EEG TECHNOLOGY

SECOND EDITION

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Second Edition

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Foreword

Thirty years ago taking an EEG was fun. In fact, one didn't 'take' an EEG, one struggled to wrest some sort of record from a home-made rig of noisy valves, leaky batteries, fragile oscilloscopes, and bulky cameras; the chance of everything working properly at the same time was small and it was all very strenuous, often exasperating, but always fun.

I hope this book will help the young people who read it to enjoy their work as much as we did long ago. We were—and still are—amateurs in the literal sense; you, the reader, will be an expert, as are the writers of this book, but expertise and professionalism need not deprive you of the excitement and satisfaction of helping people to understand people. You are very fortunate to have here so much experience and practical advice, presented by scientists who have learned the hard way, who know what really matters in this art or technology, and who are themselves still excited and dedicated —if that is not too solemn a word for people who have collaborated so cheerfully.

There are some things you should keep in the back of your mind while you read and study these pages. First, the object and purpose of it all—to learn more about people. In effect, a person's brain is the person, in sickness or in health. We know now that one can replace hearts, livers, kidneys, endocrine secretions, attach artificial limbs, hearing aids, spectacles; but all these are accessories to the brain and your job is to push our understanding of people's brains just a little further. You may be working in a 'routine' department, but no one should think of an EEG study as a routine, except in so far as the procedure may be systematic. No two brains are exactly the same, even in 'identical' twins, and very slight differences or anomalies may be of enormous help to a clinician or in a research. This leads to the second point to be remembered—by the time you

read this, much of the book will be out of date. It must and should be so, partly through the efforts of the authors themselves, who are trying all the time to make it easier to detect and measure the 'slight differences' mentioned above.

In Chapters 1 to 6 you will find that most of the information and advice fits in with what you can see for yourself any day in a 'routine' department; these are essential for your basic training. But the last two chapters embody the shape of things to come; if you are really concerned with what you are doing you will read them carefully, ask questions about them of all your colleagues and superiors, and ask, too: Why aren't we doing this? Why haven't we got a computer? C mputer is a magic word (although sometimes also a dirty word); even the simplest EEG machine is a computer, transforming electrical events into graphs, but what we mean by computer is an extension, an almost miraculous extension, of your power to penetrate the secrets of the brain. The scene is only just set, the play is still to come and you will have important parts to play. Perhaps you feel that today you are only an extra, an understudy for the lead, but if you are really engaged and feel the thrill of discovery, you will be able to participate in one of the most exciting phases of the human drama, for which this book can be your stage directions.

W. GREY WALTER

Preface to the Second Edition

In this second edition we have made many small changes and a few large ones. All have been dictated by the need to correct errors of omission and expression, to update the contents and, in some instances, to expand the discussion.

Apart from some additions to Chapter 1 and reorganization of Chapter 2 the first three chapters are much the same as in the first edition.

Chapter 4 has been modified considerably to take into account the changing pattern of the design of EEG machines. Solid state amplifiers are now always used and their construction is on a modular basis. It is no longer economic for the technician to spend time on detailed fault finding, most faults being rectified by module replacement. In this respect we think it essential that manufacturers should give an efficient after sales service, a facility which would certainly influence the choice of machine.

Chapters 5 and 6 have been revised and expanded, the latter to include more detailed information on the factual description of EEG records.

Chapters 7 and 8 have been extensively revised and enlarged and include many additional references. This is mainly because of major advances in signal analysis procedures. In the past five years, the availability of general and special purpose digital computers has made the most sophisticated methods of analysis possible in a number of EEG laboratories. However, we must emphasize that advanced methods of analysis are of little value unless the basic techniques of collecting the EEG data described in Chapters 2–6 are rigorously applied. The role of the technician, instead of decreasing with the advent of automatic methods of analysis, is becoming increasingly important. He or she may be the only person who is in contact with the patient when the data are collected and

able to say whether an elaborate computer analysis is being performed on genuine EEG activity or on artefacts.

We would like to thank those who reviewed the first edition constructively; the Department of Photography, University of Newcastle upon Tyne for many new illustrations; our secretaries, Freda Darby, Anne Ferguson, and Marianne Mason, for their devotion to manuscripts; and our wives for their forbearance of their rivals—those fascinating signals generated by the brain.

R. COOPER
J. W. OSSELTON
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Preface to the First Edition

The practice of clinical electroencephalography is but slowly evolving from an art to a science. Our hope is that this book may do something to accelerate the process by bridging the gap between an understanding of basic physics, chemistry and physiology, and the use of modern equipment and techniques. It has been written not only for EEG technicians but for all those who endeavour to treat the subject in an objective way. We hope that it may explode a few myths without creating too many of its own.

Each chapter was originally written by a single author, but the final version of the text is the product of half a dozen long weekends in which every sentence was jointly considered, every diagram jointly scrutinized. For encouragement and understanding of our great preoccupation on these occasions we are indebted to our respective chiefs: Dr. W. Grey Walter, Professor Martin Roth and Dr. Peter Sainsbury, the first of whom has generously written a Foreword.

It is a pleasure to acknowledge our gratitude for secretarial assistance to Freda Cole, Elizabeth Terry, Nadine Troughton and Elizabeth Wood, and to the staff of the Department of Photography, University of Newcastle upon Tyne, who prepared the majority of the illustrations.

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Origins of the Electroencephalogram

1.1. HISTORICAL INTRODUCTION

In 1875 Richard Caton, a British physiologist, reported that: 'Feeble currents of varying direction pass through the multiplier when electrodes are placed on two points of the external surface [of the brain], or one electrode on the grey matter, and one on the surface of the skull.' Caton was investigating the electrical activity of the brains of cats, monkeys and rabbits using non-polarizable cortical electrodes connected to a galvanometer with optical magnification.

In the years that followed, several workers, some not knowing of Caton's observations, investigated the electroencephalogram (EEG) of animals and showed changes of spontaneous activity and evoked responses to external stimuli. Considering the equipment available and the knowledge of electricity at that time, the experiments performed were of the highest order and can still be studied with profit. Caton, in 1887, worked with unanaesthetized unrestrained animals with light insulated wires, suspended from an overhead support, connecting the electrodes to the galvanometer. In 1890 Beck, in Poland, used non-polarizable electrodes and backed off the standing potentials with a Daniel cell and rheostat in one side of the galvanometer—no a.c. coupling here! In 1876 Danilevskey, in Kharkov, showed a change of the standing potential of the cortex in response to acoustic stimuli. The development in the 1930s of valve amplifiers with a.c. coupling undoubtedly impeded further study of the changes in steady potentials which the earlier workers had investigated so successfully. Only recently has this interesting aspect of the electrical activity of the brain been re-investigated.

In 1914 Cybulski recorded an epileptic seizure caused by cortical stimulation in a dog. Kaufmann, doing similar experiments in 1910,

commented on the great difficulty he had in maintaining electrode contact during the seizure—a not uncommon complaint today! For a full account of these early experiments and scientists the reader is referred to Brazier (1961).

All the early work was done on animals and it was not until 1929 that Hans Berger published the first report of the electroencephalogram of man. Berger, a psychiatrist, working almost in isolation in Jena, had been investigating the EEG for a number of years. He used many different types of electrodes driving string or double coil galvanometers. One of the main reasons for his success, apart from his almost obsessive tenacity, was his working relationship with the neurosurgeons who provided him with patients in whom pieces of skull had been removed. This enabled him to get zinc plated needle electrodes into the epidural tissue very close to the surface of cortex. Although Berger published his first observations in 1929 with one or more papers in each subsequent year until 1938, many of them were ignored until Adrian and Matthews repeated the scalp investigations and published in 1934. Berger's fourteen reports, with one correction in 1937 in which he reports an error due to 50 Hz mains interference, have been beautifully translated from the German by Gloor (1969). These show the depth of Berger's work in which polygraphic recordings and evoked responses were studied in 1930, the relative merits of unipolar and bipolar recordings discussed in 1935 and frequency analysis described in 1936!

In much of the early work photography was used to record the deflections of the galvanometer light beam, but this was expensive; many workers had to read off the scale at regular intervals, and then plot the activity. In the 1930s, when the galvanometer was replaced by valve amplifiers with a.c. coupling, the activity was displayed on cathode-ray oscilloscopes and photographed. Pen writers were available in the 1940s and made it possible to have an immediate permanent record. The other great technical advance at this time was the use of the differential amplifier which eliminated much of the interference from external sources (Parr and Walter, 1943).

Since 1940 there has been little change of basic technique; most of the technical effort has been devoted to the construction of reliable multichannel recorders. A return to d.c. recording was achieved in the 1950s using transistor chopper amplifiers, but electrodes still presented a serious limitation to the stability that could be attained. This problem remains with us today (Chapter 2).

1.2. PHYSICAL STRUCTURE OF THE BRAIN

1.2.1. Gross anatomy

The brain consists of two hemispheres, the cerebellum and brainstem. The two hemispheres are separated by the longitudinal fissure across which there is a large connective band of fibres called the corpus callosum. The brainstem is a complex agglomeration of structures including the midbrain, pons medulla and reticular formation. Between the midbrain and cerebral hemispheres is the thalamus which is composed of groups of cells known as nuclei.

The outer surfaces of the cerebral hemispheres are composed of nerve cells (neurones) and form the cerebral cortex. These surfaces are highly convoluted and are separated into regions by a number of fissures (sulci) the largest of which are the Rolandic and Sylvian (*Figure 1.1*). This complex indentation increases the surface area

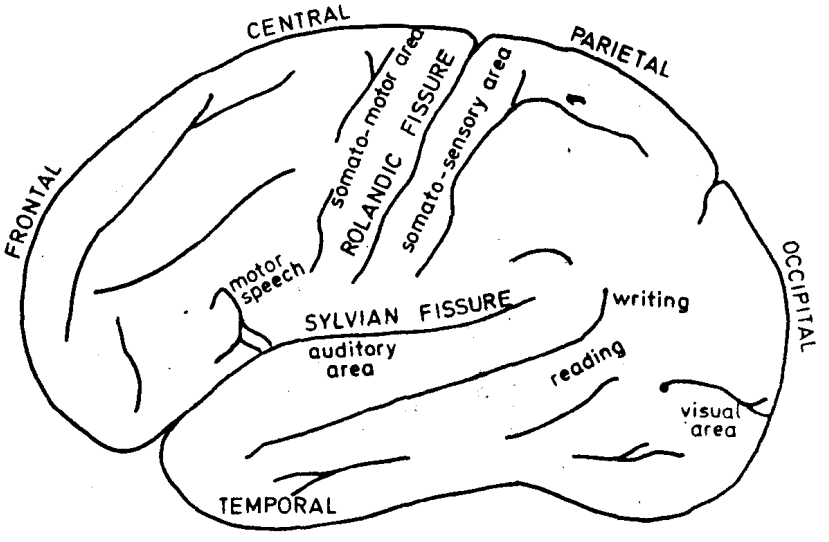

Figure 1.1. Lateral view of major areas of the brain

(and thus the number of neurones) to more than twice that of a smooth sphere of the same size. Beneath the cortex nerve fibres lead to the other parts of the brain and body. Parts of the cortex are concerned with particular functions, for example the occipital region deals with visual information, whilst auditory information is processed in the temporal lobe. Some of these regions are shown in *Figure 1.1.* Because of the colour, the regions composed of neurones,

which includes the cerebral cortex, is known as grey matter; fibrous tissue is called white matter.

1.2.2. Physical structure of tissue

Microscopic examination of brain sections yields information only if the tissue is stained with a dye or with silver. The cerebral cortex then appears as an intricate network of fibres and neurones (*Plate I*). The white matter is seen to be composed of fibres, each wrapped in an insulating sheath of myelin. Electron-microscopic photographs show that the fibres and neurones are separated by a vast system of glial cells which outnumber the neurones by a factor of 10. All these methods of examination reveal only the physical positions of the fibres, neurones and glia, and not their functional relationships.

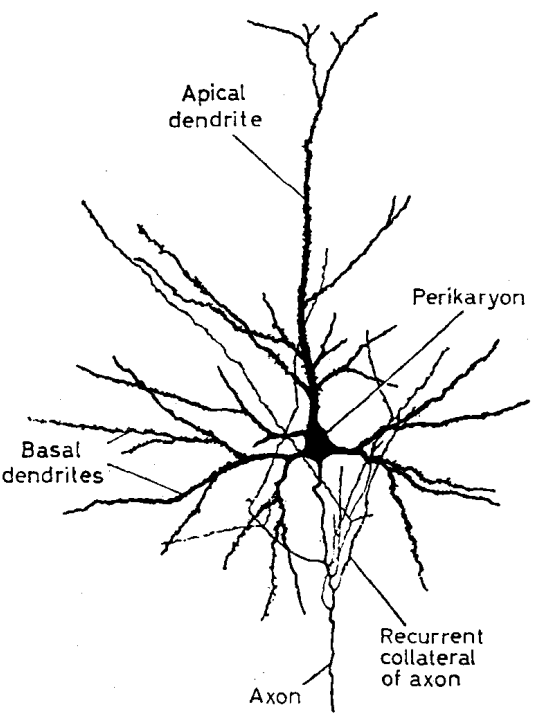

Figure 1.2. Drawing of a pyramidal neurone from the cortex of a cat (composed from 3 photographs) (reproduced from Organization of the Cerebral Cortex by D. A. Sholl by courtesy of Methuen)

The average thickness of cortex in man is 2·5 mm, the cortical area is about 2,300 cm^2 and the neuronal density about 10 neurones/ 0·001 mm^3 (Sholl, 1956). The total number of neurones is about 6×10^9. Although there are several types of neurone, the basic structure is similar to that shown in *Figure 1.2*. The branch-like

dendrites can spread through a considerable volume of cortex. Many neurones are within the dendrites of a single neurone and the number of possible interactions is astronomical.

The dendritic structure of a newly-born baby is very sparse but there is rapid growth in the first months of life and this probably accounts for the change of EEG pattern during this period. The ultimate richness and complexity of dendritic connections depend upon the environmental complexity in which an animal—and presumably also a child—is reared. Isolation results in less branching of dendrites than when the animal has been trained in a complex environment (Rosenzweig and colleagues, 1962; Holloway, 1966).

1.3. ELECTRICAL ACTIVITY OF THE BRAIN

1.3.1. Introduction

Signals from the sense organs to the brain are transmitted along nerve fibres as series of pulses whose pulse recurrence frequency is dependent upon the amplitude of the external stimulus. As these nerve fibres from the receptor organs enter the cerebral cortex there can be profuse branching, so that the incoming pulses are spread over an appreciable area of cortex. The branched fibres do not connect directly into the neurones but terminate on cell bodies and dendrites by means of small swellings called synaptic knobs. The pulses are transmitted from the fibres across the synaptic membranes into the cell structure. Because of the profuse branching, impulses being transmitted along a single primary nerve fibre will act at varying degrees of intensity on many nerve cells, and it has been estimated that as many as 5,000 can be influenced by a primary fibre. Each neurone has many synaptic knobs and can receive impulses from many fibres (*Figure 1.3*, from Glees, Hasan and Tischner, 1966).

1.3.2. Resting membrane potential

Both neurones and nerve fibres are composed mainly of fluid contained within very thin membranes. In nerve fibres the membrane is continuous along the whole length and can be covered with an insulating layer of myelin which terminates as the fibre enters the cell body. The membranes are highly organized bimolecular lipoprotein layers which severely restrict the interchange of materials such as ions (electrical charges) between the inside and outside of the cells. The ionic restriction results in the establishment of a