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From time to time, upon invitation by the National Academy of Sciences, reviews on scientific and technological matters of broad general interest will be published in the Proceedings. The following article (the first of two parts) reviews development of the field of neuropsychology in the USSR within the last several decades.

Neuropsychological Studies in the USSR. A Review (Part I)

A. R. LURIA

University of Moscow, 13 Frunze Str., Moscow, G. 19, USSR

The problem

Human neuropsychology is a new branch of psychological science that was developed at the borders of psychology and neurology. Its goal is to study the brain organization of mental processes and, especially, the higher forms of behavioral processes (1–9). The central problem of this branch of science is the "localization of functions in the brain cortex." Studies in this problem started several decades ago, but its scientific solution is still in the future.

Neuropsychology developed as a result of two basic issues: the progress of neurosurgery and a need of psychological science for a reliable knowledge of the cerebral mechanisms of the psychological processes.

In the last few decades neurosurgery has made tremendous progress. About 40 years ago, the mortality after brain operations was very high—sometimes 60–70%; now, as a result of new techniques of surgery, treatment of brain edema, and new methods of resuscitation, the mortality does not exceed 8–10%. This means that precise and early local (or regional) diagnosis of the localization of cerebral lesions (e.g., tumor, hemorrhage, vascular disorder) has become a problem of utmost importance. The solution of this problem has certain limitations. Regular neurological methods (analysis of alteration of sensibility and movements, tone and reflexes, limitations of sight and fields of vision, etc.) can be used for a local diagnosis of only a limited part of the cerebral cortex (sensorimotor areas and their pathways). X-ray studies do not bring any precise results, and even the use of contrast methods for arteriography and electroencephalography have certain limits.

The restricted limits of regular neurological symptoms is a result of some very important facts: lesions of the *highest* (secondary or tertiary) zones of the cortex—which are considered as specifically human parts of hemispheres—do not result, as a rule, in any elementary sensory or motor defects and remain inaccessible for classical neurological examination. They are associated with alterations of very complex behavioral processes (cognitive processes, elaboration of complex programs of behavior and their control), and that is why one has to establish new complex methods that could be used to study functional disorders evoked by their injuries. It is thus necessary to apply methods of *neuropsychology* for local diagnosis of lesions of these complex cortical zones.

The second issue of neuropsychological studies lies in some basic needs of scientific knowledge of the role of different cortical zones in the organization of complex forms of behavioral processes.

For many decades, psychology remained a descriptive science, and even important progress made by its different fields did not give a reliable approach to the basic cerebral mechanisms of human behavior. A certain disagreement remained among scientists. One group of scholars hypothesized that complex forms of mental processes are localized in strict circumscribed cortical areas. Another group started from an opposite assumption and hypothesized that complex mental processes are generated by the brain as a whole and are more a result of the entire brain tissue rather than of the activity of strictly localized groups of neurons. It is of importance that very often even objective physiological methods, such as analysis of conditioned reflexes and their changes after extirpation of some parts of the brain, did not give any information concerning the functional organization of the human brain.

That is why the formation of a new branch of psychological science—of *neuropsychology*, which started to analyze changes of complex behavioral processes in man associated with local lesions of the brain—became an event of utmost importance.

Basic principles

A scientific approach to the problem of the cerebral localization of the highest mental functions in man depends on a radical revision of two basic concepts: the concept of "function" and that of "localization."

It is obvious that the concept of "function" has at least *two* different meanings. We can understand the biological "function" as an *immediate activity of certain tissue*. Thus, different kinds of secretion are functions of certain glands, reaction to light is the function of retina, etc. But the word "function" can have a different meaning. It can be used to designate *complex forms of adaptive activity*, which start from an invariant goal, use different, interchangeable means, and achieve certain invariant results. This meaning can be applied to such a "function" as breathing (where conduction of oxygen to the alveola of the lungs can be achieved by diaphragm muscles, intercostal muscles, sometimes even muscles of the larynx), or to "functions" of locomotion where the subject can arrive at a goal using very different systems of muscles. Such scholars as Lashley and Hunter *et al.* showed that extirpation of cerebellum, cutting of portions of conductive portions of the fibers of the spinal cord, or reconstruction of mazes, did *not* affect the goal-oriented behavior of an animal.

Every behavioral function is really a *functional system*, which preserves a stable goal but uses different links of operative behavior to come to a desired result. It is obvious that, in all these cases, there is not only a certain "feed-back" needed for control of the effect of behavior, but also a certain "feed-forward," which establishes plans and programs and which is of decisive importance for elaboration of complex forms of behavior.

The idea of "functional systems" as complex "reflex circles" (this idea was opposite to that of the "reflex arc") was formulated in the 1930s by two outstanding Russian scholars, P. K. Anokhin and N. A. Bernstein (10, 11), and was developed in a series of their works (12–19) as well as in some publications of American authors (K. Pribram *et al.*) These ideas were a starting point for the creation of a new branch of physiological science–a "physiology of activity" (opposed to the "physiology of reactivity"). Of utmost importance is the fact that all higher behavioral processes (or "higher cortical functions") are really such *complex functional systems*, which are based on the *coordinated functions* (*or "constellations"*) *of cerebral zones* constructed in such a way that separate links of this system can be interchanged and that such a change does not affect the whole functional system. This approach is associated with a radical revision of the whole problem of "cerebral localization of functions." We do not start with any attempts to "*localize*" a complex function in a limited part of the brain; rather we try to discover how a "functional system" is *distributed* in different parts of the brain, and the role that every part of the brain plays in the realization of the whole "functional system."

One basic principle is of decisive significance for the concept of functional analysis of neuropsychology: while a certain complex of cerebral zones take part in the realization of the whole "functional system," *every zone plays a highly specific part in organization of this "functional system."* That is why *lesions of different zones result in different kinds of deterioration of "functions,"* and the analysis of the *type* of functional disorder or a "*psychological qualification*" of the symptom can provide information about which part of the functional system is deranged (1–3, 20–22). That means that a certain "double dissociation" (H.-L. Teuber) of results of a local brain lesion can be found. Lesions of certain zones of the cortex that are associated with a highly specific factor result in a disturbance of all "functional systems" that include this factor, while functional systems that do not include this factor remain undisturbed. Thus, lesions of the temporal zones that play a decisive role in acoustical analysis of sounds result in a deterioration of analysis of speech sounds, perception of words, and writing, but do not affect analysis of geographical maps, written computation, and other forms of activities where this factor is not present. At the same time, lesions of the parieto-ocipital parts of the brain associated with spatial analysis and synthesis result in a disorganization of all processes that include complex simultaneous (or spatial) analysis—such as orientation in space, reading a geographical map, constructive activity, and computation—but do not disturb perception of musical melodies, understanding of elementary phrases, etc.

Differently situated brain lesions do not affect only a certain complex of functions, but result in very different kinds of deterioration of the same "*functional system.*" Thus, lesions of the left temporal lobe (cortical apparatus of acoustical or phonematic analysis) result in deterioration of writing, which is very different from the deterioration of the same process resulting from lesions of post-central (kinesthetic) or parieto-occipital (visiospatial) parts of the cortex (1, 3, 23, 24). That is why a careful study of the *type* of disturbances of a certain function, i.e., a "*qualification of the symptom,*" can result in a description of the *factors* underlying this defect. That is a first stage of our analysis. Only after that work is accomplished can we move to the second stage of our work. This stage consists of a careful analysis of disturbances of different functions, which are of the same type and which are due to derangement of the same factors. This work results in a description of a whole *syndrome*, which is of decisive importance for our diagnostic work and which can provide reliability of neuropsychological evaluation of the site of the damage (25).

Neuropsychology of movement and action

In classical neurology, it was thought that the cortical apparatus of voluntary movements is situated in the anterior cerebral convolution (field 4 of Brodmann), whereas the cortical apparatuses of complex forms of praxis are associated with infrapariental regions of the brain (fields 39 and 40). Lesions of the first parts of the brain result in paresis or hemiplegia, whereas lesions of the second parts result in ideational or ideomotor apraxia (1–3, 26–30). It is easy to see that although these concepts have a certain clinical reality, their theoretical basis is not yet well elaborated. The concept of the "ideation center" that takes part in creating "motor schemes" that are superimposed on the "sensation of movements" does not yet have a physiological reality. That is why the most cautious authors expressed the idea that a careful physiological analysis of the mechanisms underlying voluntary movement is absolutely necessary for a scientific approach to the understanding of movement and action and their disturbance.

Important progress in the physiological approach to human movement and action was made by the outstanding Russian psychologist, N. A. Bernstein (13–15). As he showed in his studies by use of a precise cyclographic technique of recording of human movements, voluntary movements start by a constant (invariant) "movement goal," which takes part in the creation of a "general scheme of movement" and which results in a constant (invariant) effect. The most important situation that has to be taken into account is that the movement can never be realized only by a system of efferent motor impulses. The system of joints involved in a movement has practically infinite gradations of freedom, and if we add that the flexibility of muscles changes during every moment of movement, it becomes clear that no mathematical formula can be found that could provide constant, goal-linked schemes of movements. That was the basis of Bernstein's rule of a "principal impossibility of regulation of movements only by efferent impulses" and required the assumption that *afferent* influences give the brain information concerning the positions of joints and the changing flexibility of muscles at every moment of the movement. These systems of afferent impulses are organized in "afferent fields," which are situated on different levels from the most primitive (provided by the spinal cord and brain stem) to the highest (provided by the kinesthetic and visiospatial zones of the cortex and even by the highest parts of the cortex that take part in the most complicated forms of symbolic activity). These "afferent fields" play a decisive role in providing stable "afferent corrections" of motor acts; they change in subsequent phases of elaboration of motor skills. Whereas in a new unskilled movement these corrections are of a "secondary type" (they follow the movement already started), the nature of these corrections changes in the course of building of a "motor skill," and at a certain level of habituation they turn to "primary type of correction" when the correcting impulses are working as a certain "feed-forward" scheme.

This type of "feed-forward" organization of flexible movement provides a mechanism called by P. K. Anokhin "the acceptor of action" (26–29). This constitutes, an important part in the mechanisms of the physiological organization of every action. The findings of Anokhin and Bernstein were of basic importance for a scientific approach to the analysis of human movements and actions. They provide a better understanding of their disturbances associated with local brain lesions. Important results of these studies were reviewed (1–3, 26–30); these findings made it possible to describe certain basic syndromes of disturbances of movements and action with different lesions of the brain. Thus, if the lesion is situated in *post-central* (kinesthetic) parts of the cortex, the kinesthetic basis of movement becomes lost, motor impulses lose their precise addressing, and fine motor acts become impossible. In these patients a certain kind of "afferent paresis" or "afferent ataxia," which was carefully described by O. Foerster (1936), can be observed.

If the lesion is situated in *inferoparietal* or *parieto-occipital* zones of the cortex that are responsible for organization of "spatial afferent fields," disturbances of movement and actions acquire a new structure: patients with such lesions become unable to coordinate their movements in space, they confuse vertical, sagittal, and horizontal positions, and a "spatial apraxia" (1–3) develops. If the lesion destroys the *premotor* zones of the cortex, disturbances of movements once more acquire a different structure: patients become unable to make a fluent shift from one link of a movement to another, fluent "kinetic melodies" are broken down, and skilled movement becomes impossible (26, 29). In patients where lesions of this area of the cortex involve deep parts of the brain, the cortex ceases to control subcortical activities, and a pathological inertia of movement in these patients is observed. A voluntary arrest of movement started by the patient becomes impossible, and motor perseveration is now a central feature of the whole syndrome (29, 30).

A different kind of disturbance of action can be seen in patients with lesions of the *prefrontal parts* of the brain. In these patients, the technical structure of the movements remain preserved, but the goal-linked programs of human actions become severely disturbed, and well-organized, programmed actions can be replaced by inert stereotypes or by imitations of movements that the patient happens to be seeing but does not correct. These kinds of disturbances will be discussed later, and I shall not dwell on them here.

All I mentioned so far shows the importance of a careful analysis of the kind of disturbances of movements and actions in patients with different lesions of the brain, and what rich information can be obtained from a neuropsychological study of motor disturbances for a local diagnosis of brain injuries.

Neuropsychology of perception

Neuropsychological studies of patients with local brain injuries brought a wide range of new information concerning the structure of perception and its cerebral organization. Only a few decades ago it was thought that visual perception is a process of an isomorphic reflection of the form of a geometrical figure or an object and that its cortical apparatus is situated in the occipital (visual) cortex and its primary (projection) zones.

Now, after studies conducted in different countries, a large amount of data on the structure of perceptual processes has been acquired. These data showed that visual perception has a very complicated structure, and that it really is a complex active process of selection of decisive cues and of making a decision concerning the significance of the object perceived. The role of verbal coding was shown by a series of recent psychological studies (31–38), which proved that a very complex pattern of extended searching activities is displayed during formation of visual images in children. These studies showed the correctness of the famous Russian physiologist, I. M. Sechenov, who suggested, nearly 100 years ago, that human perception is really a very complex system of perceptual activities and that ocular movements play a role similar to the searching movements of the hand.

This radical revision of the problem of human visual perception resulted in significant changes in our approach to the neuropsychological studies of the cerebral mechanisms of perceptual processes. It was hypothesized that the cortical organization of visual perception is not entirely dependent on the primary parts of the occipital (visual) cortex. The information received by this part of the visual cortex is further elaborated by the secondary zones of the occipital (visual) cortex and that of the parieto-occipital parts of the hemispheres, as well as by the frontal parts of the cortex. They all play a significant role in the organization of ocular movements, and are intimately included in the functional complex of zones that take part in the organization of visual images.

After the classical studies of Hübel and Wiesel and a series of investigations that followed, it is now well known that the primary visual zone of the cortex contains a complex of neurons that react to very specific cues of visual information. As was shown by neuropsychological studies in animals and in men, lesions of this part of the cortex result in a derangement of visual fields that have a very specific spatial organization. Their functions become clear only after careful studies of patients with lesions of the primary visual zones of the cortex (1, 3, 39).

Very different data are observed in patients with lesions of the secondary zones of the visual cortex. Injuries of these zones, which have a predominance of the neurons of second and third level and which do not show any somatotopic projection, never result in defects of spatial organization of visual fields. The essential features of lesions of these zones is that they result in a functional disorganization of visual images. Patients with such lesions can see only separate details of a visually perceived object; they become unable to synthesize these features into whole patterns, and such an "amorphosynthesis" is a basic feature of the clinical picture observed in these patients (1–3, 38, 39). Such defects in visual integration can be especially observed when contours of visual forms or images are given on a background of neutral visual noise. Statistical calculations of the relation of visual figure and "visual noise" provide a new and precise approach for measurement of these disturbances of elaboration of information in secondary parts of the visual cortex (40–43).

Important data were obtained in observations of the lesions of *tertiary* (occipital-parietal) zones of the cortex. Lesions of these zones do not result in any disintegration of perception of isolated images, and no phenomena of object agnosia are observed (1–3, 38). The type of visual deficit evoked by these lesions is different. Patients with bilateral lesions of this part of the cerebral cortex can show disturbances similar to those that were described by Balint (1909) and that have the type of functional restriction of perceptual field or a kind of "simultanagnosia": they are able to perceive simultaneously only *one* object (independent of its size) and show marked pathology of coordination of their gaze and movements in space. When deep regions of this part of the brain (predominantly of the minor hemisphere) are involved, a syndrome of neglect of the left side of the visual field can be observed

(44, 45) and a special kind of "fixed left-sided hemianopia" (see refs. 52 and 53) can be seen.

As I already mentioned, ocular movements play an important part in the process of perceptual activity. They can be recorded by several techniques. One such technique, a photoelectric method of recording movements, was developed in this laboratory (46, 48). The application of this technique to the study of patients with local brain injuries shows that disturbances of ocular movements can be associated with lesions of both the posterior as well as the anterior oculomotor zones (located in parieto-occipital and in premotor areas of the cortex), but that, in each case, different deterioration of eye movements are observed. Lesions of the posterior oculomotor fields result in a deterioration of passive movements that follow the moving object. In these patients, active voluntary movements are much better preserved. On the contrary, lesions of the anterior oculomotor fields result in a deterioration of active searching eye movements, whereas passive ocular movements that follow the moving object remain less damaged (49–51). It was shown as well that lesions of posterior oculomotor zones result in a breakdown of complex analysis of the visual object and of the simultaneous synthesis of separate parts of the visual object (52), whereas lesions of the frontal lobes evoke quite different disorganization of the active searching movements (53, 55).

All the studies I mentioned, as well as those I reviewed in other publications (1–3), show that a careful neuropsychological analysis can make important steps towards a qualification of the inner structure of perceptual activities and of the role of different cortical zones in their organization. Similar important studies were done by investigations of *tactual activity* and their coordination with visual searching movements (56). These investigations can play a decisive role in neuropsychological studies of disturbances of tactual perception or of a stereognosis in local lesions of the brain cortex.

Important research was done during the last decades in the neuropsychology of *hearing* and acoustic perception. Studies showed that lesions of the temporal zones of the right and left hemispheres can result in a significant decrease of acoustic sensibility in the contralateral ear. This symptom is not observed in regular audiometric studies made by means of ordinary sounds, but it is clearly observed when ultrashort sounds (4–10 msec) are applied. This result was found in experiments with animals (57, 58), as well an in special observation of patients with unilateral temporal lobe lesions (59). It is clear that these studies describe new symptoms of lesions of the temporal lobe; they open new roads in the diagnosis of these lesions and make a significant step towards a better understanding of the role of the temporal cortex in the process of a stabilization of acoustic excitation.

I shall not dwell here on the problem of disturbances of acousticoverbal disorders associated with lesions of the left temporal lobe. That will be discussed later.

Neuropsychology of speech

Studies in cerebral organization of speech were one of the classical problems of neurology, but the classical concepts of a strict localization of different kinds of receptive and motor forms of speech became inadequate a long time ago, and approaches to this problem had to be fundamentally revised. This revision was accomplished by neuropsychological studies made during the last decades in the USSR (1–3, 60–67).

The basic approach to the study of cortical organization of speech started from the same principles that I described in the discussion of other fields of neuropsychology. To obtain reliable information of the brain organization of the speech processes, we have to provide a careful psychological analysis of the processes of verbal communication (both of coding and decoding of information in verbal acts), to single out basic components (or factors) of these processes. Only after this work is accomplished, can we start an analysis of how these processes are disturbed in local brain lesions. It is obvious that such an analysis will inevitably lead to a revision of classical concepts that started with the works of Broca and Wernicke 100 years ago and that remained without any significant change, for the most part, in neurological textbooks.

A significant revision was made in basic concepts of *sensory* aphasia. For many decades it was thought that disturbances of *understanding* of speech evoked by lesions of the left temporal lobe are due to deterioration of acoustic perception of the certain-zone of tones ("akustische Sprachsechste") or, as other scholars supposed, to disturbances of general intellectual processes. As shown by careful neuropsychological studies, both assumptions were wrong. It was proved that the primary disturbance in sensory aphasia is the disturbance of perception of the basic units of acoustic speech sounds, which change the meaning of the words (68–70). Such deterioration of *phonematic hearing* is a basic symptom resulting from lesions of the secondary areas of the temporal lobe of the dominant (major) hemisphere (1, 3, 4, 61). Such disturbance of phonematic perception is really the basic symptom of these lesions, and this disturbance results, in a series of secondary (or systemic) disturbances, such as deterioration of perception of the meaning of the words, naming, writing, etc., which are essential parts of the syndrome of sensory (acousticognostic) aphasia (61, 66, 71, 72).

The revision of basic disturbances in sensory aphasia was of great importance for a better understanding of the cerebral organization of the processes of understanding of speech and for modern phonological science. Very important data were acquired in the process of the neuropsychological revision of the theory of *motor aphasia*. From the first discovery made by P. Broca, it was firmly accepted that motor aphasia is a result of lesions of the posterior part of the third frontal convolution of the left hemisphere, which was supposed to be a "center for motor images of the world." This assumption remained for a whole century, without any considerable change.

The revision of the general physiology of movements I mentioned (13–15) showed that the efferent motor impulses are insufficient for a sound control of voluntary movements and that a system of afferent impulses is needed to provide the control of complex motor programs. The same principle can be applied to the analysis of the physiological mechanisms of expressive speech and for a better understanding of the syndromes of "motor aphasia."

Disturbances of the motor organization of speech can be seen in lesions of at least *two* different cortical zones (61, 66, 73). Motor aphasia can be observed in patients with lesions of the lower parts of the posterior (kinesthetic) parts of the left hemisphere. In these patients, a certain type of "deafferentiation" of motor speech processes can be seen; patients become unable to find proper articulations, similar (correlated or opposite) "articulemes," such as linguopa'atal *d*, *n*, *l* or labial *b* and *m*, become confused, and a kind of "*afferent* (*or kinesthetic*) *motor aphasia*" is evoked. This type of aphasia has clearcut clinical features and is close to the picture described by some German authors (74) and well-known as a "phonematic disintegration of speech" described by French neurologists (75). A very different type of motor aphasia is observed in lesions of the posterior parts of the third frontal convolution of the left hemisphere (or of the Broca's area). In these patients, the kinetic base of speech remains intact and patients can find proper articulation, but a fast and smooth transition from one articulation to another becomes impossible; the "kinetic melodies" become deranged, and a special syndrome of "*efferent* (*or kinetic*) *motor aphasia*" can be described (1, 2, 4, 61, 66).

Differentiation of two types of motor aphasia and the description of two syndromes I mentioned is of great importance both for diagnosis of local brain lesions, which result in disturbances of expressive speech, and for the better understanding of physiological theory of the speech processes that up to now had no scientifically based theory.

Neuropsychological analysis provided some progress in our understanding of the mechanisms underlying two other types of speech defects, described as "semantic" and "dynamic" aphasia. In 1926 H. Head described a special kind of speech defect that was observed in lesions of the "tertiary" temporo-parieto-occipital zones of the major hemisphere and that resulted in disturbances of understanding of complex relational grammatical structures. These disturbances were closely associated with disturbances of perception of complex spatial relations and with a defect in conversion of the successive information in simultaneous "asymmetrical" schemes (1–3, 6, 76). That is why the syndrome of "semantic aphasia" includes, as a rule, deterioration of orientation in space, constructive apraxia, and defects in computation (1, 3, 77–79). The assumption that disturbances of spatial and quasispatial organization of cognitive processes is a mechanism underlying this syndrome of "semantic aphasia" is of a basic importance for the theory of language and speech. It helps to distinguish two groups of syntactical structures of which one remains preserved in these lesions while the second is highly disturbed. (A careful analysis of these findings will appear in a special review of the progress in *Neurolinguistics*.)

A second form of speech disorder analyzed by neuropsychological studies is that of "dynamic aphasia," which was known as "transcrotical motor aphasia" or "aspontaneity of speech" of the classical authors.

Neuropsychological studies (61, 80) showed that this kind of speech disturbance can result from lesions of the anterior parts of the "speech areas" of the cortex. In these patients, the naming of objects and the repetition of words and even simple sentences is preserved, but no spontaneous fluent "propositionizing" is possible. This type of aphasic disorder is closely associated with disturbances of inner speech and predicative function (80, 81); these disturbances result in a breakdown of "the linear scheme of the phrase," and the "deep grammatical structures" which is supposed to be the basic mechanism of "generative grammar" (82). Observation showed that this defect can occur in two different forms: one is the disturbance of programming of sentences, the other is the breakdown of the grammatical structure of a sentence with a loss of predicative parts of the sentence and a "telegraphic style" (83). Patients of this group can, to a certain extent, recover their fluent speech by using some external means, compensating the deranged "linear scheme of the phrase" (81).

All these data make it possible to revise our knowledge of the basic mechanisms of speech disorders. They allow us to apply neuropsychological method to the basic problems of psychologuistics, to single out some real mechanisms underlying speech, and to open new ways for an objective analysis of speech and language that will be the starting point for a new branch of science–neurolinguistics (84, 85).

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