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On the Origin of Voluntary Movements

A study of the prehistory and genesis of so-called voluntary motor reactions, which emerged first in the animal world, is very important in the investigation of voluntary, consciously regulated human movements.

Data from comparative physiology and psychology point to the fact that so-called voluntary movements, in contrast to involuntary movements, require higher forms of reflection of reality reflection in order to form. Since A. Haller introduced the distinction between irritability and sensitivity (or, according to the terminology of other authors, unconscious and conscious sensitivity), the most prominent physiologists, G. Prochaska (1857), C. Bell (1821), F. Magendie (1839), and C. Bernard (1866) began to connect the arbitrariness of movements with sensitivity to stimuli causing these movements.

Bernard wrote:

> Sensitivity transmitted from rear radicles through the spinal cord can be of two kinds: conscious and unconscious. In the case of conscious

sensitivity, the impression reaches the brain and is received and trans-
formed by reason into a motor conscious reaction. In this case, will
precedes movement. In other cases, sensitivity can be unconscious;
but even then, a motion-reaction takes place, although reason and will
assume no participation in it. (1866, p. 277)

Somewhat earlier, Magendie (1839), following a similar path
of reasoning, classified the movements caused by simple irritabil-
ity as reflexes, and opposed them to voluntary movements caused
by the sensed stimuli.

Later, I.M. Sechenov (1947) overcame the dualism of such op-
positions and developed the reflex theory of voluntary movements,
having elucidated the general significance of sensation in their
formation and realization.

Proceeding from I.M. Sechenov's concept of the regulation of
voluntary motor acts of sensations, we considered it possible to
assume that the emergence of voluntary motor reactions in
phylogenesis is connected with the development of sensitivity and
that to correctly formulate the question on the genesis of so-called
voluntary movements, it is necessary to relate it to a question on
the origin and development of sensitivity. As soon as we connect
the problem of voluntary movements with the problem of sensi-
tivity, however, we encounter formidable difficulties at the very
first steps of the investigation. They are related to the fact that,
until recently, there was a widespread belief in psychology and
physiology that the only criterion of sensitivity is subjective and
introspective. This subjectivist understanding of sensitivity deprives
study in this field of the required scientific reliability, and, in fact,
excludes any possibility of genetic study of the problem.

In this regard, it is of paramount importance in studying the
genesis of voluntary movements to establish objective criteria of
sensitivity and the objective factors causing it. Considering the
methods of resolving this problem, it is necessary to reject as un-
founded any attempts to search for the source of sensitivity in the
subject itself, that is, in the anatomic-physiological or spiritual
properties immanently inherent to the subject. A materialist ap-

proach to the problem proposes that the emergence of sensitivity as well as the organs implementing it occurs in the process of development of the organisms' vital activity and is caused by a complication of their interrelations with the environment.

In the 1940s, A.N. Leontiev (1945a, 1945b) and I (Zaporozhets, 1940) developed a hypothesis concerning changes in the conditions of existence that lead to the emergence of sensitivity, and, at the same time, to the appearance of the simplest forms of mental regulation of behavior.

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The ability of living beings to respond to environmental impacts, to enter active mode under the effect of these impacts is called irritability. Irritability is inherent in any organism and is a fundamental property of any living matter.

At the first stages of development of living nature, interaction between organisms and the environment is characterized by the organisms' ability to be irritable, they enter the active state only under the effect of external impacts that are *directly* required for their life support and that, as a result of their transformation, can be turned into the organism's own substance. These are special features that characterize the activity of organisms at the stage of pre-psychic, vegetable life.

In the process of further development of living nature, the interaction of organisms with the environment becomes complicated and qualitatively different. Organisms develop a new form of vital activity that is mediated by psychic reflection of the environment's objective properties. A transition takes place from irritability to sensitivity. What are the material causes of this transition and what are the objective features of emergent sensitivity?

Today's state of scientific knowledge allows only a hypothetical answer to these crucial questions. There are grounds to suppose that a transition from an organism's interaction with homogeneous, objectless matter to its interaction with a more complex, object-shaped medium was a decisive condition for the appearance of sensitivity. In particular a change in nutrition

sources—the transition of living beings from inorganic to organic food—played the most important role.

Shapeless sources of life, for example, chemical substances dissolved in an aqueous medium, oxygen and carbon dioxide composing air, the energy of solar rays, and so forth, directly serve to support the vegetable life of organisms and to bring them into an active state. In contrast, the object-shaped sources of life, for example, living beings serving as sources of nutrition for organisms, act not only through their properties that have direct biological value, but also through properties (i.e., form, color, smell, etc.) that, being neutral, mediate the organism's relation to the properties of the object essential for its life. Such a change in the content of vital activity, a change in the objects of this activity finally brings about inevitable changes in its forms and structure.

The previous integral process of life splits. On one hand, *excretion functions* that realize direct interaction between the organism and the environment remain, and are inherent in both plants and animals. On the other hand, animals that existed in isolation and at a distance form discrete, object-shaped sources of life, developed new forms of relations with the external world, that is, the *functions of behavior*.

An animal, before entering into direct interaction with an agent that is of vital importance to it, must have several preparatory reactions. Such preparation consists of a preliminary practical transformation of the situation—such as approaching the object, capturing it, or, in the case of danger, distancing itself from it, fleeing from it, and so forth—which is achieved mainly through the animal's motor activity. The functions that prepare the possibility of direct contact with a positive object or ensuring in advance flight from negative ones, should be called *functions of behavior*, in contrast to *functions of excretion*, which execute direct interaction between the organism and the sources of its life support.

Now the vital activity of organisms acquires a unique, as we call it, *two-phase formation*, that is, the functions of behavior prepare the functions of excretion.

In the activity of animals, C. Sherrington (1906) correctly distinguishes preliminary (or preparatory) reactions, and "final" (or "completing") reactions. Preliminary reactions include complex motions associated with searching for sources of nutrition, while "final" reactions consist of swallowing and absorbing the obtained food. He assumes that the initiators of the preliminary reactions are stimulations of distant receptors, while the initiators of the final reactions are the stimulations of contact receptors. This last statement of Sherrington seems to have some basis, but it is not precise because, under specific conditions, the stimulation of contact receptors can also cause preparatory reactions.

We find a more detailed treatment of this topic in the works of I.P. Pavlov, who connects the reactions that Sherrington calls preparatory not with the modality of a receptor, but with the vital value of a stimulus with its ability to signal. Pavlov writes:

> It is not enough for an animal to put only food in its mouth that is directly before it; otherwise it would frequently feel hungry or starve to death. The animal has to find food using random and temporary attributes, and these are conditional (signal) stimuli, which incite the motions of the animal in the direction of food and end with the act of putting the food into its mouth." (1951, vol. 3, book 2, p. 324)

There is a basis to assume that the transition of organisms from life in a homogeneous environment to life in an object-shaped environment did not immediately lead to a change in their vital activity, and it did not immediately cause behavioral, preparatory reactions to emerge. V.A. Wagner writes:

> As for animals feeding on live prey, facts testify that the search for food was not immediate, and that this ability was preceded by a long period in the life cycle during which animals did not search for food, but expected it to be "delivered" like plants, such as, for example, actiniae from ruminant animals [*obshchepolostnye zhivotnye*]. (1928, no. 8, p. 3)

The former, vegetable methods of vital activity, however, turned out to be inadequate in the new conditions of existence, and little by little, in the course of the biological evolution of animal

organisms, behavioral functions emerged along with the development of special organs of behavior. They include first of all the mobile-articulated skeleton and the cross-striped musculature that ensures the execution of various kinds of complex grasping and locomotor motions.

"The most important organ," says Pavlov, "is skeletal musculature, the activity of which is directed exclusively toward the external world" (*Parlor's Environments* [*Pavlovskie sredy*], 1949, vol. 1, p. 345). Skeletal cross-striped musculature develops in animals only gradually from smooth musculature that forms genetically earlier and performs chiefly excretory, vegetative functions.

Thus, animals develop new forms of interaction with the external world, different forms of motor behavior directed at searching and obtaining food, distancing themselves from life-threatening agents, and so on. Behavioral functions (in contrast to the excretory functions that are inherent in both animals and plants) must be constantly adjusted to difficult and changing external circumstances in the process of their realization. Therefore, they need higher forms of reflection of reality for their regulation; they require formation of an image, a *molding* of object-related conditions for action and for timing this action accurately to specific conditions.

At this stage, not only the properties of an object that are able to directly satisfy the organic needs of animals, but also other properties that are objectively connected with the first, and, which, being in themselves vitally neutral (e.g., color, form, smell, sound), signal important effects to the organism that serve as orienting properties of what is required and desired, or, on the contrary, what is threatening and dangerous. In other words, a *transition* from simple irritability to *sensitivity* takes place.

One can say that the most vital role of sensitivity consists of serving the motor behavior of animals.

As Sechenov correctly notes, sensation at all stages of development is an "instrument of orientation" and has "only two general meanings: it serves as the instrument that discriminates the

conditions of action's conditions and as the controller of actions corresponding to these conditions" (1947, p. 416).

Caused by the new, more complex conditions of animals' existence, the development of sensitivity changes the nature of motor behavior and vastly enlarges its adaptive possibilities. Sechenov aptly comments on this:

> The environment in which the animal exists once again becomes the factor determining organization. With the equally distributed sensitivity of the body, which prevents the possibility of its movement in space, life is preserved only when the animal is directly surrounded by an environment that can support its existence. Of necessity, the region of life here is extremely narrow. In contrast, the higher the sensual organization that orients the animal in time and space, the wider the sphere of possible vital encounters and the more diverse the environment itself that affects organization and methods of possible adaptations. (Sechenov, 1947, p. 414)

These are the changes that are introduced into the sphere of motor behavior by the development of sensitivity.

Speaking about sensitivity, it is important to keep in mind, as was already observed by Sechenov and later confirmed by numerous physiological and psychological studies, that it is a process of reflection, and it includes not only the receptor but also effector components. In this process, the most important role is played by the orienting reflexes that establish analyzers to better perceive stimuli, to examine their specific features and their interrelations, and to interpret their signal value. On the basis of elementary orienting reflexes, in the course of evolution, complex forms of orienting activity develop, in the process of which animals form a sensory image of the conditions of an action, and they control their subsequent behavior on the basis of this image. This is how the simplest forms of psychic regulation of behavior appears; movements emerge as a result of received stimuli, or, as they were called by A. Bain ([in studies of] 1902–6), sensorimotor reactions (in contrast to the excitomotor reactions that appear as a result of simple irritability).

Sensorimotor reactions, however, cannot be classified as so-called voluntary movements because, although they are caused by perceived stimuli, they are themselves imperceptible.

According to our hypothesis, subsequent development of movement in animals, expressed in the transition from sensorimotor to so-called voluntary movements, is also connected with the development of sensitivity, that is, of interoceptive (specifically, proprioceptive) sensitivity. Some authors, for example, C. Tresi, A.N. Leontiev (1959), and others, argue that interoceptive sensitivity appears later in the course of evolution than the sensitivity to external stimuli; this, indeed, is the most apparent reason that sensorimotor reactions in the behavioral development of animals occur at earlier stages than do voluntary reactions. The deeper and more fundamental reasons for the appearance of voluntary movements, as well as the proprioceptive sensitivity that is necessary for them, lie in the complication of conditions for the existence of animals and the changes in their interactions with the environment. These changes occur, apparently, at the stage of appearance of vertebral animals that already possess a highly developed motor and nervous analytical-synthetic apparatus, and are connected to the transition of animals from water to a ground-based way of life.

In a new situation, the animal encounters a complex of external object-related conditions of activity in which, in a number of cases, various objects it needs appear in complex combination with other objects that acquire significance either as obstacles or the means of achieving the goal. At this stage for the animal, Leontiev writes: "on one hand, interrelated properties emerge that characterize the object, to which activity is directed, and, on the other hand, the properties of objects emerge that determine the very means of activity, that is, the operation" (1959, p. 177).

Thus, the activity of an animal begins to be determined not only by the object having the value of a goal but also by other objects serving as conditions for reaching that goal.

Along with such change in the object-related conditions of

activity, the objective biological significance of animals' motor reactions substantially changes as well. Under simpler conditions of existence, when the object of need is separated from the animal by a homogeneous environment, its reactions (both motor and secretor), although evoked by the signal conditional stimuli, preserve their former unconditional nature. Thus, a motion directed toward something always preserves the sense of a positive reaction under these conditions, while a motion away from something, a negative one. All salivary conditioned reflexes belong in this category of processes, as well as many others, including motor ones, for example defensive motor reflexes caused by the signals of electrocutaneous reinforcement. Taking into consideration their physiological characteristics, it is expedient to call these reactions, following A.G. Ivanov-Smolenskii, *conditionally unconditional*. On the basis of their psychological properties, they can be called *sensorimotor* (but not voluntary), insofar as, according to suggestions proposed above, these reactions, although caused by the perceptible stimuli, are themselves imperceptible.

In more complex object-oriented conditions of activity, the same motor reactions of animals in various circumstances can acquire a different biological sense. Thus, in the presence of an obstacle, the reaction of withdrawal from the needed object may acquire a sense of approaching it. In the presence of the lever, connected with the targeted object, the reaction of its repulsion also acquires a sense of approaching it. In other words, at a certain stage of animal development, not only diverse external stimuli turn into conditional signals, but the reactions themselves—the kinesthetic signals coming from them—acquire conditional, signal value. They become connected with unconditional supporting agents with which they were not keeping "business relations" earlier. Using Ivanov-Smolenskii's term, it would be possible to call them *conditionally conditional*. It is precisely these conditional motor reactions (not just any motor reactions, as is sometimes erroneously assumed) that are, according to Pavlov, the *voluntary* ones.

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Although the individual adaptation of animal motor behavior occurs over the entire course of their development, at the stage of conditional motor reactions, it acquires new qualitative characteristics. Initially, adaptation occurs, presumably, mainly on the basis of the animal's unconditional motor reactions (varying only within close limits) to new environmental conditions, connecting them with various external stimuli. Later, the situation changes. Apart from connecting the motor reactions with various external signals under the definitive influence of new conditions, and due to the increased potential of the motor and especially nervous, analytical-synthetic apparatuses of animals, the reactions themselves, as mentioned above, can acquire conditional value and be used to achieve new goals—apart from connecting the motor reactions with various external signals.

Because the vital significance of these conditional motor reactions change and they are used under completely unfamiliar conditions, they are initially imperfect, corresponding only approximately to their purpose, and they must subsequently be modified in accordance with the object-related conditions of activity. A process of developing new modes of motor behavior takes place that is characteristic of the formation of complex voluntary movements, or, in conventional terminology, the process of forming a habit.

Thus, in experiments by V.K. Fedorov (1955), the following characteristic changes were observed in animal behavior during the introduction of the conditional reflex from the motor analyzer. A rubber balloon was placed on the table; pressing the balloon produced a conditional stimulus reinforced by feeding. A dog could run freely on the table. In cases where it stumbled into the balloon, switching on the appropriate signal, it was given food. Although the new connection between involuntary motor reactions and obtaining the food was established by the animal sufficiently quickly, its motions were initially imperfect, only approximately corresponding to the circumstances. First the dog lingered on the table near the balloon, laying down on it with its

breast or stomach, seizing it by its teeth, and so on. Only gradually did the dog work out more differentiated and perfected motor reactions. All excessive and irrelevant motions little by little became inhibited, and the animal moved on to pressing the balloon with its front paws.

Many Russian and American scientists observed analogous phenomena during the development of motor habits. The majority of American researchers interpreted them within a trial and error concept. V.P. Protopopov (1950) underscored the uniqueness of the adaptive role and the way motor habits form, pointing out that they arise in a stimuli-impeding situation.

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Thus, the transition from sensorimotor reactions—that is, reactions, caused by perceived external stimuli—to reactions often called voluntary (during which not only external stimuli causing them are perceived, but also reactions themselves) is apparently connected with voluntary reactions acquiring conditional signal meaning.

In light of the above description, the following suggestion can be made concerning the genesis of voluntary motions: the life circumstances in which the animal's motor reactions themselves objectively acquire value ultimately result in the perceptibility of these reactions, causing them to become voluntary.

So far, we have substantiated our thesis on the conditions and psychological aspects of the emergence of so-called voluntary movements through theoretical reasoning and some references to psychological and physiological data. The value of this, as of any other scientific hypothesis, cannot be conclusively determined merely through more or less plausible reasoning or references to the results of the studies dedicated to other problems and subordinated to other goals. Only direct experimental verification of the hypothesis can play a decisive role. In connection with this, we now proceed to our analysis of data that we obtained in the process of experimental study of the genesis of voluntary movements.

Experimental study of the genesis of voluntary movements can be carried out on diverse material. At first glance, the activity of the skeletal cross-striped musculature seems the most suitable for our purpose. In this area, an interesting work by J. Bair (1901) should be noted. It deals with adults' mastery of uncommon motions, produced by facial and head muscles (motion of the ears); it was carried out at the dawn of experimental psychology. Along with obvious merits, the functions of the cross-striped musculature as the subject of a genetic study, however, have essential shortcomings.

In fact, this musculature had been developed in phylo- and ontogenesis as an organ of voluntary movements. It is no coincidence that, according to the conventional terminology of anatomy and physiology, it is generally called voluntary, in contrast to the smooth, intra-striped musculature, called involuntary. Although this terminology is, of course, not sufficiently precise, nevertheless, practically, in the highest animals and man (with the exception of early ontogenesis of their motorics, a topic to which we return later), what one can observe in the development of their skeletal musculature activity is not so much the initial appearance of voluntary movements but a formation of one type of voluntary movements and motor reactions on the basis of another already having a somewhat voluntary character.

The transformation of vegetative, excretory functions into voluntary ones is of special interest in genetic study. Such instances are exemplified by appropriate involuntary movements of internal organs (motions that are usually performed automatically and unconsciously, even in the most highly developed beings, such as adult people), which, under some experimental conditions, become voluntary and consciously controllable. The principle significance of such experiments increases even more in that they serve as an analog of sorts to the natural phylogenesis of arbitrariness, connected, presumably, with the transformation of excretion functions into behavioral functions.

Cases of voluntary control over the motions of internal organs had long attracted the attention of researchers, who described them in medical, physiological and psychological literature.

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Physiological studies created the necessary basis for a rigorously deterministic explanation of the process transforming the vegetative functions from involuntary to voluntary. Nevertheless, Russian students of the cortical regulation of vegetative reactions did not focus on the goal of investigating the ways in which the above-named reactions become voluntary and consciously controlled. Only some researchers, for example, L.I. Kotliarevskii (1936) and V.S. Merlin (1953), had touched upon this issue, describing the facts of creating vegetative conditioned reflexes to verbal stimuli.

American authors who applied conditional-reflex procedures to the study of individually acquired vegetative reactions, systematically interpreted the data obtained as being related to the problem of arbitrariness. The studies of C.V. Hudgins (1933), W.S. Hunter (1938), and others dedicated to analyzing pupil-conditioned reflexes, as well as R. Menzies's (1937) study of vasomotor conditioned reflexes, are, undoubtedly, of great scientific interest. In its time, Hunter's work was highly evaluated by Pavlov.

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As a result of imprecision in primary concepts and related flaws in research methods, the paradoxical vegetative reactions obtained by the cited authors—although conditional-reflexive and caused by verbal stimuli—only outwardly resembled voluntary reactions, but in fact did not belong in the voluntary category. The verbal directives used in the experiments (as well as self-directives) served as conditional substitutes for the direct *external* stimuli of reactions, rather than *internal signals* coming from them, whereas only the latter situation could give these reactions a truly voluntary nature. The result was that the self-order of the subject was a voluntary act, while the vegetative reaction caused by it remained involuntary. Nevertheless, this "failure" of the research in a sense seems to us highly useful and instructive, in that it prompts the need to refine the concept of *voluntary reaction* and to differentiate it from other conditional-reflex acts, similar to but not identical with it.

Critical analysis of the aforementioned studies returns us to the hypothetical thesis proposed earlier. According to it, the obligatory prerequisite for the transition of involuntary reactions into arbitrarily controlled ones is a transformation from imperceptible into perceptible reactions, which, in turn, is caused when these reactions (i.e., afferent impulses emitted by them) acquire the value of a conditional signal.

Experimental verification of this hypothesis on the material of vegetative functions was undertaken by M.I. Lisina (1957). In her study, she analyzed the conditions for transforming vasomotor reactions in man from involuntary to voluntary. She applied the method of conditioned reflexes. However, proceeding from the assumption that a decisive role in the transformation of vegetative reactions (as any others) into perceptible and voluntary ones is played by the change in their vital significance, combining them with a supporting agent with which they were not previously connected, Lisina worked out a new procedure. It differs from the one usually employed in the investigation of vegetative conditioned reflexes and reproduces the general procedural techniques used in Pavlov's laboratories during the study of the physiological mechanisms of voluntary movements.

The main difference of her method involves assigning a conditional value to the subject's vasomotor reactions, evoked using different methods by reinforcing these reactions using unconditional agents that were *uncommon* in their normal functioning.

Vasomotor reactions were registered using the optical fingertip photoplethysmograph of Whatchall-Fillipovich, which records changes in the volume of blood vessels in the finger. Over 1,000 experiments were carried out with 43 subjects. In the first two series, an attempt was made to convert the vasomotor reaction (afferent impulses it emitted) into the conditional signal of pain reinforcement.

In the first series of experiments, subjects were chosen who, in preliminary experiments, displayed live and almost permanent orienting (vasoconstrictor) reflexes to indifferent stimuli. The experi-

ment ran as follows. For twenty seconds an electric bulb was lit. As soon as application of this indifferent stimulus caused the vessels to contract, an electric shock inflicting a sensation of pain was applied to the index finger and the fourth finger of the subject's left hand. When the light did not produce the vasoconstrictor reflex or a zero reaction was observed (which happened fairly often as a result of the extraordinary instability of vascular reactions), negative reinforcement by electric current was canceled.

Analysis shows that this experiment used as the conditional signal a complicated and unique complex stimulus, consisting of exteroceptive (light) and interoceptive (afferent impulses from the vascular reactions) components. But since reinforcement was given (or postponed) only in the presence of certain vasomotor reactions (while the exteroceptive component remained constant), the interoceptive impulses from these reactions were supposed to acquire their main signal value. It was assumed that under unique experimental conditions, the usual, unconditional, vasoconstrictor reaction to light would be inhibited and instead a conditional, vasodilator or zero reaction paradoxical under these circumstances would appear. Nevertheless, despite the large number of combinations (up to 200), none of the subjects developed a paradoxical conditional reaction.

There are reasons to assume that instead of the expected paradoxical vasodilator reaction, another one opposite to it was created, a conditional vasoconstrictor reaction to light reinforced by electrocutaneous pain stimulus. The detection of such a connection is somewhat difficult (given the live and steady vascular orienting reactions in our subjects), because the unconditional orienting reaction to light and the conditional reaction to it as a signal of pain reinforcement are similar in their external manifestations (both are vasoconstricting). Nevertheless, there are still facts speaking in favor of our assumption.

First, the subjects who participated in the first series of experiments, revealed a certain tendency toward increased quantity and intensity of the vasoconstrictor reactions in response to light sig-

nals. In this respect, the results of the first series of experiments turned out to be similar to the data of the control experiments, producing a defensive vasoconstrictor conditional reaction to light with electrocutaneous reinforcement. Second, the additional experiments, conducted by employing the procedure of the first series with a female subject who had previously displayed weak and unstable vasomotor tentative reflexes, showed that under given experimental conditions, the vasoconstrictor effect of the application of a light stimulus not only does not decrease, but appears more frequently and increases in intensity.

All these data are objective evidence of the fact that under the conditions of the first series of experiments the subjects did not single out the interoceptive impulses transmitted from the vasomotor reactions they performed, and did not correlate these impulses with the effect of the negative unconditional agent. As a result, the interoceptive impulses did not acquire for them the signal value. The verbal statements of the subjects, and also the general nature of their behavior, point to the same conclusion. For the duration of the entire experiment, the subjects remained passive and saw their task to be calmly accepting the painful irritation that they believed always followed the light signal. Only one of the subjects remarked that sometimes the electric shock was not given, but suggested that this was done "to verify whether a reflex was formed."

Similar results were also obtained in the second series of experiments, which used a procedure essentially similar to the technique of the first series, although differing in a number of characteristics. The experiments were conducted on three adult subjects. A subject underwent the effect of the electric shock that caused an unconditional-reflex vasoconstrictor reaction. The vasoconstrictor reaction, however, did not last for the entire period of application of the electrocutaneous stimulus. Usually, after ten to fifteen seconds, the contracted vessels then expanded, again making it possible for them to contract. As soon as the angiospasm weakened, the experimenter turned the electricity off. Thus, under

the conditions of these experiments, vasodilation in the presence of continuous pain irritation had objectively acquired the meaning of a signal of cancellation of the negative electrocutaneous reinforcement.

One could expect that as a result of the repeated combination of the vasodilator effect with a cancellation of the negative reinforcement, the subjects would produce a paradoxical conditional reaction to the electric shock and they would begin to react to the latter not with a contraction, as usual, but by vasodilation. Nevertheless, despite repeated combination (80) in the second series of experiments, just as in the first series, such paradoxical conditional vasomotor reactions could not be obtained and their expected transformation from involuntary to voluntary reactions in this case did not occur.

Analyzing the reasons for the failure of this experiment, we arrived at the following considerations. According to the hypothesis that we proposed above, the most important prerequisite for the arbitrariness of reactions must be their perceptibility. But it was precisely the perception of afferent impulses from one's own reactions that was extremely difficult to trace in the experiments. Interoceptive impulses from acting vasomotors, although being objective signals of vitally important actions, were extremely weak in comparison with the painful irritations used simultaneously. Moreover, performing the completely unusual role of conditional behavior mediators, they did not draw the subject's attention and were not distinguished from the totality of the stimuli acting on analyzers. Because the interoceptive irritations remained undetected, their signal value could not be revealed and the corresponding temporal circuit could not be closed. It was possible that precisely this circumstance caused the negative results of the first two series of experiments.

To verify this assumption, M.I. Lisina conducted three additional series of experiments in which the information that the subjects received about their own vasomotor reactions was strengthened by the introduction of additional signalization. The value of addi-

tional signalization in the formation of voluntary motions was noted earlier by Sechenov, who pointed out that will can also control the motions, which, although "not accessible to direct observation through sensory organs, are accompanied with indirectly clear sensations" (1947, p. 290).

Following these considerations, the third to fifth series of experiments, in addition to interoceptive signalization, introduced exteroceptive (acoustic, tactile, and optical) signalization of the vasomotor reactions performed by the subjects. Additional signalization changed in precise correspondence with the change in volume of the vessels.

The conditions of the third set of experiments were the same as those in the first, but the subjects were given signalization using an audio frequency oscillator. The signalization was modified in accordance with changes in the vasomotor reactions: during vasodilation, the pitch was reduced, and during vasoconstriction it was increased. As a result of these experiments, all five participants formed a paradoxical conditional vasodilator reaction to light.

The role of additional afferentation in the formation of this type of conditional vasomotor reaction was most vividly manifested in the behavior of two subjects, who had earlier participated in the first series of experiments. While at the time, a large number of combinations produced no effect, now, after the introduction of additional sound signalization, a noticeable and steady shift in the vasomotor reactions was detected as early as during the first two combinations. By the end of the experiments, as a result of numerous combinations, the light, while gradually losing its vasoconstrictor effect in all subjects, in 80–100 percent of cases, began to produce the vasodilator or zero reaction. The gradual replacement of vasoconstrictor reactions to light with the vasodilating and zero reactions in the course of the third series of experiments is clearly expressed in the indexes shown in Figure 1.

Thus, under these conditions, the subjects perceive afferent impulses from specific vasomotor reactions as a signal of cancellation of the electrocutaneous reinforcement and forms a paradoxical vasodilator reaction to light.

Figure 1. **Changes in Vasomotor Reactions in the Process of Forming a Conditional Vasodilator Reaction to Light in Experiments with Additional Sonic Afferentation**
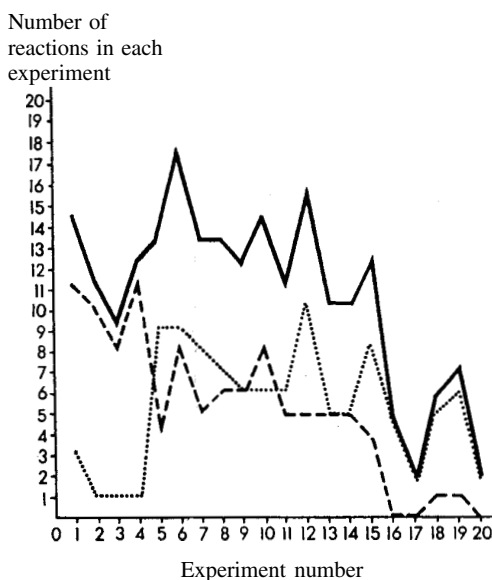
Note: In the course of the experiments the number of vasoconstrictor reactions (dashed line) decreases and the number of vasodilating reactions (dotted line) increases. A solid line marks the total number of reactions in each experiment (experiments of M.I. Lisina).

The subjects made verbal statements during the third series of experiments indicating that they began to identify conditions for the cancellation of electrocutaneous reinforcement. They connected this cancellation first of all with the special aspects of additional signalization. The subjects indicated that the shock was given only when light was accompanied by an increase in pitch of the sound. As for the connection between the cancellation of pain reinforcement and its own vasodilator reactions that were established through additional acoustic signals, this connection is formed at the level of the first signal system (as convincingly confirmed by the appearance of paradoxical reactions) and is usually not reflected in the second signal system. The majority of the subjects do not realize at all that the input of the electrocutaneous irritation depends

on the activity of their vasomotor reactions. Only one of the sub-
jects vaguely realized this connection, saying, that the pain rein-
forcement was gone when something happens "like a dying down,
like your heart stops or something."

Although the manufactured reaction was not recognized by the
subjects or was recognized insufficiently, subsequently, after the
introduction of some additional conditions, it could be caused by
a verbal command.

After the vasodilator reaction to electricity that was preceded
by light was developed and firmly established, some of the sub-
jects were told that the change in sound was produced by their
own reactions (which was not indicated); after that, they were in-
structed to reduce or increase the pitch (causing contraction or
vasodilation). With this instruction all subjects were immediately
able to achieve the contraction of their vessels. Only one of them,
however, was able to produce the dilation of his vessels.

Similar results were obtained in the fourth and fifth series of
experiments, which resembled the experiments of the second se-
ries, but differed in that they introduced additional afferentation.
In the fourth series, additional tactile afferentation was used (a
change in the force of pressure on the subject's hand in accor-
dance with the change in volume of the vessels). The fifth series
used additional visual signalization (the subjects could observe
the dynamics of their vasomotor reactions through the inspection
window of the plethysmograph). The additional afferentation in
the fourth and fifth series caused the formation of a paradoxical
vasodilator reaction to electricity directly, which the second series
of experiments failed to produce.

The worst results were obtained in the fourth series, where it
was possible to form a paradoxical reaction in one out of three
subjects only. This could possibly be explained by the fact that
(for technical reasons) the additional tactile signal was given only
at the moment the pain stimulus took effect, instead of continu-
ously (as was done in the experiments with additional acoustic
and optical signaling).

The best results were obtained in the fifth series of experiments during visual observation by the subjects of their plethysmogram. All the subjects participating in the tests developed a vasodilator reaction to electricity. The paradoxical vasomotor reaction was developed faster in the fifth series than in the third and the fourth.

Thus, the introduction of additional signaling not only facilitated the production of an unusual connection between vasodilator reactions and pain electrocutaneous irritation, but also helped, aided by special verbal instruction addressed to the subjects, to produce in certain cases conditional vasomotor reactions at the level of the second signal system. The reasons for the phenomena in question lie, apparently, in the following. In the first two series of experiments, distinctions between the two forms of vasomotor reactions (differently stimulated) remained undetected as a result of the extraordinary weakness of interoceptive impulses. In the series of experiments with additional signaling, the more extensive and intensive information about the activity of the subject's own vasomotor reactions attracted his attention to them and caused orienting reactions, thus facilitating their isolation and correlation with vitally important agents.

The data testify in favor of the assumption that the perceptibility of afferent impulses from their own reactions plays important role in transformation of the reactions into voluntary ones. Due to the specifics of the procedure, however, the experiments do not provide an answer to the question of in which temporal sequence these processes arise. Does the emergence of sensitivity to one's own reactions precede their transformation into voluntary ones, or do they occur simultaneously?

Although, thus far, we do not possess sufficient data to answer this question, as results of the third and fifth series of experiments, we nevertheless obtained some indirect evidence in favor of the fact that the perception of one's own reactions is the prerequisite of their arbitrariness. As we pointed out earlier, in these series additional signaling was given continuously, that is, not only at the moments of electrocutaneous stimulus, but also interoceptively,

at intervals between them. Both the behavior and verbal statements of the subjects testify that during the intervals between negative reinforcements, an especially intensive orienting-research activity developed. It was directed mainly toward elucidating the darkest and most difficult aspect of experimental situation: the relationship between the nature of the subject's own reactions and the change in additional signalization. (The connection between additional signalization and the application of pain reinforcement was easier to detect and was usually grasped by the subjects considerably earlier, during the first few combinations.)

It was precisely during the intervals between the switching on of electric current that the subjects, attentively following the changes in the additional signaling (which had already acquired conditional meaning for them), first noticed that these changes were somehow connected with their own motions—changes in their posture, unusual respiration, and so on—that is, by voluntary reactions, connected as an unconditional or conditioned reflex to certain vasomotor effects.

Apparently, during such pauses, when strong pain irritations were not suppressing other simultaneously acting stimuli, especially favorable conditions were created for exploring their own reactions and the results they cause under new, unusual conditions. The role of pauses in isolating one's own reactions and detecting their new conditional value is underscored by the negative experiments of the fourth series, where the absence of additional signalization in the intervals between the input of electrocutaneous irritation led to a sharp reduction in the effective formation of paradoxical conditional vasomotor reactions.

After the subjects noticed the connection between their own reactions and additional signalization, they attempted by various movements, actively to produce a change in this signalization and thus to achieve the cancellation of painful reinforcement as well.

Therefore, some facts indicate that a certain psychological reflection, the perception of one's own reactions (by their direct–interoceptive or indirect–exteroceptive criteria) precedes their trans-

formation into voluntary reactions and is an obligatory prerequisite for such a transformation.

If such a supposition was accurate, then the best conditions for transition of the vasomotor reactions from involuntary to voluntary would be formed in cases where subjects received preliminary training in the discrimination of afferent signals coming from functioning vasomotors. Following these considerations, M.I. Lisina conducted a sixth series of experiments. Since man possesses the second signal system, it is possible to set the task of distinguishing his own vasomotor reactions in verbal form, as well as to draw his attention and alert his orientation to the weak interoceptive impulses coming from these reactions. These were the methods used in the sixth series of experiments. The subjects acted in it on verbal instruction, and their direct and vocal reactions were reinforced by the experimenter's verbal approval or disapproval.

In the first stages of experiments, the subjects received general information about vascular reactions and about the structure and operating principles of the plethysmograph. Then the subjects were asked to observe their vasomotors attentively and to inform the experimenter when the stimuli provided in the experiment began causing vasoconstriction or vasodilation. Correct answers were followed by the experimenter's approval and incorrect answers, by disapproval. During the very first experiment all the subjects began to provide verbal qualification of their vascular reactions. The number of correct responses reached 55–60 percent. The subjects' statements confirm that their perceptions of their own vasomotor reactions were very unclear. In most cases, they could only state the presence of a specific reaction, but could say very little about the properties on which they based their statement. Most probably, the subjects initially oriented themselves less to the interoceptive impulses from the vasomotors than to the tactile sensations caused by the change in pressure of the small tube of the plethysmograph tightly embracing the finger, and that reveals changes in volume of the finger's vessels.

Sometimes the subjects correctly and confidently qualified their

vascular reactions, and in other cases they hesitated and made frequent mistakes. The quantity of accurate responses only slightly exceeded the number of erroneous ones.

During the first stage of the sixth series of experiments, no noticeable increase in the number of correct responses was observed. Basic shifts occurred, apparently, at the very beginning of the experiment, when the experimenters drew the subjects' attention to their own vasomotor reactions. Although subsequent training did not lead to an increase in the number of correct answers, it produced other important changes. The subjects gradually learned some specifics of their vasomotor reactions as well as the connection that exists between these reactions and other components of the situation. The subjects noticed, in the first place, the individual characteristics of their vasomotor reactions, second, their dependence on the nature of the external stimuli given in the experiment, and, finally, they established the connection between the vascular changes and the motions of the skeletal musculature. Their understanding of all these connections, and especially of the latter, apparently played a significant role during their attempts to actively evoke the appropriate vasomotor reactions, to carry them out arbitrarily, which exactly coincided with the main task in the second stage of the sixth series of experiments.

The subjects went on to the second stage after completing eight to eleven experiments, during which they were trained preliminarily to distinguish and to verbally qualify the afferent impulses coming from their own vasomotors. Although, as mentioned earlier, this training did not lead to a 100 percent correct evaluation of their own vascular reactions, it nevertheless had a decisively positive effect on their subsequent mastery of these reactions. In contrast to the control subjects who had no preliminary training in the discrimination of the specific vasomotor reactions, and could not evoke them voluntarily, all the subjects who passed the first stage of experiments described above, proved in the second stage to be capable of almost immediately accomplishing contraction and vasodilation upon verbal instruction from the experimenter, and

then on self-instruction as well. Initially, these reactions were primitive and weakly expressed. In the course of the experiment, however, they became stronger and more perfected.

All the subjects succeeded in performing vasoconstrictor reactions on verbal and self-instruction relatively easily and rapidly. The voluntary arousal of vivid and prolonged vasodilator reactions was possible only after sufficiently extended exercises, which apparently, can be explained by the primitiveness of their innervational mechanism. It is necessary to emphasize once again that it is precisely this verbal instruction type of production of vasomotor reaction that gives grounds to place it in the voluntary category, insofar as here verbal instruction is addressed directly to the reaction itself and connected with it through the afferent impulses (either direct or indirect) coming from it. These cases should be distinguished from others, where, as it happened, for example, in the experiments of C.V. Hudgins (1933) that were mentioned above, the verbal instruction was addressed not to the reactions directly, but rather to their external stimuli, and served as their conditional substitute. We call such conditional reactions to the verbal stimuli *pseudo-voluntary*, in contrast to those established in our experiments.

The physiological aspects of the processes taking place under the conditions of the sixth series of experiments can be schematically visualized as follows. At the first stage, the influence of the verbally evoked orientation on the weak afferent impulses coming from their own vasomotor reactions facilitates the subjects' isolation of these impulses, as well as their connection of these impulses to specific verbal responses. The formation of this connection is reinforced by the experimenter's evaluations. At the second stage of the experiments, when the subject faces the task of reproducing arbitrarily certain vasomotor reactions on verbal instruction, the following occurs. According stipulations in I.P. Pavlov's theory on the physiological mechanisms of voluntary movements, excitation traveling along a previously laid nerve path now moves in the opposite direction. It proceeds from points in the cortex, excited by verbal instruction, to the cortical representation of

vasomotors, activating the latter and causing the appropriate vascular reaction.

In this way, the subjects' voluntary performance of the vasomotor reaction to the verbal or self-instruction has a physiological explanation.

The characteristic psychological aspect of the subjects' behavior under conditions of the sixth series of experiments is their activeness and purposefulness. Their activeness is especially striking when comparing their behavior with that of the subjects in the first two sets of experiments, where the subjects were extremely inactive; they did not attempt to find ways to resolve the situation. In the sixth set of experiments, the subjects *listen* very attentively and intensely to their sensations and react emotionally to the evaluations of the experimenter; they constantly search for ways to achieve the required results.

In their attempt to arbitrarily cause a certain vasomotor reaction, the subjects initially depend not merely on the dark interoceptive impulses coming from it, but mainly on various more obvious indirect indicators (tactile, kinesthetic, etc.), which arise both in realization of these same reactions and in the reactions associated with them. At the same time, at the first stages, the voluntary performance of vasomotor reactions happens not in isolation, but in combination with the entire system of other reactions unconditionally or conditionally connected with them. Among them, the most important role is played by various reactions of skeletal musculature: a change in posture, the general relaxation or tension of musculature, the holding of one's breath, and so forth. Reliance on indirect indicators, as well as the use of well-mastered reactions, apparently are very characteristic of the early stages of formation of voluntary actions and are revealed during the first stages of natural ontogenesis of the voluntary motions of skeletal musculature, and also the early stages of restoration of disrupted functions.

In the process of further formation, there is a reorientation to the characteristics that are more immediately relevant to the per-

formed reaction. The motions associated with it also gradually decrease, which adds a more differentiated, specific nature. Some subjects who, at the beginning of the experiments widely used different auxiliary methods, later abandoned them, declaring that the vasomotor reaction required by instruction "happens by itself."

Thus, voluntary movement, which at the moment of its emergence is performed by depending on the support of various indirect properties and in combination with various associated reactions, gradually liberates itself from its accompanying features and times itself both in its afferent and efferent parts to fit new conditions for its realization. It should be noted that this timing during the mastery of vegetative reactions is by no means precise; in particular, orienting to indirect properties remains a leading factor, presumably, at all stages of their genesis due to the fact that the afferent and efferent apparatuses of these reactions are themselves not fitted to the realization of behavioral functions. However, even here there is a tendency to differentiate, to release the excess of associated phenomena, a tendency that finds its full realization only in the development of the voluntary movements produced by the skeletal musculature.

These are some of the most important facts of Lisina's study. The results of her study in general confirm the hypothesis proposed at the beginning of this article concerning the role of perceptibility of movements in their transformation from involuntary to voluntary. It is significant that additional arguments in favor of this hypothesis were obtained in experimental-genetic research. By artificially recreating the assumed conditions of the emergence of voluntary movements, we obtained the real transition of involuntary vegetative responses to consciously controlled voluntary reactions.

Analysis of the received data attests to the fact that the central, crucial point in this passage is the transformation of reactions from imperceptible into perceptible ones. The described moment—usually masked when investigating the process of controlling the motions of skeletal musculature because the latter (at least in adults)

are always to some degree perceptible—is revealed fully exposed and in its true significance in the dramatic experiment with vegetative functions. On the basis of the facts obtained, it is possible to assume that the perceptivity of motions is not only an obligatory satellite of their arbitrariness, but is also its obligatory prerequisite. Before transforming into voluntary and controlled, the movement must first become perceptible (whether by direct or indirect characteristics).

   [. . .]

The data attest to the fact that the main condition for transforming previously imperceptible functions into perceptible ones is the change in their vital significance, their combination with reinforcing agents with which they previously had no "working relations." Combining the movement with new reinforcing agents, however, in itself might not necessarily lead to its perceptibility. Even if the afferent impulses, coming from movement, will objectively assume the signal meaning, the subject still might not detect the movement. Such phenomena were observed in the first two series of Lisina's experiments (1957). Essentially similar facts, albeit obtained based on other material, were noted earlier by Leontiev (1959) in his study of genesis of the sensitivity of hand tissue to visible rays of the solar spectrum.

The value of some additional conditions for forming the required temporary connection is clearly revealed in all similar cases. Before any stimulus acquires a signal value for the subject, this stimulus must draw his attention and be selected from a totality of other stimuli acting simultaneously with it. This initial separation of stimuli is accomplished, according to I.P. Pavlov, with the aid of the "orienting reaction and the research reflex, producing a secondary effect on conditional reflexes either in an inhibiting or releasing manner" (1951, vol. 4, p. 142).

In a situation similar to that in Lisina's experiments, given the extreme weakness of the afferent impulses coming from their own reactions and a complete redundancy of their roles as reference-point for external behavior (and therefore, no ready forms of orienting to such signs), these afferent impulses initially did not attract

the attention of the subjects and remained unnoticed. Only through increasing information about these reactions is it possible to attract the subject's attention to them and thus make them perceptible, and, subsequently, voluntary.

In experiments with people, stimulating orienting activity and drawing the subjects' attention through various techniques to the emergent conditional motor reactions, as a rule, involve their connections with the second signal system in the process of their formation, which gives these reactions a voluntary, consciously regulated nature in the proper and true meaning of this word.

As far as animals are concerned, in similar circumstances, they develop only the so-called voluntary movements, the regulation of which is achieved at the level of the first signal system with the aid of direct impressions from external conditions, as well as from the actions themselves performed without their conscious programming.

References

Bair, J. 1901. "Development of Voluntary Control." *Psychol. Rev.*, vol. 8, no. 5.

Bell, C. 1821. "On the Nerves Giving an Account of Some Experiments on Their Structure and Function, Which Lead to a New Arrangement of the System."

Bernar, K. [Bernard, C.]. 1866–67. *Lektsii po fiziologii i patologii nervnoi sistemy*. Vol. 1–2. St. Petersburg.

Fedorov, V.K. 1955. *Fiziologicheskie osobennosti dvigatel´nogo analizatora sobaki*. Leningrad.

Hudgins, C.V. 1933. "Conditioning and the Voluntary Control of the Pupillary Light Reflex." *Journ. of Gen. Psychol.*, vol. 8.

Hunter, W.S. 1938. "An Experiment on the Disinhibition of Voluntary Responses." *Journ. of Exper. Psychol.*, vol. 22.

Kotliarevskii, L.I. 1936. "Serdechno-sosudistye uslovnye refleksy na neposredstvennye i slovesnye razdrazhiteli." *Fiziologicheskii zhurnal SSSR im. I. M. Sechenova*, vol. 20, no. 2.

Leont´ev, A.N. 1959. *Problemy razvitiia psikhiki*. Moscow.

Lisina, M.I. 1957. "O nekotorykh usloviiakh prevrashcheniia reaktsii iz neproizvol´nykh v proizvol´nye." *Doklady APN RSFSR*, no. 1.

Magendie, F. 1839. *Leçons sur les fonctions et les maladies du système nerveux*. Paris.

Menzies, R. 1937. "Conditioned Vasomotor Responses in Human Subjects." *Journ. of Psychol.*, vol. 4.

Merlin, V.S. 1953. "Svoeobrazie uslovnykh reaktsii v strukture volevogo akta." *Uchen. zap. Kazanskogo gos. un-ta im. V. I. Ul´ianova-Lenina*. Vol. 113, bk. 3.

Pavlov, I.P. 1951. *Polnoe sobranie sochinenii*. Vol. 3, bks. 1, 2. Moscow and Leningrad.

Pavlovskie sredy. 1949. Vols. 1–3. Moscow and Leningrad.

Prochaska, G. 1957. *Traktat o funktsiiakh nervnoi sistemy*. Leningrad.

Protopopov, V.P. 1950. *Issledovanie vysshei nervnoi deiatel´nosti v estestvennom eksperimente*. Kiev.

Sechenov, I.M. 1947. *Izbrannye filosofskie i psikhologicheskie proizvedeniia*. Moscow.

Sherrington, C.S. 1906. *The Integrative Action of the Nervous System*. New Haven.

Vagner, V.A. [Wagner, V.A.]. 1924–25. *Vozniknovenie i razvitie psikhicheskikh sposobnostei*. Leningrad.

Zaporozhets, A.V. 1940. "Osobennosti i razvitie protsessa vospriiatiia." *Nauch. zap. KhGPI.*, vol. 6. In Ukrainian.