# The Ballistocardiogram

## A DYNAMIC RECORD OF THE HEART BEAT

JOHN R. BRAUNSTEIN, M.D., Ph.D.

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## *A Dynamic Record of the Heart Beat*

*By*

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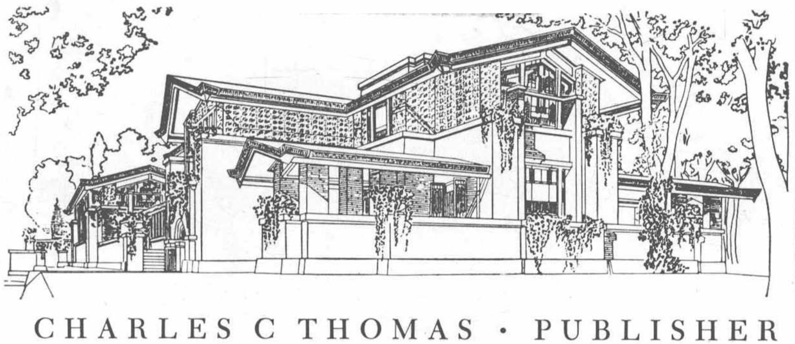

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# PREFACE

THIS MONOGRAPH represents a pair of lectures delivered at the University of Cincinnati in the Spring of 1951. No attempt has been made to cover the field of ballistocardiography in specific fashion, even though it is a small one. As a matter of fact, the time is not yet ripe for even a modest text; for if one were written today, it would be nearly useless by the time of publication. And yet it may not be without point to present, in more comprehensive fashion, a picture of this most challenging and rapid-moving field.

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## ACKNOWLEDGMENT

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J.R.B.

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# The Ballistocardiogram

# I

## INTRODUCTION

IT IS SOMETHING over 10 years since Isaac Starr coined the term *ballistocardiogram,* described a workable instrument to produce the record, and published his first major paper in the newly named field. In the interval, many cardiologists have been frankly skeptical of the tool, others have failed to grasp the physiological implications of the method, some hardy souls have tried to improve the technique; but only a few have been more than transiently attracted to a record whose fascination lies in the fact that in it is locked the secret of the dynamic action of the heart. Quite recently, however, the condition has begun to change. Many more papers are being published, both of a clinical and fundamental nature. Gradually the record is beginning to yield its secrets; and, although the field is now in a state of healthy flux, it may be worthwhile to take a look at its remote and recent ancestors, its present condition, and hazard a guess or two as to the direction it will take in the future.

# II

## HISTORY

When early man first became aware of his heart beat is lost in antiquity, whether or not he had yet woven a basket or baked a pot is unknown, and what biophysicist it was that secretly in the middle of the night applied the law of the conservation of momentum to his own heart action has not transpired, yet it remained for a modern Scot to make the first recording of the forces imparted by the heart to the body. In 1877 in a paper entitled *"On Certain Molar Movements of the Human Body Produced by the Circulation of the Blood,"* J. W. Gordon describes a light bed suspended by ropes from the ceiling. He also describes an earlier record taken from a spring weighing machine which suggests that he made his invention while standing on one of these. A record taken by each of these techniques is shown in Figure 1. Nothing much seems to have come from Gordon's work, and a hiatus exists until 1905 when Yandell Henderson, who was unaware of Gordon's paper, suspended a plank from the ceiling by wires. Side motion of this plank was prevented, and the head to foot motion magnified by a series of levers and recorded on a smoked drum. His recording device is shown in Figure 2, and some of his early records in Figure 3. Henderson suggested that the amplitude of the record was related to cardiac output. Unfortunately, however, his table, which had quite a long period, required cessation of breathing with excellent and simultaneous muscular relaxation in order to obtain a record free of artefact, an athletic feat not easily achieved by the average subject.

In the 30-odd years which intervened between Henderson's paper and the early work of Iscaac Starr numerous records were obtained in a variety of ways by different workers, but in no instance did any show the sustained interest or singleness of purpose required to develop so complex a project. These are reviewed in Starr's early article. Douglas and his group (which included Henderson) used a plank supported on piles of cork during the Pike's Peak expedition to determine whether altitude affected cardiac output. Their observations may be noted in Figure 4 and the instrument employed in Figure 5. In the same year (1913) Thomas Satterthwaite of New York obtained a good record from a patient sitting on a spring weighing machine (Figure 6). Heald and Tucker (1922) devised a platform, on which the patient stood, which was suspended from

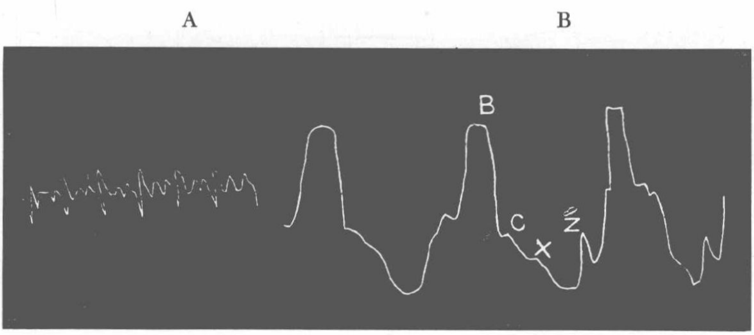


Figure 1. Traces from Gordon's original article published in 1877. These are the first known ballistocardiograms. A. Record from a spring weighing machine. B. Record from the constructed bed. These illustrate the difference between records obtained on a high frequency (A) and those obtained on a low frequency (B) instrument. Journal of Anatomy and Physiology: *11,* 533, 1877.

the diaphragm of a drum. Change in the internal volume of the drum was recorded by changes in the current flowing through a hot wire placed in the inlet. This instrument is illustrated in Figure 7 and the results of an experiment performed on it in Figure 8. A few years later (1928), two German physicists, Angenheister and Lau, obtained

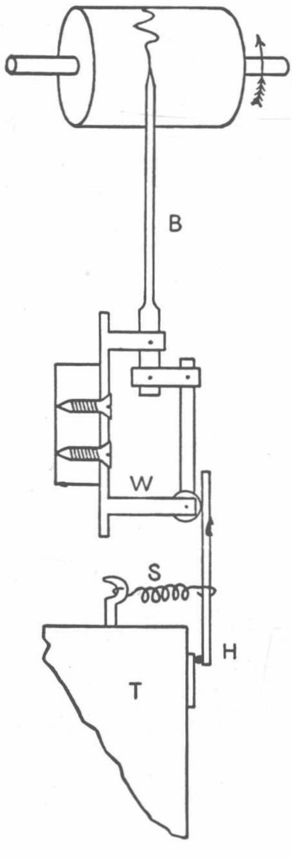


Figure 2. Henderson's recording device as illustrated in his original article. This is an excellent example of the crude type of instrumentation with which so much important physiological work was done in the not too distant past. Courtesy of American Journal of Physiology.

records from a seismograph placed alongside a subject lying on a rigid table (Figures 9 and 10). In 1933 Abramson, a Swedish physiologist, built a chair of aluminum alloy suspended from springs imbedded in a cast steel base on a concrete foundation (Figure 11). This is said to have a natural frequency of 75 cycles per second when loaded with 70 kilograms of mass, an indication of the quality of the engineering employed in its construction. A record is illustrated at both slow paper speeds and fast paper speeds. Abramson, however, soon became ill and

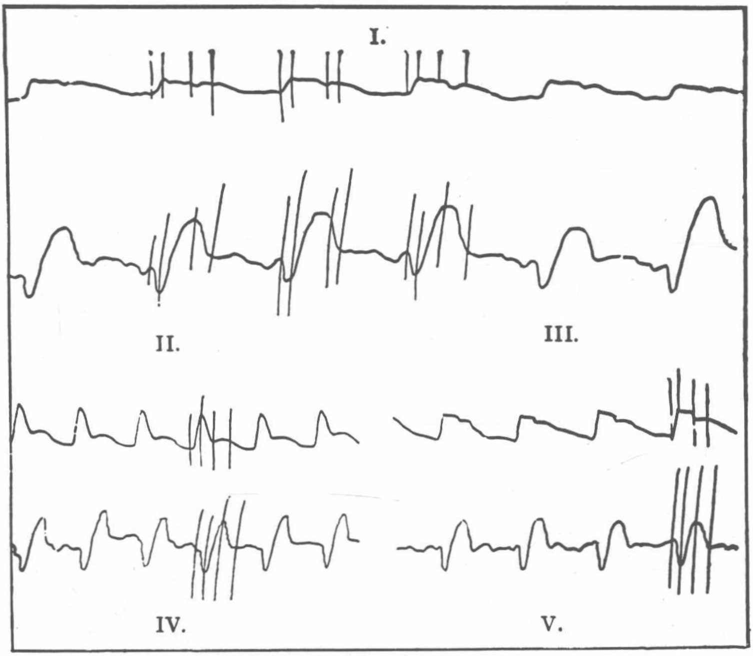


Figure 3. Some of Henderson's original "recoil curves." The upper of each of the paired curves is a pulse tracing. The lower is the "recoil curve." Vertical lines are time markings. Since the table had a long period, the records are not unlike those produced on Gordon's instrument (Figure 1, right-hand tracing). Courtesy of American Journal of Physiology.

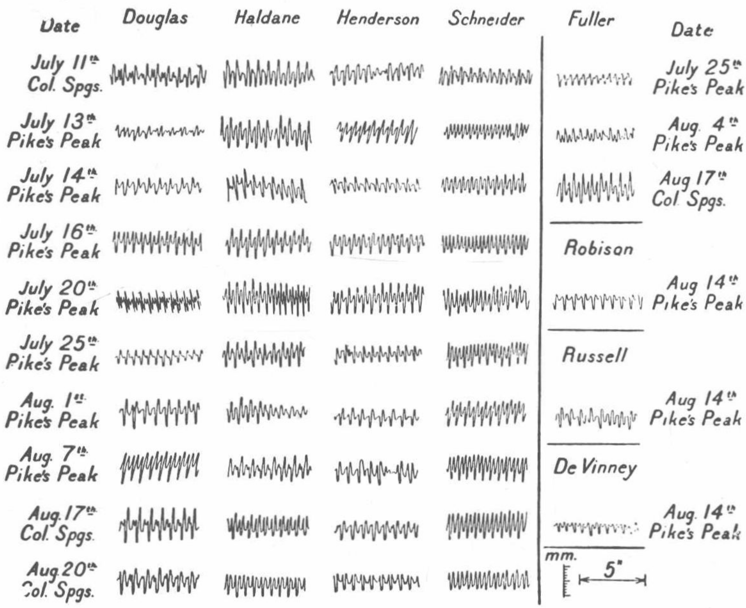


Figure 4. Records taken on the Pike's Peak expedition. Courtesy of The Royal Society.

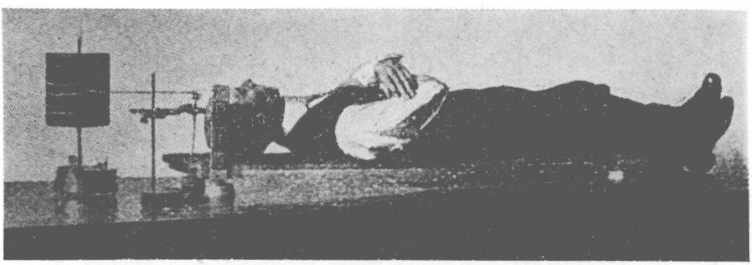

Figure 5. The instrument used on the Pike's Peak Expedition. Courtesy of The Royal Society.

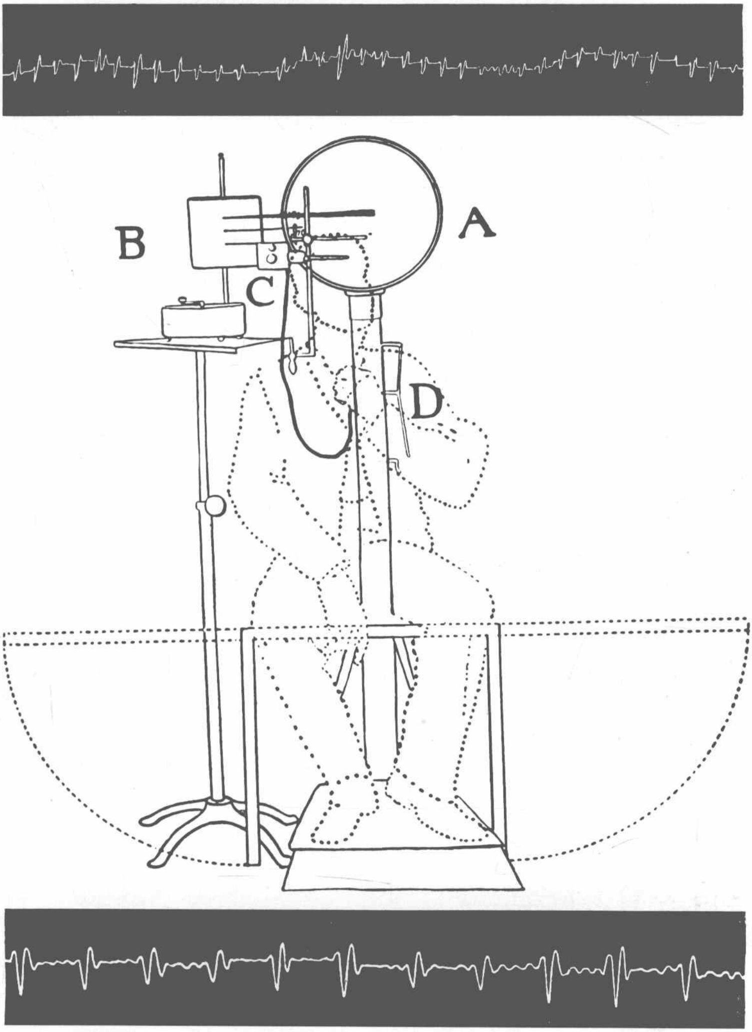


Figure 6. Thomas Satterthwaite of New York employed a standard doctor's spring scale, popular at the time, to which he attached a long light writing arm as illustrated. The second pen is a pulse recorder and the bottom one, a time marker. The record illustrated shows only what we now call the ballistocardiogram. Note that the head-foot convention is the reverse of that now usually employed. The upper trace probably represents auricular fibrillation. From Satterthwaite, T. E.: "*Cardiovascular Disease*," Leincke and Buechner, New York, 1913.

his project was abandoned in spite of its auspicious beginnings.

In 1939, Starr published the now classic paper in which he described a simple and workable high frequency instrument, investigated the damping of the human body, and set up empirical equations for calculating the stroke volume and minute output of the heart. In the years which have followed, and in spite of World War II, he has continued to develop the field, which, for all practical purposes, he founded; he has made numerous contributions to ballistic theory, instrumental design, and the clinical application of the technique. During the war, Nickerson developed the so-called low frequency, critically damped ballistocardiograph. He and his followers were at first primarily interested in output studies and

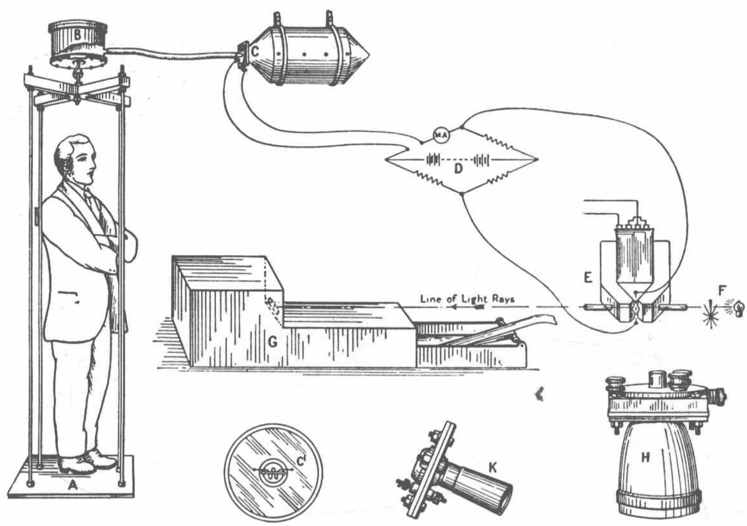


Figure 7. Heald and Tucker's Instrument. Courtesy of The Royal Society.

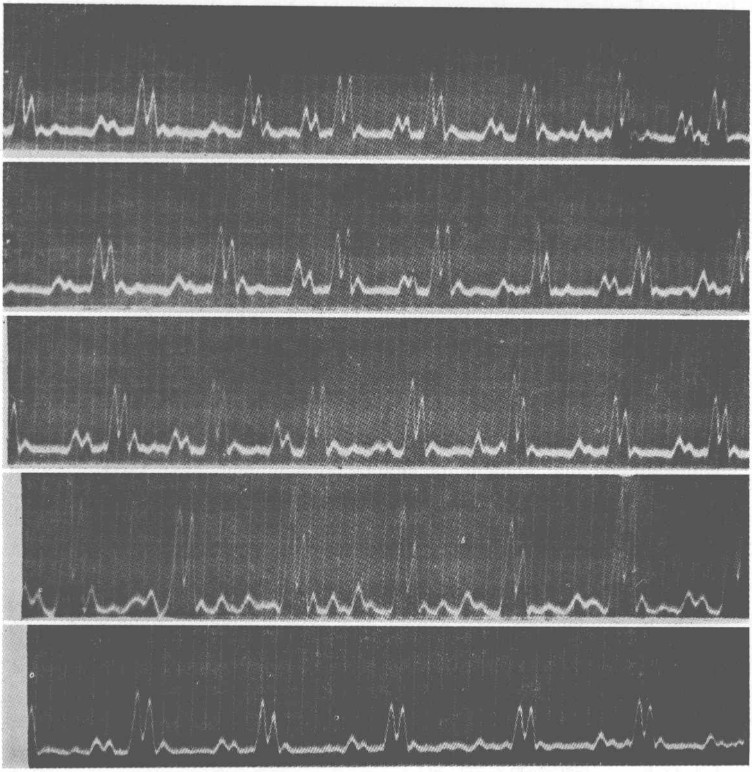

Figure 8. Series of curves from one of Heald and Tucker's experiments. These look quite unlike curves previously illustrated since the hot wire was unable to tell which way the air was moving. Courtesy of The Royal Society.

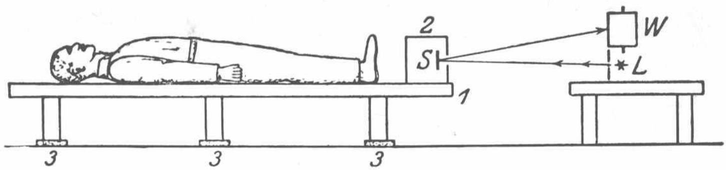


Figure 9. Angenheister and Lau's method. The table is supported on felt pads.