

Kornhuber H H & Deecke L. Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale (Changes in brain potentials with willful and passive movements in humans: the readiness potential and reafferent potentials). *Pflügers Arch.* 284:1-17, 1965. [Neurologische Klinik, Abteilung für Neurophysiologie, Universität Freiburg, Freiburg im Breisgau, Federal Republic of Germany]

A method for recording brain electrical activity prior to voluntary movement in man by noninvasive means and fundamental results obtained with this method were described. A slow negative electrical cortical potential was discovered preceding human voluntary movement, termed the *Bereitschaftspotential* (BP) or readiness potential. The BP is the electrophysiological sign of planning, preparation, and initiation of volitional acts. [The *SCJ*® indicates that this paper has been cited in over 290 publications.]

Readiness for Movement— The *Bereitschaftspotential* Story

Hans Helmut Kornhuber
Abteilung Neurologie
Universität Ulm
D-7900 Ulm
Federal Republic of Germany
and
Lüder Deecke
Neurologische Klinik
Universität Wien
A-1090 Vienna
Austria

August 29, 1989

On a sunny Saturday in the spring of 1964, H.H. Kornhuber (then chief physician at Richard Jung's Neurological Clinic at Freiburg) and L. Deecke (his doctoral student) went for lunch to the "Gasthaus zum Schwanen" on the foot of the Schlossberg hill in Freiburg. Sitting alone in the beautiful garden, we discussed our frustration with the passive brain research prevailing worldwide and our desire to investigate self-initiated action of the brain and the will. Consequently, we decided to look for cerebral potentials in man related to volitional acts and to take voluntary movement as our research paradigm.

We planned to store the electroencephalogram and the electromyogram of the movement on tape and to analyse the movement-related cerebral potentials time-reversed with the start of the movement

as the trigger. We did the experiment right away by literally turning the tape over for analysis, since we had no reverse playback or programmable computer. A potential preceding human voluntary movement was discovered and was published in the same year, introducing the term *Bereitschaftspotential* (BP, readiness potential).¹ After detailed investigation, the *Citation Classic* was published in 1965.

The German term *Bereitschaftspotential* made its way into the English terminology as well (recently, there was a humorous spelling debate about "Dr. Bereitschaft").^{2,3} When in the summer of 1964 Hans Lukas Teuber visited the Freiburg clinic, he took the information back to H.G. Vaughan in New York, who subsequently confirmed the results.⁴

The response of the scientific community is best reflected by Sir John Eccles's comment: "There is a delightful parallel between these impressively simple experiments and the experiments of Galileo Galilei, who investigated the laws of motion of the universe with metal balls on an inclined plain."⁵ For some of the several potentials that were found upon closer consideration (pre-motion positivity, motor potential, and so on), it took years until they were confirmed by other laboratories.⁶ Certain potentials that actually came from muscles were mistaken as cerebral potentials by some investigators.

The physical signs of cerebral processes related to human volition opened new fields of research and theory into volition,⁷⁻⁹ frontal lobe physiology,⁹ learning,¹⁰ attention,⁹ and the movement-related EEG frequency changes in health and diseases such as schizophrenia.¹¹ Even human freedom came within reach of scientific investigation.^{6,9}

We believe that the paper is frequently cited for the following reasons: First, because it offered the new technique of time-reversed averaging. Second, because it made clear that cerebral preparation for voluntary action starts as early as one to two seconds prior to movement onset and is bilateral. Third, in the later course of our research, we suggested on the basis of BP recordings in Parkinson patients that the supplementary motor area must have a priming role in the preparation and initiation of voluntary movement.⁷ For the work the Berger Prize of the German EEG Society has been given to HHK, the Science Prize of the City of Ulm to both of us, and the Dr. Honoris Causa (Brussels) to HHK.

1. Kornhuber H H & Deecke L. Hirnpotentialänderungen beim Menschen vor und nach Willkürbewegungen, dargestellt mit Magnetbandspeicherung und Rückwärtsanalyse (Changes in human brain potential before and after voluntary movement studied by recording on magnetic tape and reverse analysis). *Pflügers Arch.—Eur. J. Physiol.* 281:52, 1964. (Cited 55 times.)
2. Woodward K G. Dr. Bereitschaft? *Ann. Neurol.* 21:512, 1987.
3. Deecke L. Dr. (in) Bereitschaft. *Ann. Neurol.* 23:103, 1988.
4. Gildea L, Vaughan H G & Costa L D. Summated human electroencephalographic potentials associated with voluntary movements. *Electroencephalogr. Clin. Neuro.* 20:433-8, 1966. (Cited 160 times.)
5. Eccles J C & Zeier H. *Gehirn und Geist (Brain and spirit)*. Zurich, Switzerland: Kindler, 1980. 210 p.
6. Kornhuber H H & Deecke L, eds. Motivation, motor and sensory processes of the brain: electrical potentials, behaviour and clinical use. (Whole issue.) *Prog. Brain Res.* 54, 1980. 811 p.
7. Deecke L & Kornhuber H H. An electrical sign of participation of the mesial "supplementary" motor cortex in human voluntary finger movements. *Brain Res.* 159:473-6, 1978. (Cited 55 times.)
8. Heckhausen H, Gollwitzer P H & Welmert F E, eds. *Jenseits des Rubikon: der Wille in den Humanwissenschaften (Beyond the Rubicon: the will in human intelligence)*. Berlin, FRG: Springer-Verlag, 1987. 420 p.
9. Kornhuber H H. Attention, readiness for action and the stages of voluntary decision—some electrophysiological correlates in man. *Exp. Brain Res. Suppl.* 9:420-9, 1984. (Cited 10 times.)
10. Lang W, Lang M, Kornhuber A, Deecke L & Kornhuber H H. Human cerebral potentials and visuomotor learning. *Pflügers Arch.—Eur. J. Physiol.* 399:342-4, 1983. (Cited 15 times.)
11. Diekmann V, Reinke W, Grözinger B, Westphal K P & Kornhuber H H. Diminished order in the EEG of schizophrenic patients. *Naturwissenschaften* 72:541-2, 1985.

1A 74