in the neuropsychology of praxis.

Key words: Luria, Bernstein, neurocognitive models of praxis, apraxia assessment, level theory of motor acts

LURIA'S THEORY OF PRAXIS

Modern Russian neuropsychology uses the classification and methods of apraxia diagnosis developed by A.R. Luria in the framework of his theory of the systemic and dynamic localization of higher mental functions (HMF). In Luria's work "The motor analyzer and the problem of organizing cortical movement" (Luria, 1957), four forms of manual apraxia are described. Luria demonstrated that "the cortical terminus of the motor analyzer presents as a complex system of zones in the human brain, which carry out specific functions in the organization of the motor act" (Luria, 1957, p.8). The idea of the systemic, multicomponent structure of the cortical terminus of the motor analyzer, where each area plays a particular role in the organization of movement and provides separate components of motor act, was brought forward. The cortical terminus of the motor analyzer includes not only the anterior central gyrus, but also the secondary fields of the inferior parietal cortex, the parietal-temporal-occipital, premotor and prefrontal areas of the cerebral cortex. According to Luria, various types of apraxia develop due to lesions in these areas.

Manual kinesthetic apraxia occurs with damage to the inferior parietal cortex. The mechanism of this type of apraxia is based on kinesthetic reverse afferentation disorder (a disorder of the analysis and synthesis of kinesthetic impulses), when movement cannot be regulated correctly. When this type of apraxia occurs, the patient's movements become dysregulated and undifferentiated; there is a search for the correct posture, and postures change to kinesthetically similar ones. This disorder becomes especially clear when the patient does not receive visual feedback from the performed movement (Luria, 1969b). With left hemisphere lesions, manual kinesthetic apraxia develops bilaterally; with lesions in the right hemisphere, disorders develop mostly in the left hand (Luria, 1957, 1969b, 2002; Korsakova & Moskovichute, 2003; Chomskaya, 2007).

In *manual kinetic apraxia,* the main disturbance is the disintegration of serial movement organization, which disrupts the analysis and synthesis of movements in time. In other words, the process of switching between postures is disturbed, producing a disorder in the sequential change of motor acts. The patient cannot inhibit the previous movement's elements and switch to new ones (it presents as elementary perseveration when the movement continues uncontrollably). That is why complex motor skills disintegrate. This type of apraxia emerges with lesions to the premotor areas of the left hemisphere of right-handers, and mostly develops in both hands (Luria, 1957, 1969b, 2002; Korsakova & Moskovichute, 2003; Chomskaya, 2007).

The leading problem in the *spatial form of apraxia* is the disintegration of spatial analysis and synthesis, leading to a dysfunction of the spatial organization of movement. Patients have difficulties in performing space-oriented movements, and in distinguishing left and right or up and down. Increasing visual control does not facilitate the performance of movements. This form of apraxia develops because of lesions to the TPO area (Luria, 1957, 1969b, 2002; Korsakova & Moskovichute, 2003; Chomskaya, 2007).

The last form of apraxia distinguished by Luria is *regulatory apraxia*. The main symptoms here are problems in the programming, voluntary regulation and control of movement. Patients have disorders in purposeful actions, and usually cannot control impulsive motor acts. Complex motor programs are replaced by inactive motor stereotypes. In contrast to manual kinetic apraxia, where elementary perseverations develop (for example, the patient starts drawing a circle and continues it several times), in regulatory apraxia systematic perseverations develop (for example, if the patient is asked to write his name after drawing a circle, he writes the word "circle"). That is why the main defect relates to switching between entire programs of general activity. Echopraxia (uncontrolled repeating of the movements of the examiner) occurs with massive lesions to the prefrontal cortex. This form of apraxia appears in left prefrontal cortical lesions in right-handers (Luria, 1957, 1969a,b, 2002; Korsakova & Moskovichute, 2003; Lebedinsky, 2004; Chomskaya, 2007).

To sum up, according to Luria's theory of systemic and dynamic localization of higher mental functions, such components as 1) the kinesthetic basis of movement, 2) the serial organization of movement in time (in other words, the complete kinetic basis of movement), 3) spatial synthesis, and 4) programming and voluntary regulation of movement are necessary for performing normal movements.

In his monograph *Higher cortical functions in man*, Luria thoroughly describes his methods of diagnosing different forms of apraxia (Luria, 1969b). The main diagnostic method in Luria's approach is the qualitative, syndromic analysis of HMF disorders, which is aimed at finding the mental component responsible for various neuropsychological symptoms. Different methods aimed at investigating one of the components mentioned above were offered in the framework of syndromic analysis.

To assess the kinesthetic component of movement, Luria suggested the task of reproducing various positions of the fingers according to the example given by the examiner. To identify the disturbance it is necessary to shield the patient's hand from his view in order to reduce visual control of movement. In the case of kinesthetic disorders, there is a search for the right postures and incorrect reproduction of postures.

To investigate the possibility of manual kinetic apraxia, the patient is asked to perform the "fist-edge-palm" test, when the examiner shows the patient a series of 3 hand positions, fluently changing one for the other: fist, edge and palm. This series is performed 3 times, and after that patient is asked to repeat it. In a case of kinetic disorders, the performance of the test is non-automated (elements are performed separately, with pauses between them); elements are missing or extra elements are added, the sequence is broken, and perseverations are possible.

To assess the spatial component of praxis patient is asked to complete Head's test, where patient is asked to imitate spatial oriented hand poses (Head, 1926). Patients with spatial difficulties make topological mistakes (touching the wrong part of the face, for example, cheek instead of ear); they have difficulties with spatial recoding (a long latent period of analyzing the spatial relations in the demonstrated postures); they attempt to perform the movement with the wrong hand and then correct their mistake; there is a search for the localization of a touch (for example, left ear instead of right ear), and mirror mistakes are often make (symmetric repeating of postures after the examiner). Spatial praxis tasks are also used, including constructing whole figures from separated parts (for example, Koos cubes) and coping with complex figures.

Various tests called "reaction of choice" are used to investigate the regulatory component of praxis. In the process of conducting these tests, stable motor stereotypes are first formed and then discarded. For example,the patient is asked to react by raising the right hand to one knock and the left hand to 2 knocks. In the beginning, the signals are given in a simple sequence (A-B-A-B-A-B) to form a stereotype. Then the examiner breaks the stereotype and begins giving signals in a chaotic order. Regulatory apraxia usually appears as inertia, with impulsive mistakes and echopraxia in severe cases.

Until recently, the methods described above were widely used in Russia for the diagnosis of voluntary movement disorders in patients with focal brain lesions (Shklovsky & Vizel, 2000; Vizel, 2009; Grigoryeva, Kovyazina & Tkhostov, 2012). Each method is multifunctional; in other words, it is possible to test several components of movement with one method. For example, during Head's test we can observe regulatory and spatial mistakes, during the manual finger posture test kinesthetic and spatial mistakes can be observed, and so on. These methods provide a qualitative analysis of disorder: it is possible to ascertain which component of praxis suffers in each particular case, and which type of apraxia develops accordingly. These methods also have a number of significant advantages: the tests are easy to use, have a short duration, and can be conducted without special tools.

At the same time, however, it is important to mention that from the modern point of view, the methods developed by Luria have a number of limitations. First of all, they deal mostly with movements classified as "meaningless" actions without objects (De Renzi, 1985; Goldenberg & Hagmann, 1997; Bartolo et al., 2001; Sunderland, 2007). It is true that the various finger and manual poses performed by the patient do not have any specific meaning and cannot be found in everyday life. Besides, apraxia diagnosis in Luria's framework is conducted in terms of immediate imitation (for example, finger posture) and postponed imitation (for example, "fist-edge-palm"). It is important to mention that research on imitation assumes only the use of the visual modality and no others.

APRAXIA IN COGNITIVE FRAMEWORK

H. Liepmann, the founder of apraxia theory, was one of the first investigators to pay special attention to disorders of meaningful transitive actions (actions with objects) in patients with brain lesions (Pearce, 2009). At the very beginning of apraxia research in 1900, Liepmann described the case of an imperial councilor, known as the *Regierungsrat*, a patient who had suffered from a large brain lesion. The autokinesis dysfunction manifested itself as, for example, an inability to button up the shirt (without any significant signs of paresis). When his fingers were put on the button, he could perform the desired action, but then he could not perform it with the next button on his own initiative. The distinctive feature of this patient was that, on the one hand, spontaneous movements were relatively preserved (such as the right use of a spoon), but on the other hand the performance of tasks with verbal instructions, including using objects or performing actions with imaginary objects, was impeded or impossible. It is important to recall that the patient had no speech and vision defects, paralysis, or paresis.

Following the framework established by Liepmann, modern classifications involve three main types of voluntary actions (see Table 1):

- transitive gestures (actions performed with an object or actions assuming the use of an object, such as hammering a nail, using a toothbrush, opening a bottle);
- intransitive gestures (in other words symbolic gestures, such as saluting, waving goodbye, pointing);
- meaningless movements, as in Head's test (De Renzi, 1985; Duffy & Duffy, 1990; Bartolo, Cubelli & Della Sala, 2008).

The motor act itself can be performed in different conditions. There are three types of transitive gestures (see Table 1):

- actual performance (when it is necessary to achieve a real result, such as hammering down the nail or combing the hair);
- demonstration of the gesture (patient the demonstrates the action with an object but without reaching a result);
- pantomime (the action is demonstrated without any objects or tools actually present; Heugten, 1998; Bartolo, Cubelli, Della Sala, 2008; Vanbellingen et al., 2011).

Table 1. Assessment of voluntary movements in patients with limb apraxia

Types of gesture	Conditions of performance					
	Real performance		Demonstration of gesture		Pantomime	
	instruction	imitation	instruction	imitation	instruction	imitation
Transitive	+	?	+	+	+	+
Intransitive	+	+				
Meaningless	+ Luria	+ Luria				

Actual performance, demonstration, and pantomime can be performed in turn according to instructions, as in the case of imitation (or copying the action performed by the examiner; see Table 1; De Renzi et al., 1968; Roy, Heath, Westwood et al., 2000; Bartolo, Cubelli & Della Sala, 2008; Dovern et al., 2012). In the first case, then, the patient has no example of the action and has to perform it on his own; in the second case, an example is given. Attention should be drawn to the fact that transitive actions in imitation have virtually not been investigated, and so this would be an interesting topic for future studies.

Such a detailed classification was developed due to the larger number of dissociations between preserved and disrupted types of gesture performed in different conditions by patients with a brain lesion. As we can see in Table 1, the methods established by Luria in most cases correspond to actual performance of meaningless movements in the case of imitation.

At present, researchers are paying the most attention to transitive actions, which take a significant place in apraxia diagnosis (see Fig. 1; De Renzi, 1985; Heilman & Rothi, 1985; De Renzi & Lucchelli, 1988; Hodges, Bozeat et al., 2000; Ochipa & Rothi, 2000; Lezak et al., 2004; Bartolo, Cubelli & Della Sala, 2008).

When examining the actual performance of transitive gestures according to instruction, all the requisite objects are given, and the patient is asked to perform various actions. Their performance (such as hammering down the nail, combing the hair, opening the door with a key, etc.) is then assessed. As stated above, the actual performance of transitive gestures in the case of imitation is not used, but it could involve the examiner performing the action and then asking the patient to do the same.

While demonstrating transitive gestures according to verbal command, the patient is given up to 20 objects (such as comb, hammer, pen, key, ring, needle

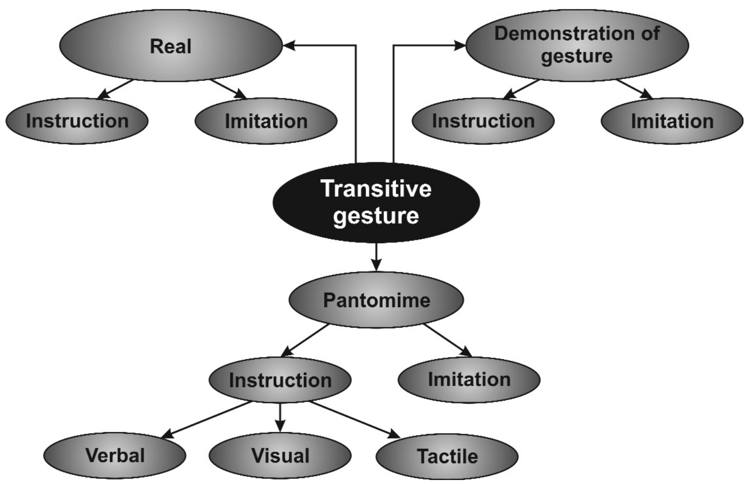

Figure 1. Methods of transitive gesture examination

etc.) and asked to show how he would use them. Unlike actual performance, this task includes only demonstration of the way of using the object, without reaching the result. For example, to demonstrate how to use a key, it is enough to take the key in the hand and present a rotational movement, while actual performance means opening a door with a key. The demonstration of imitative transitive gestures is done with objects, repeating after the instructor.

One distinctive feature of pantomime is the possibility to give instructions in different modalities: auditory, visual and tactile (see Fig. 1).The verbal instruction to pantomime includes several objects named one by one; the patient is asked to demonstrate how he would use it by hand (without actually using it). For the visual representation of objects, the patient is shown objects one by one and asked to demonstrate how he would use them, if he were holding them. While testing pantomime in tactile modality, the blindfolded patient is given an object to touch. When he recognizes the object, specialist takes it away and asks the patient to demonstrate how he would use the object. While imitating pantomime, the patient repeats pantomimes after the examiner. The dissociations recognized while performing transitive gestures in different conditions makes it possible to study more thoroughly the mechanisms of disrupted voluntary actions.

BERNSTEIN'S LEVEL THEORY OF THE MOTOR ACT

Many Soviet psychologists (especially A.N. Leontiev and N.A. Bernstein) indicated objectivity (using objects of material culture) as one of the most important characteristics of human movement (Leontiev, 1972, 1977; Bernstein, 1967, 1991,, 2008; Leontiev & Zaporozhets, 1945). They demonstrated that human movements are usually involved in meaningful activity, performed according to the current task, aimed at achieving an objective result, and mediated by tools.

The most significant contribution to the study of movement structure in Russia was made by a Soviet scientist, physiologist, psychologist, and theorist of the physiology of activity, N.A. Bernstein, who developed the level theory of motor acts (Bernstein, 1967, 1991, 2008). The model proposed by Bernstein shows a number of significant differences from A.R. Luria's model (Luria, 1957, 1969b, 2002), as well as from the cognitive model, especially the dual-route model (Rothi, Ochipa & Heiman, 1991; Cubelli et al., 2000; Chainay & Humphreys, 2002).

Bernstein argued against the mechanistic views of motor act formulated in Pavlov's classical physiology (Pavlov, 1951). Bernstein denied that motor acts are an actualized invariable stereotype, as emerges from reflex theory or cognitive models of praxis. In his studies of working movements (Bernstein, 2008) he demonstrated that even ordinary, repetitive actions (for example, walking or working operations) is not performed stereotypically, but rather is composed anew from the start on each occasion(see Figure 2). Bernstein labeled this phenomenon "repeating without repeating". He claimed that movement should be considered an active, creative act, which every time is constructed again.

This so called "live movement" (Gordeeva & Zinchenko, 1982; Zinchenko, 1996) is necessary for accommodation to the constantly changing environmental conditions (including changes in the outer world and within the body). To explain this, Bernstein proposed the principle of sensory corrections, stating that to construct effective movement in terms of changing environmental conditions, besides feedback from the result of the movement, it is necessary to have:

- ongoing feedback about current performance of the movement;
- present, ongoing correction of the movement according to this feedback (sensory correction).

The model of reflex ring (Bernstein, 2008) offered by Bernstein, instead of Pavlov's model of the reflex arc, is based on this principle of sensory corrections. To sum up, Bernstein was one of the first scientists to call attention to the importance of current feedback (afferentation) for effective realization of movement.

Bernstein also concluded that during life the individual faces motor tasks of different classes. As the environment makes more serious demands in the course of evolution, individual encounter more complex motor tasks. To provide execution of these tasks, new types of sensory corrections and more complex types of feedback are required. New structures develop in the nervous system, superimposed over old ones, to provide new types of afferentation. To solve the motor task, a corresponding level of movement composition was formed in the process of phylogenesis, and provided with specific brain structures. Each new level forms above an older one anatomically (for example, cortical over subcortical brain structures) and functionally (newer levels provide more complex motor tasks).

Accordingly, N.A. Bernstein proposed a hierarchical structure of movement. He claimed that every movement is the result of the work of several structural and functional levels of the nervous system, each one of which makes a specific contribution to performing the motor act (Bernstein, 1967, Bernstein, 1991, Bernstein,

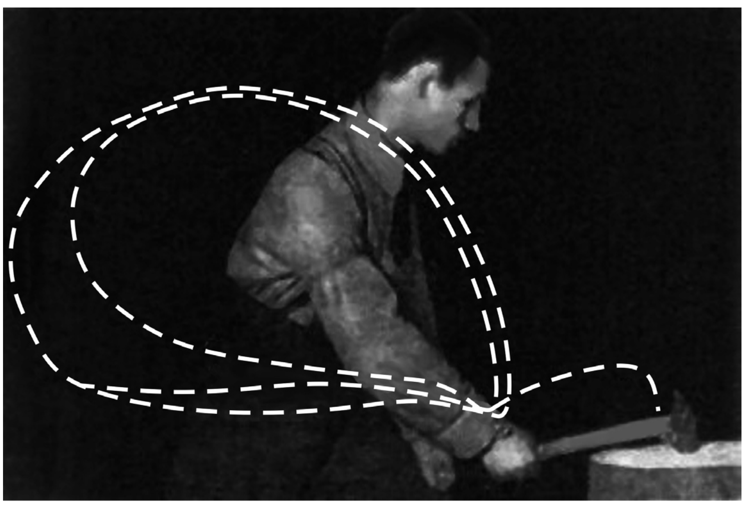

Figure 2. Working cycles (from Gastev, 1924)

2008). Depending on the meaning of the motor task , one of these levels is primary and the others are subordinated. The primary level coordinates all other levels.

The primary position of the current level is determined by the fact that each new class of motor tasks has its own type of feedback (the author calls this "primary afferentation"), which signalizes the successful performance of movement and provides corresponding sensory corrections. The primary afferentation required for the particular motor act determines the primary level of this particular movement.

There are 5 levels of movement structure suggested by Bernstein (Bernstein 1991, 2008), listed from the lowest to the highest:

A – *the level of maintaining the tonus of muscles*. This is controlled by the spinalc cord, the red nucleus group (red nucleus, substantia nigra, Darkshevich's nucleus and probably the corpus Luysi), the hypothalamus, Deiters' nucleus, the paleocerebellum, and the central part of the vegetative parasympathetic and sympathetic nervous systems. The type of motor task supplied by this level maintains muscular tonus. The primary afferentation for this level is deep proprioceptive, protopathic sensitivity. The number of movements in which this level is primary is severely limited: for example, muscular contraction when freezing.

B – *the level of synergy*. The anatomical substratum consists of the thalamus and the corpus pallidum. The motor task provided by this level is the regulation of movements "in the coordinates of one's own body", the coordination of body parts movements relative to each other without corresponding to environmental space. The primary afferentation for this level is particular joint-angular proprioceptive sensitivity and pain, temperature, vibration and tactile sensitivity. This level is primary, for example, in physical jerks.

C – *the spatial level*. Bernstein claimed that this is provided by newer nervous structures: the neocerebellar cortex, the corpus striatum, the fourth pyramidal area, and also the visual, tactile-proprioceptive, auditory and vestibular areas of cerebral cortex. The motor task of this level is performing movements in the coordinates of environmental space. The primary afferentation for this level is spacial perception ("synthetic space field"). This level is primary in throwing an object to hit the target, drawing or tracing the outline of a specific configuration.

D – the level of actions. This is provided completely by cortical structures: inferior parietal lobule, the premotor area of cerebral cortex. This level is responsible for movements with objects, which are considered not as geometric figures having a certain form, size and position in space, but as tools that are used to achieve a result in a particular way. In other words, it is critically important why and how we use the particular object. For example, this level is primary for all movements involved in the purposeful use of objects: eating with a spoon, writing with a pen, playing musical instruments, etc. "Object" is understood here not just as a physical object. It can be a scheme (for example, a plan to draw, a letter to write are considered objects). The primary afferentation is the result of the action with an object, achieved in a certain way (for example, the nail was hammered in the right way, the melody was played correctly).

E – symbolic level (Bernstein supposed that this is a group of levels). The E-level was the least studied by Bernstein, and the brain structures of this level are not sufficiently described. Bernstein mentioned only the frontal lobes in this context. The movement task of this level includes the conveyance of meaning through movement. This level is primary for all the movements of speaking and writing, when pronouncing and writing words is a means to transmit meaning. Bernstein claimed that pronouncing or writing a word according to instruction will be performed by the D – level as primary. The primary afferentation of E-level is the symbolic meaning of movement. In free dialogue, the success of speech will be judged according to whether or not the sense of the statement is conveyed, not the way the words were pronounced (that is why spelling mistakes are so common and do not influence the meaning of our speech). The E-level is specific for human activity, and for almost all human movements D and E are primary.

It is important to note that Bernstein's theory significantly differs from Luria's (Luria, 1959; Luria, 2002) as well as from modern cognitive models of praxis (Bartolo, Cubelli, Della Sala & Drei, 2003; Buxbaum, Giovannetti & Libon, 2000; Cubelli, Marchetti, Boscolo & Della Sala, 2000). Luria's theory and the cognitive models state that voluntary movement is the result of the work of several psychological components. Each component makes a specific contribution to movement, but the functional role of a component does not change when they are included in motor acts of different meaning. In this case each component is relatively independent.

In Bernstein's theory a hierarchy of levels is proposed, every newer level (starting from the lowest to the highest, from A to E) is based on lower levels and regulates their work. The work of a higher level is nothing but the work of a lower one organized (coordinated) in a new specific way according to a more complex type of afferentation. In particular, a movement with primary B-level (for example, physical jerks) includes a subordinated level A, because synergies can be implemented only through changing of muscular tonus. In this case the maintenance and changing of muscular tonus is guided by the more complex afferentation of B-level in a way that fulfils the requirements of physical exercise.

A movement with primary C-level (for example, touching a point on the wall) is also performed by changing muscular tonus (A-level) and moving body parts relative to each other (B-level), which are again controlled by more complex, spatial afferentation. Indeed, muscular tonus and body synergies are organized here to successfully solve a spatial task. In other cases, movements are organized in the same way: the higher level is a specific way of organizing the lower levels' activity, based on the afferentation of the higher level.

In contrast to Luria's theory and cognitive models, the hierarchy of levels in Bernstein's theory of motor act is considered holistic, which means that the functional role of each level can change, depending on what type of structure it belongs to (in other words, what movement task should be performed). For example, the D-level, depending on the structure of the motor act, can be:

- the primary level, in which case its afferentation will indicate the movement's success (for example, for when hammering a nail with a hammer the indicator will be the correctly hammered nail), and the activity of all other levels is regulated by the D-level.
- the subordinate level of an E-level act, in which case the E-level coordinates the work of the D-level. For example, when hammering the nail during a theatrical performance, the indicator of success will be the effectively transmitted symbolic meaning of this act, but not the accuracy of the way the nail was hammered.

The holistic structure of the motor act has one more characteristic described by Bernstein: the psychological structure of movement, which is dynamic and determined by the type of motor task. The change of meaning of a motor task leads to reorganization of the psychological structure of movement, despite the fact that visually these movements can be identical. In other words, according to Bernstein's theory, even similar movements (which look identical) can be performed under different primary levels.

Consider, for example, a movement such as those involved in playing the piano. From the point of view of modern cognitive models and Luria's systemic/dynamic localization theory, this action has its own fixed structure. According to Bernstein, this is wrong. Playing the melody, when learning to play, can be done with a primary D-level (in which case the problem of the technically correct performance of the piece of music is solved). Along with the change of motor task, the psychological structure will change as well. Performing the same piece of music at a concert has a primary E-level. The motor task changes from correct performance to transmitting feelings, the sense of the music and one's own interpretation of it. Technical performance is only a way to complete the main symbolic task. In other words, D-level is regulated by E-level.

The determination of psychological structure by the task allows us to look at motor acts in the context of the physiology of activity, which states that the motor act is defined by the meaning of performed movement, not by the environmental stimuli or its belonging to a formal type of movement: transitive, intransitive, etc.

COMPARATIVE ANALYSIS OF THE THREE THEORIES OF PRAXIS: BERNSTEIN, LURIA, AND NEUROCOGNITIVE MODELS

To sum up, Bernstein's idea of the hierarchical structure of movement has a number of significant differences from A.R. Luria's theory of voluntary actions and modern neurocognitive models of praxis (Skvortsov, 2012):

1. According to Bernstein, the structure of the motor act is determined by the type of motor task. In cognitive models (in the dual-route model particularly), the psychological structure is determined by the formal fixed classification of: 1) the movement itself (meaningless, transitive, etcc), 2) the task (actual per-

formance, pantomime, etc.), and 3) the modality of task presentation (visual, audio, tactile; Bartolo, Cubelli, Delle Salla & Drei, 2003; Rothi, Ochipa & Heiman, 1991; Chainay & Humphreys, 2002). Luria's concept is closer to cognitive models, since it states that one and the same movement is provided by the same psychological components, not depending on the type of motor task.

2. According to Bernstein, the motor act has its own holistic structure, which cannot be decomposed into independent parts: the functional meaning of each level can change according to changes in the whole structure of the movement itself, which depends on the type of motor task. Unlike Bernstein's theory, cognitive models and Luria's approach can be characterized as elementaristic. They state that the components of a movement's structure do not depend on the whole structure itself. For example, the action input lexicon will have one and the same functional meaning in all types of movements and tasks (Rothi, Ochipa & Heiman, 1991; Cubelli, Marchetti, Boscolo & Della Sala, 2000; Chainay & Humphreys, 2002).
3. Bernstein suggested that the motor act has a hierarchical structure (there are several levels in each movement, one of which is primary and regulates the work of the others). Cognitive models are usually characterized by linear structure: information processing goes consequently through a number of stages, each of which has its own cognitive mechanism. The next stage can be reached only after the previous stage is completed, and the material of the previous stage becomes the working material for the next stage. We can take the performance of spontaneous movement as an example of sequential information processing in the neurocognitive model of praxis. The work of cognitive components starts from the action semantic system, which saves and actualizes knowledge of objects and tools, and ways of using them. After this knowledge is actualized, the information goes to the next stage: the action output lexicon, which contains a number of fixed motor representations, stereotypes of common movements. The result of this stage's work is an actualized motor representation, which goes to the gestural buffer, which makes it possible to keep the representation actualized during the performance of the movement (Cubelli, Marchetti, Boscolo & DellaSala, 2000). In Luria's theory, the psychological components of praxis are disposed in a fixed structure; they work together at the same time and provide movement performance "from different sides." This structure is also not hierarchical.
4. Bernstein states that corrections based on constant feedback are necessary to provide accommodation to changing environmental conditions in real time, as well as real-time tracking of successful performance of the result of the movement. Modern cognitive models do not pay attention to real-time feedback. Both Luria and Bernstein stressed the importance of real-time feedback.
5. Developing the principle of feedback, Bernstein claims that every movement is a creative act. This means that every movement performance is constructed anew every time, unlike the idea of a fixed movement stereotype. Keeping rigid invariable stereotypes in memory is useless and maladaptive, since en-

vironmental conditions constantly change. According to Bernstein, every individual develops a universal ability to construct movements in order to solve a specific type of motor task. Cognitive models state that the motor act is provided by actualization of a fixed stereotype, kept in long-term memory (action representations in lexicons). Luria's views on this problem are similar to those of Bernstein.

CONCLUSIONS

In this article we have compared threw views on the principles and mechanisms of human voluntary movements:

1. A.R. Luria's theory of the systemic/dynamic localization of higher mental functions;
2. neurocognitive models of praxis;
3. N.A. Bernstein's concept of the level organization of movements.

We can state, based on the results of our comparative analysis, that each point of view has its own strengths and weaknesses. In Bernstein's framework, which is the least used in clinical practice, far-reaching principles are proposed for the study of motor acts. Movements should be considered as meaningful (the structure of movements is determined by the task, not only by the stimulus), holistic, hierarchical, dynamic, and creative. All these principles have been widely discussed in neuropsychological literarure (Leontiev & Zaporozhets, 1945; Zaporozhets, 1956; Vygotsky, 1982; Leontiev, 1972; Leontiev, 1977; Anokhin, 1971; Anokhin 1975; Wertheimer, 1987; Goldstein, 1939; Goldstein, 1942; Jackson, 1996; Keller, 1998; Koffka, 1998), but until recently they have rarely been used in the neuropsychology of movement, or in psychology in general. Therefore, we claim that Bernstein's theory is a fruitful and promising one for studying normal and pathological voluntary movements.

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