Early contributions of Russian stress and exercise physiologists

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Abstract

In Russia, the free development of scientific ideas was suppressed in 1950 as a result of the actions of the Joint Session of the Academy of Sciences and the Academy of Medical Sciences of the USSR. Hans Selye's theory on the general adaptation syndrome was considered unscientific. From 1956 to 1958, Pjotr Anokhin and Pjotr Gorizontov presented definitive arguments for having the theory accepted by scientists while the significance of hormones in adaptation became a topic of endocrine studies (Boris Aleshin, Igor Eskin, Vassily Komissarenko, Samuel Leites, and Michael Kolpakov). Later, Felius Meerson made essential contributions to the adaptive significance of protein synthesis and stress-limiting systems. The area of exercise physiology dealing with acute and chronic adaptation to strong physiological stressors was founded by Leon Orbeli and developed by Aleksei Krestovnikov. Significant contributors to this area were Vladimir Farfel, Nikolai Yakovlev, and Nikolai Zimkin. Although the majority of their publications have remained unknown outside of Russia, it is interesting that many of their results have been “rediscovered” by others. Yakovlev also deserves recognition because he was among the founders of contemporary exercise biochemistry and because his research has provided the foundation for current investigations. Several generations of young scientists have been inspired by the above-mentioned Russian scientists. Today, however, the research activities of scientists are no longer limited by political pressures but by financial resources instead.

- adaptation
- exercise biochemistry
- exercise physiology
- general adaptation syndrome

the purpose of this paper is to recognize the impact of Russian physiologists who introduced studies on general adaptation syndrome and who ensured development of exercise physiology in the Soviet Union.

In the 19th century, several Russian physiologists were known for their pioneering research, for example, the discovery of the central inhibition by Ivan Sechenov (26), studies on nerve physiology by Nikolai Vvedenski (30), recognition of inotropic effects by cardiac nerves (22), and establishment of the main principles of digestion physiology by Ivan Pavlov (23). During the beginning of the 20th century, Pavlov (24) started his extended studies on the central nervous system and Leon Orbeli (21) elaborated the theory of adaptive-trophic action of sympathetic innervation.

The scientific research climate was altered after 1917. The economic conditions after World War I and the Russian Revolution restricted opportunities for extended research activities, although Pavlov and a few other outstanding scientists (e.g., Orbeli) had adequate facilities and funding. In addition, an increased distrust of capitalist countries arose, which meant suppressed international contacts for Soviet physiologists, who required approval from Pavlov (as a result of his Nobel Prize) to maintain contact with foreign scientists.

The Cold War arising after World War II disrupted what remained of international scientific contacts, and the “iron curtain” separated the Soviet Union and capitalist countries. Leaders of the Communist party promoted the attitude that Soviet scientists had better ideas than their foreign colleagues who were looking for Soviet ideas to obtain grant funds in their countries. The possibilities to take course work and to participate in joint research with foreign universities disappeared; these opportunities did not reappear until the 1960s and then only to a limited extent. For example, to publish a paper in a foreign journal, scientists had to receive special permission and only leading scientific institutions were permitted to purchase advanced research equipment that was manufactured abroad.

The development of disciplines such as physiology was disturbed by political interference into the activities of scientists. In 1950, the Joint Session of the Academy of Sciences and the Academy of Medical Sciences was held (25). The purpose of the session was to promote the use of Pavlov's findings on scientific inheritance for the development of physiology. However, the session actually canonized Pavlov's concepts and suppressed the free development of scientific ideas. The requirement to follow Pavlov's ideas was a form of political control on the research work of physiologists and other scientists. Because of this, the scientific authority of Pavlov was discredited, even though Pavlov was known to be an active fighter for the scientific method as well as for the principles of democracy.

As a consequence of the Joint Session, several outstanding physiologists such as Orbeli, Pjotr Anokhin, and Aleksandr Ginetsinski were removed from their leading positions in

institutes. In addition, several research directions were officially labeled as being undesirable, which meant that they were forbidden. During the latter portion of the 1950s, Soviet physiology began to be gradually released from political suppression. Unfortunately, the consequences lasted much longer, as research work was seriously disarranged and competent progressive scientists were replaced by those who were politically loyal but had limited scientific ability. However, a number of moral and scientifically respected physiologists survived this period (e.g., Anokhin, Farfel, Ginetsinski, Pjotr Gorizontov, Yakovlev, Zimkin, to name a few). Later, they became leaders in restoring previous scientific traditions and the practice of the scientific method. They were soon joined by many young scientists who strived to become acquainted with the results of foreign physiological research and to have the opportunity to study abroad.

STRESS PHYSIOLOGY

The theory of Hans Selye on the general adaptation syndrome was among the forbidden research themes. Two scientists who introduced the stress theory into scientific understanding in the Soviet Union were Anokhin (2) and Gorizontov (9).

Pjotr Anokhin (1898–1974).

Anokhin graduated from the Leningrad (Saint Petersburg) Medical Institute. In 1921, being a degree candidate, he began his research work at the Institute of the Brain under the supervision of Vladimir Bekhterev. Later, he became a postgraduate student of Pavlov. In 1930, he was recommended by Pavlov to be professor of physiology at the University of Nizhni Novgorod. In 1935, he moved to Moscow and became the Director of the Institute of Physiology of the Academy of Medical Sciences in 1946. After the Joint Session of the Academies, he was assigned to the Rjazan Medical Institute (□200 km southeast of Moscow). Although the opportunity for experimental research was limited at Rjazan, he remained scientifically active and focused on theoretical generalizations. In 1953, he returned to Moscow; three years later, he was elected to be professor of physiology at the Moscow First Medical Institute, which meant that his "political rehabilitation" was complete. Later, he founded the Research Institute of Normal and Pathological Physiology.

Anokhin was a neurophysiologist whose main scientific contribution was developing integrative physiology. In 1935, he published the first outlines of this theory. Further development made it a fundamental generalization of functional integration having adaptive and behavioral aims (4). Unlike the widespread approach, he analyzed the relationships between Pavlov's theory on conditioned reflexes and recent advances of neurophysiology (see Ref. 4). This integral approach guided him to the analysis of emotional states and the theory of stress as a general adaptive response. In 1958, Anokhin (2) described the essence of Selye's stress theory: that specific physiological processes ensured the body's adaptation to unfavorable conditions and that these made

the body more resistant. This was a courageous scientific statement because, in the late 1950s, the political control of science pronouncements was still in existence. For that time, the positive evaluation of the stress theory by a leading scientist was highly significant.

In 1962, Anokhin published a profound analysis of adaptation processes and their relationships to homeostasis (3). He discriminated between *1*) plastic constants of the body, which were changeable to a great extent; and *2*) rigid constants, which have a very narrow range of fluctuation between the resting and activity levels from which deviations cannot be associated with maintenance of life. However, the main contribution of Anokhin for the adaptation processes was his theory of integrative physiology. The further development of this theory was made by Sudakov in 1984 (29).

Pjotr D. Gorizontov (1902–1987).

Gorizontov graduated from Omsk Medical Institute and in 1962 became the director of in the Institute of Biophysics in Moscow. In the Joint Session of the Academies, he exhibited great courage by defending the banned scientists. In 1956, Gorizontov published (9) a review paper on the general adaptation syndrome and diseases of adaptation in which he criticized the approach that attempted to explain all findings in clinical and experimental pathology by actions of the nervous system, an approach that ignored the responses of endocrine glands. He later emphasized that the unspecific nature of stress responses has only a relative significance because these responses depend on the initial state of the body. Gorizontov considered that a limitation in Selye's approach was that Selye only dealt with pathogenic mechanisms of diseases and not the etiological mechanisms (11). In 1976, Gorizontov (10) edited a large volume on the significance of homeostatic regulation in adaptation.

Two books by Selye were published in Russian in 1960 (28) and 1961 (27). The second book was introduced by Vassily Parin, a leading cardiologist and an initiator of space physiology in the USSR.

Because of the restrictions imposed by the Joint Session, endocrine studies were possible only if they contributed to the neural regulation of endocrine functions. However, in 1955, a journal on problems of endocrinology (*Problemõ Endokrinologij*) was founded. Subsequently, hormones in adaptation became a topic of study by many investigators [Aleshin (1), Eskin (6), Kolpakov (13), Komissarenko (14), and Leites (17)], and several research centers were established that produced relevant research in endocrinology. Significant contributions were made by Yudayev (36) and his team on the biosynthesis and metabolism of steroid hormones.

Meerson made essential contributions to short- and long-term adaptations to stress. In 1965 (19), he indicated that a molecular mechanism exists that links cellular function with its genetic apparatus. Through this mechanism, the synthesis of proteins is

enhanced. He implicated his findings in the analysis of cardiological problems (20) and elaborated a concept of stress-limiting systems (antioxidant mechanism and endogeneous opioid responses).

EXERCISE PHYSIOLOGY AND ITS CONTRIBUTION TO STRESS PHYSIOLOGY

Exercise physiology deals with acute and chronic adaptations to strong physiological stressors. In Russia, the development of exercise physiology is attributed to activities of Krestovnikov (16), Orbeli (21), and Zimkin (37), as well as of Farfel (8) and Yakovlev (33, 34). The first three were pupils of Pavlov and professors of exercise physiology in the Leningrad (Saint Petersburg) Leshaft Institute of Physical Education (Orbeli from 1919 to 1927, Krestovnikov from 1927 to 1955, and Zimkin from 1961 to 1975). Farfel (8) initiated strong centers of exercise physiology in Moscow. Yakovlev (33, 34) made the Leningrad Research Institute of Physical Culture well known by his research in exercise biochemistry.

Aleksei N. Krestovnikov (1985–1955).

Krestovnikov graduated from Saint Petersburg University (1912) and from Petrograd Medical Institute (1923). In 1912, he worked in Pavlov's laboratory and later became senior assistant to Orbeli in the Department of Physiology, Leningrad Leshaft Institute of Physical Education. Orbeli demonstrated the increase of contraction amplitude of fatigued muscle when sympathetic nerves were stimulated (21). Krestovnikov, his collaborator, found an increased oxidation rate of muscle when sympathetic nerves innervating the muscle were stimulated (15). In 1927, Krestovnikov replaced Orbeli as professor of physiology in the Leshaft Institute and introduced studies on the physiological changes during exercise and training. Noteworthy were his studies on the reflexes evoked by movements of the head. He used a special plaster cast to exclude any movement of head. Even in highly qualified athletes, the result was disturbed motor skills. The same effect occurred when peripheral but not central vision was excluded. In regard to exercise training, he found conditioned reflexes were necessary for increased performance. His research has been summarized in two monographs that were edited in 1939 and 1951 (16).

Nikolai N. Yakovlev (1911–1992).

Yakovlev graduated from the Leningrad Medical Institute in 1928 and joined the Laboratory of Physiological Chemistry at the Leshaft Research Institute of Natural Sciences. Later, he moved to the Laboratory of Pathological Physiology, Leningrad Research Institute of Physical Culture. His work concerned the role of vitamins in the training process and the contribution of hormones from the pancreas during exercise. After World War II, his responsibility was to establish a laboratory of exercise biochemistry at the Leningrad Research Institute of Physical Culture.

He discovered (1949–1959) the phenomenon of “supercompensation” of muscle and liver glycogen and muscle phosphocreatine during postexercise recovery and with training (32, 34). In 1955, his work on the significance of anaerobic resynthesis of ATP in intensive exercise was published (32). His research on metabolism involved several areas:*1*) the training effect on the mitochondrion; *2*) ATP, ATD, and AMP concentrational changes in muscles with various exercises; *3*) lipid and phosphorous changes in brain tissue;*4*) the relationship between GABA and fatigue (brain GABA content increased in rats with fatigue); *5*) the role of ornithine and polyamines in muscle hypertrophy; *6*) cAMP changes and the action of hormones; *7*) anticipatory changes in blood of athletes before competition; *8*) dependence of carbohydrate and phosphorous metabolism on the state of the central nervous system during exercise; *9*) exercise-induced metabolic responses in myocardium and liver; and *10*) several problems related to nutrition of athletes (for reviews, see Refs.33 and 34). Beginning in 1949 and continuing to 1976, he founded the concept of the biochemical specificity of tissue responses to training, which indicated that the biochemical response of a tissue depended on the type of training that was performed (31,34). During 1973–1975, he found that the training-induced increase in tissue sensitivity to epinephrine was typical for the first period of training and related the change to an increased activity of adenylate cyclase. He also showed (35) that this was followed by an increase in AMP-phosphodiesterase and a normalization in the sensitivity to epinephrine.

Yakovlev was among the founders of contemporary exercise biochemistry, and his work influenced research in other laboratories. Although biochemical research techniques have been vastly improved since his time, contemporary studies have confirmed his findings and continue to be an inspiration to contemporary researchers.

Nikolai V. Zimkin (1899–1990).

Zimkin graduated from the Academy of Military Medicine in 1926. He started his scientific career under the supervision of Pavlov. By 1945, he was the head of a Laboratory in the Institute of Evolutionary Physiology (Leningrad). In 1947, he received a professorship in the Military Institute of Physical Education (in Leningrad) where he conducted longitudinal experiments on training of various motor abilities (37). Because most of his monographs and articles were unknown in other countries, many of his results have been “rediscovered” by others (e.g., cross-training and detraining effects; positive and negative interaction in improvement of strength, speed, and endurance; mastery of motor skills). It is noteworthy that his studies on training effects on body resistance to heat, poisons, hypoxia, and radioactive irradiation provided the first experimental evidence of changes in body adaptivity with chronic exercise (38). These results showed increased adaptation under the influence of exercise training. However, if the training regime was too intense, survival of the experimental rats was decreased.

Other meaningful results from his scientific research were the concept of “fatigue focus” and the demonstration of extrapolation in athletes' motor skills (rapid adjustments of

precise motor skills in changeable situations). According to the concept of fatigue focus, published in 1962, the type of exercise, the external and internal conditions, and the individual peculiarities of the subject determine a critical complex of changes, disturbing the activity of neural centers or of muscle metabolism and causing a decrease in work capacity. This concept is in accord with the catastrophe theory of fatigue (see Ref.5). According to Zimkin, latent fatigue has to be recognized. This is manifested by a feeling of tiredness or discoordination of functions without any decrease in work quantity.

Vladimir S. Farfel (1904–1979).

Farfel was educated as a physiologist at Leningrad University. His mentor was Aleksei Ukhtomski who was an expert in central nervous system physiology. Farfel became the head of the Physiological Laboratory of the Central Research Institute of Physical Culture (1934–1947) and professor in the Pedagogical Institute of Moscow's Region (1947–1958). Later, he directed a laboratory in the Institute of Ontogenetic Physiology, Academy of Pedagogical Sciences (1958–1960), and finished his career as a professor of physiology in the Central Institute of Physical Education (1960–1972). At every institution, he established a strong team, conducted meaningful research, and was chiefly responsible for making his laboratory well known in the USSR.

Farfel became recognized for his systematic physiological classification of exercise. In following the practice of Archibald Hill (12), he analyzed track events by logarithmically plotting the running velocity (intensity) against exercise duration and found that four straight lines were present. Consequently, he was able to discriminate four different types of cyclic exercise by their intensity (7). He concluded from his studies (1939–1940) on elite athletes during important competitive events that trained subjects during maximal exercise have more pronounced functional cardiovascular and respiratory manifestations than untrained subjects, even though their responses are less with submaximal exercise.

Farfel conducted an extensive study on endurance that is seldom cited. In 1949, a member of his research team demonstrated that glucose administration just before the start of a long distance event will cause hypoglycemia to occur during the early stages (18). Obviously, it was related to glucose effect on insulin secretion.

Several generations of young scientists were inspired by these four Russian “giants.” Because their results have been published predominantly within the Russian literature, a language barrier greatly limited the distribution and awareness of their findings. During the 1980s, the leading scientists were Yakov Kots (neural mechanisms of movement), Viktor Karpman (cardiovascular studies), Sergei Kuckin (respiration), Erlena Matlina (catecholamine metabolism), Viktor Rogozkin (mechanism of induction of protein synthesis), Jelena Sologub (EEG studies), Vitali Thorevski (circulation), Nikolai Volkov (muscle energetics), and Vladimir Zatsiorsky (biomechanical mechanisms).

In summary, an educated and inquisitive mind can find opportunities for creative activity despite restrictive and oppressive conditions. Fortunately, politically driven restrictions for scientific contacts and exchanges between Russia and other countries are no longer present as they were before and during the Cold War. Today, the effectiveness of research work is limited only by the availability of funding. However, new generations of scientists remain in debt to the important research work of the above-mentioned “greats.”

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Footnotes

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