# EDWARD VAUGHAN EVARTS
## 1926–1985

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Edward V Ewart

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BY WILLIAM THOMAS THACH, JR.

ON JULY 2, 1985, Edward Vaughan Evarts, Chief of the Laboratory of Neurophysiology at the National Institute of Mental Health (NIMH), died suddenly in his office from a myocardial infarction. He was fifty-nine years old and at the peak of his career.

Born in New York City, Evarts received his undergraduate education at Harvard College and was granted his M.D. by Harvard Medical School in 1948. After an internship at Boston's Peter Bent Brigham Hospital, Evarts worked for one year with the psychoneurologist Karl Lashley at Yerkes Laboratories of Primate Biology in Orange Park, Florida, and for another year at the National Hospital for Nervous Diseases in London. He completed his postdoctoral training with a two-year residency in psychiatry at the Payne Whitney Institute in New York. Evarts then began his lifelong association with the NIMH in Bethesda, upon his appointment as head of the section on physiology in its new Laboratory of Clinical Science directed by Seymour Kety. He remained in that position until he became chief of the Laboratory of Neurophysiology in 1970.

Evarts's neurobiological research spanned three and a half decades, starting with his work on the behavioral effects of ablating various areas of the visual and auditory cerebral cortex in monkeys that he carried out in Lashley's laboratory. On moving to the NIMH, he investigated the neurophysiological effects of LSD, which at that time promised to provide a fruitful approach to understanding schizophrenia. He also studied post-tetanic potentiation in the cat's visual pathway, as a possible model for behavioral adaptation.

At the age of thirty-six, Evarts made his first major discoveries, when he began to take electrophysiological recordings from single cortical neurons in cats and monkeys in their waking and sleeping states (1962, 1964). He observed that such single unit activity is higher during the rapid eye movement (REM) phase of sleep than during visual experience in the waking state. This was a crucial finding, and it showed that sleep is not attributable to a passive state of the cerebral cortex. In further support of this inference he showed, in collaboration with Kety, that cerebral blood flow during REM sleep is also higher than during the wakeful state. To pursue the study of brain function during waking behavior Evarts developed the methods for recording single-neuron activity during operantly conditioned movements in monkeys (1966), for which he is well known. The principle of correlation of brain cell activity with behavior, well established by that time, was rooted in the pioneering studies of E. D. Adrian, Vernon Mountcastle, David Hubel, and Torsten Wiesel in anesthetized paralyzed animals. There had been some prior studies in awake animals by Ricci, Doane, and Jasper, who first recorded brain function in trained monkeys, and by Hubel who recorded brain function in freely moving cats; but it was Evarts's own brilliant perfection of the method of single unit recording from the cortex of awake animals that would lead to its later widespread use.

Evarts's first studies of movement control proved the utility of this method and supported previous inferences about the role of motor cortex in voluntary movement based on ablation and electrical stimulation studies. He trained monkeys to release a telegraph key promptly at a visual or acoustic signal. In this way he found that a motor cortex neuron projecting toward the spinal cord (identified by electrophysiological back-excitation from the medullary pyramid) usually alters its firing pattern just prior to the onset of movement (1966). While any one neuron fires (or pauses) at some fixed time before (or after) the movement, the average time of change across all neurons precedes the electromyographic (EMG) activity of the target muscles by as much as 60 ms (1973, 1974). Some of these neurons increase their firing rate with the force generated in the movement (1968), while others do so with the force needed to hold still (1969). With Fromm, he found (1981) that neurons in the motor cortex appear to be organized according to a “size principle” similar to the one Henneman applied to the activities of spinal motor neurons. This principle states that, for the command of smaller movements involving lesser force, only the smaller cortical neurons are recruited, while for the command of larger movements involving greater force the activity of the smaller neurons is supplemented by an additional recruitment of larger cortical neurons. Thus, motor cortex neurons would appear to behave similarly to spinal motor neurons in controlling muscle force by a dual mechanism of modulation of neuronal firing rate and neuronal recruitment.

Evarts presented these early results at a meeting jointly sponsored by the Parkinson’s Disease Foundation and the National Institutes of Health (1967), where they aroused considerable interest. He obtained even more exciting results when he addressed questions about the roles of other parts of the brain in motor and mental activities that had not been answerable hitherto by less direct approaches. As for his aspirations regarding the ultimate goal of understanding the physical basis of mental activity, he agreed with Roger Sperry, who held that one must understand movement before one can understand the mind behind it. According to Sperry, (as quoted by Evarts):

> An analysis of our current thinking will show that it tends to suffer generally from a failure to view mental activities on their proper relation, or even any relation, to motor behavior . . . We conclude that the unknown cerebral events in psychic experience must necessarily involve excitation patterns so designed that they intermesh in intimate fashion with the motor and premotor patterns. Once this relationship is recognized as a necessary feature of the neural correlates of psychic experience, we can automatically exclude numerous forms of brain code which otherwise might seem reasonable but which fail to meet this criterion.

As to a method for pursuing this goal, Evarts credited C.S. Sher rington for having recognized the need for recording brain cell activity during the actual performance of behavioral tasks that critically identify dissociate and control the pertinent motor and mental variables. Evarts (1967) wrote:

> Sherrington had written that the problem of whether the discharges of motor cortex neurons represents a step toward psychical integration or, on the other hand, expresses the motor result of psychical integration or are participant in both is a question of the highest interest, but one which does not seem as yet to admit of satisfactory answer . . . [but] by combining methods of comparative psychology . . . with the methods of experimental physiology, investigation may be expected ere long to furnish new data of importance toward the knowledge of movement as an outcome of the working of the brain.

Here then was a plan for future experiments laid out for all to see, in that open manner so very characteristic of Evarts. In his own laboratory his students began to study the neural timing and coding of eye movements and of cerebellar, basal ganglia, red nucleus, and premotor cortical neural control of limb movements. Evarts took little or no direct credit for his students' achievements. He did not put his name on papers reporting the results of projects carried out by his junior colleagues, although Evarts's contributions to them were obvious. Their studies followed questions and strategies that he had pursued himself in his work on the motor cortex and had prescribed for other areas in his seminal 1967 article. Inspired by the sense of independence that Evarts had nurtured and the skills that he had taught, students left him to set up their own laboratories. Evarts unstintingly helped this process with ideas for projects, plans for building equipment, computer programs for data analysis, and hardware for making their startups possible and successful. Soon his students' laboratories began to make significant contributions, and their productivity testified to the generosity and genius of their mentor. Other laboratories in the NIH and its vicinity quickly adopted Evarts's methodologies, if only to adapt and modify them further to meet their individual needs, all with his enthusiastic help. Eventually, more distant laboratories in the United States, Europe, Asia, and Australia began to study sensation, movement, motivation, attention, and their integration and adaptation by means of the methods Evarts had pioneered. Their common goal was the direct observation of neural signals as they are correlated with and, by inference, generate overt behavior. The fruits of this endeavor reflected Evarts's energy and generosity that had made it possible to create a new field of scientific endeavor within a decade

Perhaps Evarts's most important contribution was the elucidation of the phenomena termed "psychomotor set" and "transcortical reflex" (1973, 1976). In the former the word "set" refers to the state of psychological preparedness for a motor action in response to an anticipated stimulus. As established by Evarts, the psychomotor set is manifested in the temporal correlation of single unit activity in the motor cortex with the preparation of an animal (and therefore with its intent) to carry out a trained movement and its subsequent implementation. In the latter term the word “transcortical” implies a motor reflex arc in which the stimulus is provided by neurons in cortical areas outside the motor cortex and the responding motor neurons are located in the motor cortex.

Evarts’s experimental paradigm was to train a monkey to make a particular movement by contracting a particular muscle in response to two successive signals. The first, or set, signal is an instruction to implement the movement by contracting the particular muscle as quickly as possible after a second, or “go,” signal. (The go signal was a brief passive stretching of the same muscle). Evarts observed a sustained increase in firing rate in motor cortex neurons that began soon after the occurrence of the set signal and lasted for many seconds while the animal expectantly awaited the go signal (i.e., had the intent to implement the movement for which it had been trained). When the muscle to be contracted was passively stretched by the go signal, a burst of EMG activity occurred with a 12- to 25-ms delay, followed by a brief twitch contraction that was insufficient to accomplish the instructed move. Evarts reasoned that it was the spinal stretch reflex arc leading from the muscle spindle stretch receptor to the spinal cord motoneuron that evoked this twitch. However, 20 ms or so after the go signal’s passive muscle stretch, motor cortex neurons underwent a burst of activity. After another 10-20 ms, the motor cortex activity burst was followed by a second burst of EMG activity in the muscle that, in turn, was followed by a second contraction. That second contraction differed from the first in that it was sufficiently prolonged to implement the instructed movement.

Evarts inferred that the instruction (i.e., the set-related activity burst of motor cortex neurons) must have been set off by cerebral neurons outside the motor cortex that are involved in the expectancy of and planning for implementation of the movement. That set-related activity burst must be used, in turn, to gate the motor cortex for its response to the go signal to implement the trained movement. Without the set signal and its gating of the motor cortex the go signal could not have excited the motor cortex neurons enough to reach the threshold for command of a muscle contraction. This phenomenon thus constituted what Evarts referred to as a transcortical reflex.

Evarts acknowledged the predictions of other workers regarding the presence of neuronal activity representing transcortical gating signals in psychomotor set. But it was his direct observation of these phenomena at a single unit level that connected them and provided important clues about psychomotor mechanisms. Because of the novelty and the importance of Evarts's discovery, his findings and claims gave rise to controversy; however, they were soon confirmed by the independent work of others and a decade later were crucially extended by Cheney and Fetz (1984). Evarts lived to see the controversy definitively resolved in his favor.

In his book *Neurophysiological Approaches of Higher Brain Functions* written jointly with Shinoda and Wise (1984), Evarts summarized the advances in understanding of set and attention made possible through single unit recording in awake behaving trained animals. In his characteristically open manner he laid out plans for future experiments that he (and others) would use to study the mechanisms of synthesis and use of set and attention signals in brain cell activity. Some experimenters applied Evarts's method of single unit recording in trained monkeys to locate the cortical areas giving rise to set signals and to characterize the nature of their timing and coding. But many more investigators still used the older methods of controlled electrical stimulation, combined with extra- and intracellular recording to reveal the nature of the interaction between the set and go signals that result in the triggering of a motor response. Evarts supposed that gating for the go signal most probably occurred in a vertical column of cells of the motor cortex. According to him, set signals from supplementary motor, premotor, and ultimately from the prefrontal cortex impinge on these cells, while the go signal reaches them from the dentate nucleus of the cerebellum. Before long, both of these suppositions would be shown to be correct by many other workers. Another of Evarts's suppositions was that the cerebellar go signals would set off activity of motor cortex neurons if, and only if, the motor cortex was primed by set signals. He predicted, moreover, that other cortical areas would be found where convergent inputs to the cortex would perform similar gating and trigger functions. Indeed, he concluded that such a gating process is likely to provide a general basis for linking an appropriate motor response to an adequate stimulus. Evarts's book was his last will and testament. His death prematurely stopped his own skilled hand, but he left a legacy of ideas, plans, methods, students, and competitors that guaranteed the continued pursuit of his long-range goals.

Throughout his life, Evarts found the energy and made time for many activities outside the laboratory to serve the cause of the neural sciences. In addition to his membership in the National Academy of Sciences, he belonged to the American Physiological Society, the International Brain Organization, the Neurosciences Research Program, and the Society for Neuroscience. He served on the editorial boards of nine journals and was the editor in chief of the *Journal of Neurophysiology*. His many honors included the Karl S. Lashley Award of the American Philosophical Society.

Persons who knew Edward Evarts remember him as a tall, spare, and fastidious man with blue eyes that never wavered, with a deep, rich voice that was quiet, reasonable, and gently persuasive, and with an open manner that was usually friendly and smiling (but could also be quite otherwise). For Evarts, science was deeply personal. He relied on experience and introspection to put him in touch with the abstract. He related his work on the neurophysiology of sleep to his own sleep, wondering about the relation between dreams, rapid eye movement sleep, and somatic exercise and repair functions. His own mental and physical exercise became a setting for his work on movement control. He organized a study group that met three or four times a year and included his own students, as well as senior neurobiologists from other institutions, such as Eric Kandel and Alden Spencer. The group was dedicated to trying to solve such problems as the linkage between stimulus and a response; the temporal programming of multi-jointed movements; how the spatial guidance of movements is guided in space; and the mechanisms that underlie the learning of motor routines.

Evarts's life was thoroughly integrated; every component seemed grist for his work. Perhaps the most ironic parallel was his study of mental set as a preface to action—a paradigm and parable of his own determination. He tried hard and worked hard, and he encouraged in others the perfection that he demanded of himself. He was always the first one to arrive in the laboratory in the morning, and he insisted that others arrive on time, a practice that he once tried to enforce by having his younger colleagues sign in with a time clock. He would not tolerate idleness, dishonesty, or second-rate work in his associates. He would dismiss a person he thought was not suited to a job that he controlled, even if that person was a friend. He was as hard on himself as he was on others.

Edward's joy of life was unforgettable. His laugh was always the loudest in the room. It was infectious. If he laughed everyone laughed with him. He was a thinking man, and he found amusement in human foibles and even in genuine villains. He usually saw the humorous side of things, even when he was the victim, which was often enough. He lost some of his battles, but accepted defeat with stoic humor, making the best of it and living gracefully with his adversaries. He could make his point with tact, without giving offense.

To the many for whom Edward Evarts was a friend, he gave insightful and wise advice and unstinting help. Ever generous, he was a loyal friend.

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