Reports

Measurement of Human Heart Rate during Usual Activity

Abstract. A small, rugged, self-contained cumulative heart-beat counter has a transistorized amplifier, a watch movement made into a counter, and a battery. The counter is activated by each *R*-wave of the electrocardiographic complex obtained from newly designed precordial electrodes. Heart beats can be counted for as long as 24 hours.

The human pulse rate is usually expressed as the number of heart beats per minute. The normal rate varies from less than 50 to more than 120 per minute, depending on many factors, one of which may be the act of taking the pulse. Pulse rates for longer than a few minutes have been obtained with the electrocardiograph, but the equipment is bulky and the activity of the tested individual is limited. Quantitative data on heart rate in beats per many minutes to many hours during various kinds of activity and work are not available.

In cooperation with engineers of the Illinois Bell Telephone Co. (L. Harrington, W. B. McCreary, L. J. Murphy, and L. Ryan) we have developed a small, rugged, self-contained "pulse counter" capable of totaling heart beats over periods ranging from a few minutes to more than 24 hours (*1*). The counter is packaged as a single unit containing an amplifier, cumulative counter, and power source. It measures 9.0 by 7.0 by 1.5 cm and weighs 100 gm. The instrument is connected by a flexible cable to precordial electrodes (Fig. 1).

The *R*-wave of the electrocardiographic complex is selectively amplified by 5 *R-C* coupled transistor stages. Each pulse of output current (10 ma) activates an electromagnet (100 ohms) which attracts a spring-loaded armature. Each excursion of the armature displaces a modified pallet fork which releases one tooth of the escapement gear of a spring-wound watch movement. In this way the *R*-wave is recorded on the watch face as 1/5 of a second. The modified watch movement with a conventional 12-hour dial, operating as a cumulative counter, can record up to 216,000 heart beats occurring at rates from less than 40 to more than 150 per minute. A pen-light battery supplies sufficient current to operate the pulse counter for more than 24 hours.

The electrodes must conform to rather strict specifications if a signal free of distortion is to be obtained during strenuous activity or for long periods of time, or both. Conductive contact between skin and a lead wire is made by a cylinder of electrode jelly contained in a soft rubber well 0.5 cm deep. The lead wire supported by the rubber well is held 0.25 cm from the skin surface, preventing direct contact between skin and the lead wire (see upper electrode, Fig. 1). A circular sheet of fine-mesh cotton gauze is cemented to the base of the well, providing a large area for fixing the electrode to skin. The gauze base is dipped in dilute rubber cement and allowed to dry completely. The skin site for the electrodes is cleaned, treated with aluminum chlorohydroxide to limit perspiration, and covered with a thin film of liquid latex surgical adhesive which is allowed to dry. The rubberized gauze base of the electrode is pressed onto the prepared site, producing an immediate firm bond. The well is then filled with electrode jelly and capped with a disk of pliable plastic (see lower electrode, Fig. 1).

The flexible gauze base allows free skin movement, and the electrodes remain firmly attached for as long as 72 hours. The electrodes can be detached easily with ether. The lead wires of the electrodes are connected to the counter by a thin flexible cable 35 cm long. The counter is carried in a shirt or blouse pocket. During the first few hours after application of the electrodes, contact resistance decreases, altering the effective input voltage to the low-impedance amplifier (3000 to 5000 ohms). A gain control in the amplifier compensates for this change.

In order to measure the accuracy of the pulse counter, a second means for counting heart beats simultaneously with the pulse counter was needed. By using the precordial electrodes described above with a direct-writing recorder, electrocardiograms with stable base

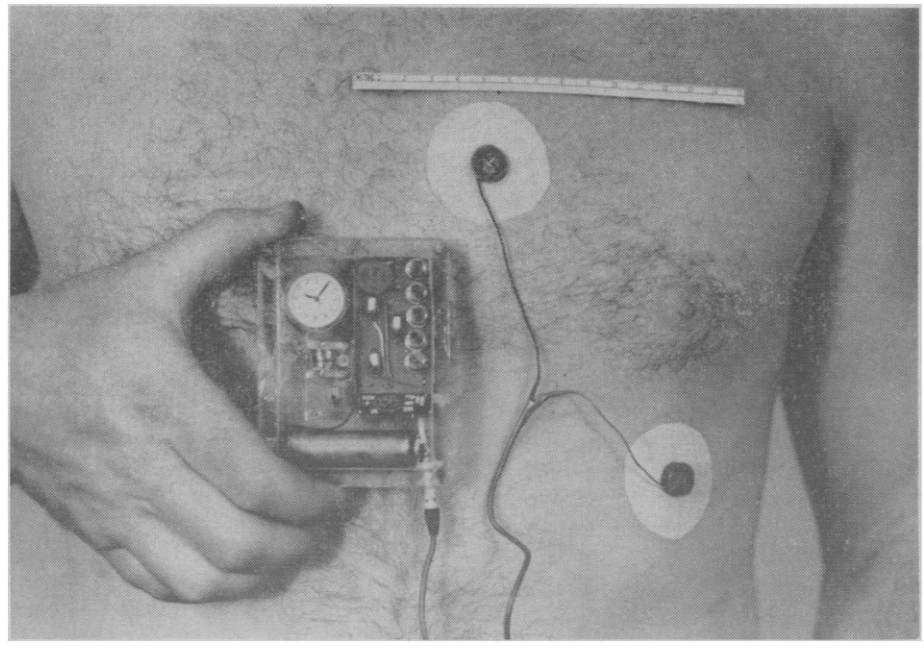

Fig. 1. Pulse counter and precordial electrodes. The upper electrode well is empty and shows the lead wire. The lower electrode well is filled with electrode jelly and capped.

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to Contributors" [*Science* **125**, 16 (1957)].

lines could be obtained. For checking the accuracy of the pulse counter, an additional set of precordial electrodes was applied and connected by long lead wires to a direct-writing electrocardiograph. The *R*-wave counts on the electrocardiogram have been compared with 3000 heart beats recorded by the pulse counter. Check periods include 15 minutes of vigorous exercise, 15 minutes lying in various positions, and the remaining time sitting and walking. During three consecutive 24-hour counts on one of us (D.A.R.), check electrocardiograms were obtained eight times at 8- to 12-hour intervals. The differences between pulse counter counts and electrocardiogram *R*-wave counts ranged from 0.1 to 3.8 percent with a mean of 1.3 percent. (The error in reading the pulse counter dial is up to ± 5 heart beats at the beginning and at the end of a test period. A difference up to 0.3 percent between the two methods for counting 3000 heart beats could, therefore, be expected.) Similar results have been obtained during 24-hour counts on one other man and on two women, all between the ages 32 and 36. During many additional check periods, the pulse counter has functioned with a similar degree of accuracy in men and women in other age groups.

When the pulse counter was used for 24-hour counts, a log of standard time, pulse counter time, and activity was kept, with entries made at about hourly intervals during waking hours. The three consecutive 24-hour counts noted above were 117,000, 115,000 and 122,000. Average minute rates calculated from the logs were 65, 68, and 66 while asleep and 88, 91 and 92 while awake. Average minute rates calculated from hourly counts while awake ranged from 70 to 110. By keeping a log, much additional information about pulse rates during different activities can be obtained.

In our studies we are concerned with the effect of factors such as age, sex, and occupation on pulse rates of apparently healthy people in whom differences in minute rates obtained by the usual means are probably small. A pulse count per 24 hours of usual activity, integrating the amplitude, duration, and frequency of variations in rate over a reasonable physiological cycle, may reveal larger differences among individuals. The pulse counter may also be used for other measurements of heart rate—for example, during work, physical training, disease, or therapy.

DONALD A. ROWLEY
SEYMOUR GLAGOV
PETER STONER
Department of Pathology, University of Chicago, Chicago, Illinois

16 OCTOBER 1959

Note

1. This investigation was aided in part by a grant from the Chicago Heart Association; the work by Seymour Glagov was done during the tenure of a research fellowship of the American Heart Association.

13 August 1959

Vitamin-A Content of the Frog Eye during Light and Dark Adaptation

Abstract. Rhodopsin is synthesized from 11-*cis* retinene (vitamin A aldehyde), but releases all-*trans* retinene when bleached by light. In the frog, both isomers of vitamin A are stored in the eye. Total ocular vitamin A, including that bound as retinene in rhodopsin, remains constant during light and dark adaptation. Stores of 11-*cis* vitamin A, however, diminish in the light and are replenished in darkness.

The bleaching and synthesis of rhodopsin involve a cycle of stereoisomerization of retinene (vitamin A aldehyde). Rhodopsin is synthesized from 11-*cis* (neo-*b*) retinene, but releases all-*trans* retinene when bleached by light. Each of these isomers is reduced reversibly by alcohol dehydrogenase and diphosphopyridine nucleotide to the corresponding isomer of vitamin A (*1*).

Vitamin A is stored in the retina and pigment layers (pigment epithelium and choroid) of the eye, and may thence exchange via the blood with stores in other tissues (*2*). However, ocular vitamin A is not in equilibrium with other stores. For example, in cattle up to 65 percent of the vitamin A in the eye may have the 11-*cis* configuration (*3*), whereas this isomer has not been found in other tissues (*4*).

Several years ago, Wald showed that in frogs the bulk of the vitamin A released upon bleaching rhodopsin, leaves the retina during light adaptation, and re-enters during dark adaptation to re-form rhodopsin (*2*). However, he did not decide whether the vitamin A leaves the eye altogether, or is merely transferred from the retina to the pigment layers.

Table 1 shows that *Rana pipiens* has more vitamin A in its eye (retina and pigment layers) when light adapted than when dark adapted. However, if one includes the retinene bound in rhodopsin, the total remains essentially constant in light and darkness. It seems, therefore, that during light adaptation there is a flow of vitamin A from retina to pigment layers, which is reversed during dark adaptation (*4a*). This process is no doubt facilitated by the close anatomical contact between these tissues (see *5*).

The proportion of 11-*cis* vitamin A fluctuates in light and darkness as shown in Table 2. In the light, about 10 percent of the vitamin A has the 11-*cis* configuration, but the concentration increases to about 25 percent during 6 hours of dark adaptation.

Taken together, Tables 1 and 2 show that the frogs of group A, which contained about 1.7 μg of vitamin A per eye, stored about 0.17 μg (that is, 10 percent) as the 11-*cis* isomer when light adapted. After 6 hours of dark adaptation, however, the eye contained about 0.94 μg of the 11-*cis* isomer: 0.24 μg (24 percent of 1 μg) as 11-*cis* vitamin A, and 0.7 μg bound in rhodopsin. During this period in darkness, therefore, 0.7 to 0.8 μg per eye, or about half the vitamin A, was isomerized to the 11-*cis* configuration. Similar computations for the frogs of group B show that during the dark period about 0.9 μg of vitamin A per eye—about one-third of the total—was isomerized to 11-*cis*.

The percentage of stored 11-*cis* vitamin A begins to rise after about 3½ hours of dark adaptation, which is roughly the time it takes for rhodopsin

Table 1. Vitamin A content of the frog eye (*R. pipiens*) following light or dark adaptation in vivo. Temperature 22° to 23°C. In each experiment, three frogs were either light adapted 1 hour in a white pan, illuminated with two 75-watt lamps with reflectors, or dark adapted 6 hours. Following light adaptation, the eyes contained no detectable rhodopsin; after dark adaptation, their rhodopsin content was maximal. The retina and pigment layers were dissected and extracted together. Dark-adapted eyes were dissected in dim red light, light-adapted eyes in diffuse room light. To determine free vitamin A, tissues were ground with anhydrous sodium sulfate and extracted with petroleum ether. Rhodopsin was determined as follows: the tissues were ground with anhydrous sodium sulfate under red light, and vitamin A was extracted as above. The powder was then bleached in white light to convert rhodopsin to retinene and opsin, and retinene was extracted with acetone containing 0.5 percent water. All extracts were transferred to chloroform, and vitamin A and retinene were determined by the antimony chloride reaction. Experiments were performed with two groups of frogs (A and B), which differed as shown.

Exp.	Vitamin A (μg per eye)		
	Free	Bound in rhodopsin	Total
	Group A: dark adapted		
1	1.2	Not measured	
2	1.1	Not measured	
3	1.0	0.7	1.7
	Group A: light adapted		
3	1.8	Negligible	1.8
4	1.7	Negligible	1.7
	Group B: dark adapted		
2	1.9	Not measured	
3	2.6	0.7	3.3
4	1.9	0.7	2.6
	Group B: light adapted		
1	2.8	Negligible	2.8
3	3.25	Negligible	3.25
4	2.6	Negligible	2.6