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The circulatory reaction to graduated work as a test of the heart's functional capacity.

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As a preliminary to a new form of exercise treatment for cardiac insufficiency which we have described elsewhere, we investigated the test of the heart's functional capacity described by Graüpner. The essential features of his test are the deductions made from the form of the curve of the systolic blood-pressure after measured amounts of work. Although we were unable to confirm his most important results, we believe that the method of making frequent readings of the pulse-rate and systolic pressure after measured amounts of work furnishes the key to this problem of determining the heart's efficiency.

Our work may be divided into two parts. The first consisted in experiments on 23 normal persons. In three persons the graduated work was performed by means of a bicycle ergometer of the type described by Krogh and Lindhard,[1] and in 20 persons by means of dumb-bell and bar movements.

The second part comprised experiments on 32 patients suffering from cardiac insufficiency. The ergometer was used in two patients, and dumb-bell work in the remaining 30.

[1] *Skandinavisches Archiv für Physiologie*, 1913, XXX, p. 378.

EXPERIMENTS ON NORMAL PEOPLE WITH ERGOMETER.

Each person performed successively increasing amounts of work during which the systolic blood-pressure and pulse-rate increased in direct proportion to the amount of work done. After work the blood-pressure and pulse-rate generally fell rapidly to the original figures. As soon, however, as the work exceeded a certain amount, which varied for different individuals, we regularly found that the systolic blood pressure did not reach its highest point immediately after work, but a minute or so later at a time when the pulse rate had dropped back toward normal. This delayed rise of the systolic blood-pressure after heavy work is of much significance and we direct particular attention to it.

EXPERIMENTS ON NORMAL PEOPLE WITH DUMB-BELL AND BAR WORK.

Various movements with heavy dumb-bells and a steel bar weighing 25 pounds were carried out on 20 normal persons in a way which permitted an approximate estimation of the foot-pounds of work performed. Naturally the pulse-rate and blood-pressure could not be taken during the work, but they were taken before and every minute or half-minute after work. The delayed rise in systolic blood-pressure was obtained after large amounts of work which varied according to the subject's physique and condition of muscular training.

EXPERIMENTS ON PATIENTS WITH CARDIAC INSUFFICIENCY USING THE ERGOMETER.

Ten experiments were carried out on two patients who rode the bicycle ergometer for periods of 2½ minutes with successively increasing loads. Seven experiments were made with the same patients turning the bicycle pedals by hand instead of by the feet.

These experiments presented several striking features and some marked contrasts to the experiments on normal persons. A delayed rise in systolic blood-pressure was produced by much less work than in the normal subjects. Again the pressure *during* work, instead of rising decidedly as in normal subjects, rose but slightly or fell below the original level.

The most important result of this particular group of experiments was the discovery that approximately the same amount of work was followed by a delayed rise in systolic pressure whether performed by the legs or arms. This is the first time as far as we can ascertain that this law of circulatory physiology has been demonstrated.

EXPERIMENTS ON PATIENTS WITH CARDIAC INSUFFICIENCY USING DUMB-BELL WORK.

Several hundred experiments were carried out on thirty different patients. The pulse-rate and blood-pressure could not be taken during the performance of the dumb-bell work but were measured every 30 or 60 seconds after work.

The following example is selected because it represents the usual type of reaction following work.

C. G.—A man aged 31, with a history of 4 attacks of rheumatic fever, and symptoms of cardiac involvement for 4 years. On June 21, the following test was made.

Time.	Pulse-rate	Systolic Blood-pressure.
10:55	100	136
10:58	88	130
11:00	100	126
	250 foot-pounds in 20 seconds (10 lb. bell flexed 10 times)	
11:02	108	138
:03	108	136
:04	96	132
:05	92	126
:06	90	128
11:22	96	128
	500 foot-pounds in 35 seconds (10 lb. bell flexed 20 times)	
11:23½	106	140
11:24	102	130
11:25	96	136
11:26	92	130
11:28	100	128
11:34½	96	122
	750 foot-pounds in 45 seconds (10 lb. bell flexed 30 times)	
11:37	114	146
11:38	102	136
11:39	102	136
11:42	96	136
11:44	100	122

	1000 foot-pounds in 40 seconds (15 lb. bell flexed 27 times)		
11:47	126		136
11:48	114	Delayed rise	142
11:49	108		138
11:50	108		134
11:51	96		138
11:52	96		124

Our *clinical experiments* demonstrate conclusively, we believe, that in the pulse-rate and blood-pressure reactions to graduated work we possess a valid test of the heart's functional capacity. If the systolic blood-pressure reaches its greatest height not immediately after work but from 30 to 120 seconds later, or if the pressure immediately after work is lower than the original level, that work, whatever its amount, has overtaxed the heart's functional capacity, and may be taken as an accurate measure of the heart's efficiency.

METHOD OF PERFORMING OUR TEST OF THE HEART'S FUNCTIONAL CAPACITY.

The apparatus used consists of pairs of 5, 10, 15 and 20 pound dumb-bells, and a steel bar about 40 inches long weighing 25 pounds. Two types of movements are done with the bells.[1] In the first a pair of dumb-bells is held at the shoulder, one in each hand and then pushed alternately above the head and toward the median line until the arms are fully extended. As one bell moves up fairly rapidly the other bell returns to the shoulder, the two moving in a sort of see-saw rhythm. In the other movement a bell is held in each hand, the arms hanging by the side of and close to the body, and then each forearm is alternately flexed, raising the bell to the shoulder. The patient stands or sits according to his condition. But one movement is performed with the steel bar. It is picked up from the floor with both hands raised first to a level with the shoulder then pushed above the head until the arms are fully extended and then quickly lowered to the floor again with a single rapid motion.

It is possible to calculate approximately the number of foot-

[1] These movements were first described to us by Dr. Jacob Teschner, of New York.

pounds of work performed in each of these movements. There is a certain amount of work, however, which we cannot estimate in foot-pounds. When a patient stands holding a pair of dumb-bells at his shoulders, work is done as shown by his circulatory reactions, but we cannot estimate it in foot-pounds. This unknown factor may be ignored, however, for our purpose.

Most adults average 2 feet as the distance through which a bell is pushed from the shoulder to full extension of the arm. In the flexion movement, the distance through which the bell is carried from the side of the body to the shoulder averages from 2 feet to 2 feet 6 inches. Now if a 5 pound bell is pushed through 2 feet, 10 foot-pounds of work are done. If the total number of pushes are 20, 200 foot-pounds are done. For the sake of comparison, the time it takes a patient to do any quantity of work should be noted.

If the patient whose heart is to be tested has but recently recovered from an attack of cardiac insufficiency it is well to start with a pair of five-pound bells, the patient sitting on a stool. Two hundred foot-pounds of work are then given either by flexing or extending the bells alternately. The pulse-rate and blood-pressure are taken every 30 or 60 seconds according to the examples given on a preceding page. After the pressure and pulse have returned to the original level, 300 or 400 foot-pounds are done in the same way. The work is increased with each experiment until we reach a delayed rise in blood-pressure. *The experiment which has caused a delayed rise should always be repeated after a few minutes rest with a slightly increased amount of work for the purpose of confirmation.* When once the amount of work which will produce a distinct delayed rise in blood-pressure is ascertained, it is quite remarkable how slightly the results vary upon a repetition of the experiment with the same or increased work. Yet if our test is valid this should be so.

THE TESTING OF PATIENTS WHOSE CARDIAC CAPACITY EXCEEDS AN ABILITY TO PERFORM 100 FOOT-POUNDS OF WORK IN 60–90 SECONDS.

People with normal hearts, or patients with well compensated heart lesions, afford a more difficult problem in mechanics when