BIOLOGICAL RHYTHM RESEARCH

By A. SOLLBERGER

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Metabolic Ward, Highland View Hospital, Cleveland, Ohio (U.S.A.)
Secretary of the Society for Biological Rhythm

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FOREWORD

Rhythmic phenomena in the animated world early claimed the attention of the naturalists. One needs only recall LINNEAUS' famous flower clock, which was founded on the fact that the flowers of various plants close and open at different times of the day but each so regularly that one could set a clock by them. A further phenomenon which demanded attention was the sleep movements of the leaves of many plants. Such periodic plant behaviour was studied in detail by, for instance, ROSE STOPPEL. Its exogeneity or endogeneity long remained a matter of dispute. However, it was gradually realized that the 24-hour periodism is in no way restricted to the plants, but occurs in all living beings. Rhythms of the body temperature in man were discovered by JÜRGENSEN, 15 years after the introduction of thermometry by WUNDERLICH. In 1927 FORSGREN discovered the periodic alternating storage of glycogen and bile in the liver, thereby opening up a wide field of 24-hour-periodic phenomena to investigation. Thus a new branch of science unfolded, biological rhythm research, which slowly acquired manifold interconnections with the other biological sciences, including medicine. In 1937 seven scientists—five physicians, one botanist and one zoologist—founded an international society for the study of biological rhythms. Since then this new and interesting scientific discipline has spread all over the world. As is so typical of our time, the accumulated wealth of observations and experiments is well-nigh impossible for the single scientist to grasp.

Dr. SOLLBERGER, for many years the secretary of the mentioned society and also intimately connected with rhythm research through his own investigations, has in this work endeavoured to present a comprehensive review covering the whole field. In this presentation the various problems of biological rhythm research are examined. Much space is devoted to the theoretical background of this science. Data gathering techniques and especially the mathematical treatment of the material, the dependency of the rhythms on internal factors and on external conditions, as related to the time of day, lunation and seasons, and finally the most important findings in botany, zoology and medicine; all these aspects are explored. Thus a work has been created which both introduces this new domain and through its comprehensive presentation facilitates an orientation within it, not only to the specialist but also to much wider circles in science. Dr. SOLLBERGER has certainly earned our gratitude for all his laborious, scrupulous and diligent work on this book.

A. JORES

PREFACE

Undoubtedly, the reader has come across many manifestations of biological rhythms. The latter represent functions inherent in the living structure and appearing in all its expressions, also being most sensitive to shifts in the physical environment. This makes biological rhythm research an interdisciplinary science. It äts well into the space age, discussing – as it does – cosmic influences. Lately, cybernetics and computers have widened the future scope.

Nevertheless, biological rhythm research is a young science. Though the endeavours of the last 30 years have produced a wealth of data, yet we know little about the origin and mechanism of biological rhythms. There are thus many problems to challenge the young and the unprejudiced scientific mind. We have, for instance, to apply the knowledge of rhythms in medical diagnosis and therapy. We must also identify the environmental synchronizing agents and their action on the body, which involves the question of how to isolate a specimen perfectly from external influences.

One aspect is the analysis and comparison of simultaneously recorded physical and biological rhythms. This requires complicated statistical computations, that are, unfortunately, somewhat uncertain. There exist few well-established methods of time series analysis. A large literature is founded on the theory of stationary time series; rhythms are, however, eminently non-stationary. New methods of analysis have to be found. Once, when explaining this state of affairs to an inveterate antirhythmologist, I was informed that one should not work in a field where nothing can be proved. This is a kind of wisdom, however, which could never add anything to human knowledge.

This book purports not only to offer comprehensive information on biological rhythm research, but also to provide a basic understanding of future problems. It opens with a short introductory orientation of the whole field (Chapter 1).

The bulk of the book is divided into four parts. Part I discusses the spontaneous oscillators, leaning on cybernetic concepts (Chapters 2-4). This leads up to the biological counterpart, the endogenous rhythm or 'biological clock', and the problem of the time sense (Chapters 5-7). A few special subjects are added here (Chapters 8-11), *viz.* chronopathology, developmental rhythms, population cycles and basimetry.

Part II deals with such rhythmic phenomena in the environment as may control the biological rhythms, and with their possible pathways of action (Chapters 12-17), including the concepts of photoperiodism and thermoperiodism. This leads to a discussion of animal navigation (Chapter 18).

The natural sequel to the first two parts would be a presentation of the exogenous rhythms, that is, the synchronized endogenous rhythms. However, any

serious discussion of biological control demands some knowledge about the mathematics and physics of periodic phenomena. Part III introduces this subject. Chapter 19 presents several rhythm models in addition to those given in Chapter 4. Chapters 20 and 21 outline the statistical analysis of time series. Chapter 22, finally, is intended to present the mathematical background for the handling of rhythms.

Part Three thus deals with problems of rapidly growing importance in biological rhythm research. Especially, the mathematical presentation is wide, including the essentials of differential equations, phase planes, complex variables and transform functions. The emphasis is not on mathematical stringency or teaching but on an attempt to develop a general understanding of the subject.

Being thus acquainted with the components of a biological rhythm system (Parts I and II), we may now try to couple them together, using the instructions in Part III. Thus we arrive at the exogenous rhythms, Part IV. Chapter 23 resumes the theoretical considerations of the previous chapter, as applied to the control of vitrating systems, also emphasizing the energy aspect of rhythmic processes. Chapter 24 discusses the actual control of biological rhythms. The remaining Chapters 25-27 survey the exogenous rhythms with regard to the different periods of duration (*e.g.* 24-hour, lunar and seasonal rhythms), and to the fields of study (botany, zoology, physiology and medicine).

I have strived to make each section in the book a complete whole, rather repeating a line of thought than breaking the continuity with cross references. To facilitate orientation, a paragraph numbering system is used. The numbers, appear on top of the pages, but also in the figures and formulae, linking text and illustrations together. The subject index indicates the paragraph in which the item appears.

The references are extensive, though the field is now so enormous and the papers so scattered that it is impossible to make a comprehensive list. I have also had to lean upon the literature compilations of other authors and want to express my gratitude in this respect to all anonymous contributors.

The numbering system of the references aims at brevity and adjustability. Though new, it is almost foolproof. The author's name is found in the alphabetically arranged reference list, whereupon the number (showing in the left margin) jumps to attention. The numbering is renewed for each new name. If there are several authors with the same name, they are distinguished by the range of numbers. 0-199 represents one author, 200-399 another, 400-599 yet another, *etc.* Three-figure numbers starting with 1, 3, 5, etc. indicate the presence of co-authors (equal to the usual notation *et al.*).

In trying to write an integrated presentation of biological rhythm research, I was aware of the wide span of sciences which had to be covered, and which a single investigator cannot really hope to encompass. I beg the reader to endure such inadequacies as may have arisen therefrom. All criticism is welcome. On the other hand, one learns much from the attempt to cover such a pronouncedly interdisciplinary field and there are few things as satisfying as new knowledge. I hope that the reader may feel some of the enthusiasm I experienced.

I started on this book years ago in Sweden, while residing at the Anatomical Department of the Caroline Institute. Most of the work was, however, performed

in Puerto Rico, at the Pharmacological Department of the Medical School. I am indebted to Dr. JOSÉ DEL CASTILLO for the wholehearted support which was offered there in the form of leisure, stimulating criticism and secretarial help, and which made it at all possible for me to finish the book.

Especially, this book would not have been possible without the devoted help and healthy criticism of many friends. A profound gratitude goes to my wife who not only patiently endured all my author's woes and whims for four long years, but also helped with much of the typing and indexing and sat through innumerable evenings of proof-reading. Most of the figures have been prepared with remarkable draftsmanship by Miss MARGARETHA ANDERSON, the rest by Miss JEAN DEBELL, Miss MAJ BERGMAN, Mrs. BARBRO PEREY, Mr. S. PETTERSSON and Mrs. ULLA SÖDERBÄCK. Miss CARMEN CHICO has helped with the indexing and produced several perfect editions of type-scripts. I am also grateful to the publishers for giving me a free hand with the layout and the figures for the book, and for their efforts to produce only the very best in the way of printing.

Many improvements in the book are due to the valuable discussion and advice by Drs. JAMES DICKSON, HUN SUN, RICHARD LEVINS and LAWRENCE STARK. More than anything else, however, I have profited from the discussions with Miss JEAN DEBELL (M.S.), which saved me from innumerable pitfalls in the formulation of my thoughts.

San Juan, September 1964

A. SOLLBERGER
Professor of Pharmacology,
University of Puerto Rico Medical School

CONTENTS

INTRODUCTION

CHAPTER 1

Introduction

1.1– This introduction serves several purposes. It discusses why biological rhythms should exist. It defines their basic properties. It draws a broad outline of the contents of the following chapters. This should help considerably in the study of the present book.

Biological rhythm research is a young though rapidly expanding science which embraces many disciplines: botany, forestry and agriculture; various branches of zoology; veterinary and human medicine; biochemistry, physiology, psychology and pathology; mathematics, statistics, cybernetics and philosophy. It is already difficult for a single student to cover all aspects. Let us, nevertheless, try to build up the concept of biological rhythms from the simplest possible premises, to interrelate the various subfields, and to present the essential problems of today and tomorrow.

1.2 – Living matter displays incessant movement; in space and time. We may call the study of the temporal aspect 'chronobiology'. Indeed, complete cessation of movement means death.

Time is the medium in which biological rhythms revolve, the independent variate in our graphs. Yet, we know almost nothing about it. According to older philosophers time was a measure of movement, in the modern version it reflects the increase in entropy. Maybe it is an entity of its own, maybe serial with time measuring time measuring time. Perhaps, time is vectorially related to space, or included in the concept of events (with dimensions duration – mass).

Rhythms constitute only one type of movement, the periodic fluctuation of values between two limits, regular chronobiological variation.

The existence of rhythmic variation in biology is evident, whatever the reason. Let us start with some simple considerations, as visualized in Fig. 1.2a, alternatives I-III.

1.3 – *The Rhythmic Universe* (*cf.* Fig. 1.2a, alternative I). All living organisms are set into the solid framework of the physical world, the structure of which pulses with an abundance of 'external rhythms': diurnal, tidal, seasonal, solar, sidereal. The capacity to follow them, to oscillate, would certainly enhance the survival potential of a species. Early man and his prey possessed 24-hour activity patterns, the poikilothermic and hibernating animals follow the seasonal changes in temperature, the tiny shore animals march up and down the beach with the tide. The construction of our bodies (randomly, genetically and selectively determined)