Answer #203

The answer is (f): my heartbeat causes the scale to read slightly less than my weight W for a small interval of time each heartbeat, as seen in an mpeg video by clicking your mouse on the graph below. This video has been converted from standard NTSC into mpeg format while slowing down the motion by a factor of three so that the motion of the scale may be more easily observed.

This area of the physics of the human body is known as "ballistocardiography." Dr. John Cameron, Professor Emeritus at the University of Wisconsin Medical School, has provided a concise explanation of this phenomenon, which is well-known to physicians:

> The reduction in "weight" is due to the bolus (about 80 g) of blood hitting the aortic arch and heading for the lower parts of the body. The rough speed is about 30 cm/s at the peak of contraction of the left ventricle. The distance to the aortic arch is a few cm. The short time between the contraction and the reversal of direction is only about 15 ms.

Additional information regarding this and other phenomena involving the physics of the human body can be obtained from the following references (obtained from John Cameron before his death):

1. Physics of the Body, by Cameron, Skofronic & Grant, 2nd ed: Med Phys Publ. Madison, WI. URL: www.medicalphysics.org or 800 442-5778

2. "How the Body Works" by John Lenihan (medical physicist from Glasgow of fond memory). It is also available from Medical Physics Publishing. I strongly recommend it. The last sentence in the book is rated PG 15.

   (from John Cameron) A year before he died John Lenihan agreed to publish an updated version of his 1974 book "Human Engineering," which had been long out of print. He had agreed to the new title as being more descriptive. Unfortunately John died before he got a chance to update it. His widow gave me permission to publish a new revised edition under the new title. The only major revision was to the chapter on organ transplants. In 1973 organ transplants had a very poor success rate. Now thousands are done every year and a large fraction (over 90%) are alive a year later. The book is very readable but Medical Physics Publishing was not able to market it appropriately. I am not sure it was reviewed in TPT or other appropriate journals.

3. If you are curious about the "origin of ideas" see my article: Cameron J.R. A proposed model of imagination and creativity: Wisconsin Academy Review Vol. 34, No. 3 pp33-36 June 1988. Click here for on-line copy.

A more recent description of ballistocardiography is found in rhe web site The Ballistocardiogram, written by David M. Harrison, Dept. of Physics, Univ. of Toronto, in July 2003.

Question of the Week

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For questions and comments regarding the *Question of the Week* contact Dr. Richard E. Berg by e-mail or using phone number or regular mail address given on the Lecture-Demonstration Home Page.

The Ballistocardiogram

Blood from the heart is mainly ejected upwards along the ascending aorta. When pulling blood into the heart, the major motion is also along the axis parallel to the spine. Thus the major motion is *longitudinal*. For both ejecting and pulling blood, according to Newton's 3rd Law the force exerted on the blood by the heart is matched by an equal and opposite force on the body by the blood.

$$\vec{F}_{\text{on blood}} = -\vec{F}_{\text{on body}}$$

If a patient is placed on a table with very low friction, then the force on the body causes the body and the table to move back and forth as the blood is being pumped. A sensitive *accelerometer* on the table measures its acceleration, and one can compute the acceleration of the blood with:

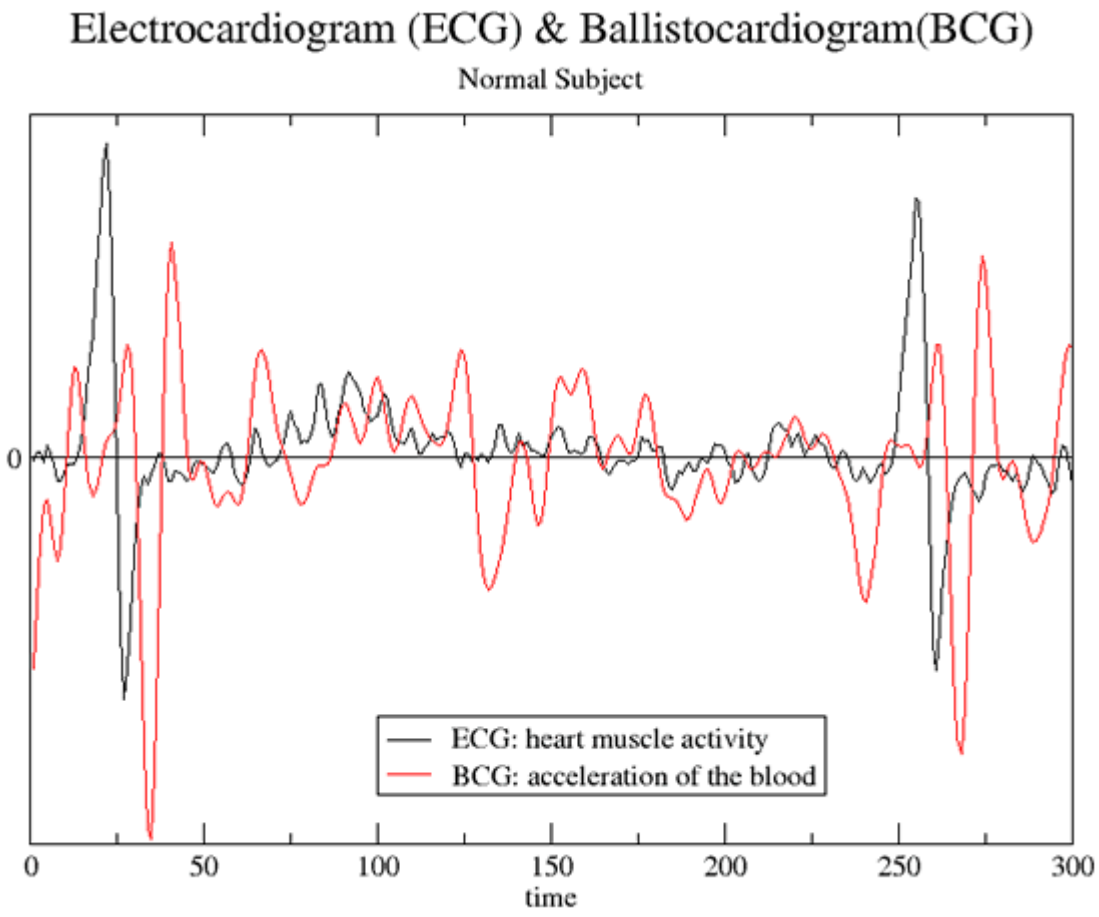
$$m_{\text{blood}}\,\vec{a}_{\text{blood}} = -m_{\text{body + table}}\,\vec{a}_{\text{body + table}}$$

This is called a *ballistocardiogram* (BCG), and an apparatus to make one is shown to the right.

The apparatus was made by Nihon Kohden in 1953, and we use the figure with permission. The original figure is at http://www.nihonkohden.com/50th/history2.html

Although the technique has been known for over 50 years, because the mass of the accelerating blood is small compared to the mass of the body and table, the experimental errors in the measured blood acceleration were large. Thus it was not very useful as a diagnostic tool. Recently modern signal processing techniques have allowed these experimental errors to be greatly reduced, and BCG's are now often used in a medical context.

As you will learn in the third quarter, the *electrocardiogram* (ECG) measures the activity of the muscles in the heart; there is also an experiment in the laboratory on ECGs. The BCG measures the effect of this muscle activity by directly measuring the acceleration of the blood. The following figure shows an ECG and a BCG for a normal patient.



The data for the above figure was supplied to us by Dr. William McKay, Department of Anesthesia, University of Saskatchewan.

Author

This document was written by David M. Harrison, Dept. of Physics, Univ. of Toronto, in July 2003.