Correlation of Ballistocardiogram with Work Performance and Energy Cost for Guidance in Rehabilitation of Cardiac Patients

By Henry Brown, M.D., Seymour H. Rinzler, M.D., and Joseph G. Benton, Ph.D., M.D.

Correlative studies of the resting ballistocardiogram and the ability to expend energy in cardiac patients indicate that the resting ballistocardiogram may be a useful tool in evaluating the functional or work capacity of a cardiac patient for rehabilitation purposes and vocational guidance, and may serve as a screening device for finding those cardiacs, other things being equal, who possess the functional capacity to perform jobs or activities whose energy requirements are known or can be estimated. However, in view of the relatively higher incidence of abnormal resting ballistocardiograms in the older age groups, for practical purposes, this usefulness of the ballistocardiogram may be limited to the cardiac patient under the age of 50.

With the introduction in 1949, by Dock and Taubman,1 of a simplified electromagnetic device for recording the ballistocardiogram, great impetus was given to the study of clinical ballistocardiography and considerable experience has been accumulated2-7 which does not differ essentially from that derived from the use of the more complicated instruments of Starr and Nickerson.8-11

Significant diagnostic ballistocardiographic changes have been found in patients with coronary artery disease, particularly with angina pectoris. Taymor and associates1 found that the resting ballistocardiogram was abnormal in 62 (83 per cent) of 75 patients with angina pectoris, normal resting electrocardiograms and positive Master two-step tests. After exercise the ballistocardiogram became abnormal in an additional eight patients, or a total of 70 (93 per cent). Rinzler and co-workers7 compared the usefulness of the resting ballistocardiogram with the exercise tolerance test in the diagnosis of coronary artery disease in 24 patients with chest pain and normal resting electrocardiograms, and found a 91 per cent correlation; that is, an abnormal resting ballistocardiogram was associated with an abnormal exercise tolerance test, or a normal resting ballistocardiogram with a normal exercise tolerance test, in 91 per cent of instances. The Mandelbaums9a reported that 200 of 224 patients with clinical angina pectoris had abnormal resting ballistocardiograms. These findings suggest that the resting ballistocardiogram may serve as a sensitive indicator of coronary artery disease.

Since the ballistocardiogram is a reflection of the mechanical or pumping activity of the heart, it might be expected to give information about cardiac functional capacity. Evidence for this has been presented by Starr12 who found that patients in congestive heart failure demonstrated abnormal ballistocardiographic patterns, with return to normal patterns upon recovery of cardiac compensation. Starr and Wood8 also noted good correlation between the ballistocardiogram and subjective exercise tolerance as determined by history from the patient. The Mandelbaums9a found, as a rule, that following a myocardial infarction, those patients whose records approached normal or showed only grade I changes made a better
functional recovery and were able to return to "full activity."

We have been particularly interested in the problem of rehabilitation of cardiac patients\textsuperscript{13, 14, 15} and since definite knowledge of the functional capacity of such patients would be of value in guiding the course of rehabilitation, especially vocationally, the present study was undertaken with the following purposes: (1) to determine if any correlation existed between the ballistocardiogram at rest and the ability of a cardiac patient to do work or expend energy, and (2) if a correlation were found, to decide if it warranted the use of the resting ballistocardiogram as a simple, clinical source of information for guidance in planning rehabilitation programs for cardiac patients.

**Methods**

This study was conducted during the course of an investigation of the energy cost (in terms of oxygen consumption) of standardized activities in a series of ambulant cardiac patients.\textsuperscript{*} Included in these activities was step-walking on a staircase, which was chosen because it represents an activity requiring no learning or training and one which is essential in the daily life of every individual who is employed outside of his home. Inability to perform this function would place an almost insurmountable barrier in the path of occupational rehabilitation of most cardiac patients.

The patients in this study were drawn from several sources\textsuperscript{†}: (1) Medical wards (Second and Fourth Divisions) of Bellevue Hospital; (2) Fourth Medical Division Cardiac Clinic of Bellevue Hospital; (3) College Cardiac Clinic, New York University College of Medicine, University Hospital; and (4) referrals to the Bellevue Hospital Rehabilitation Service for job placement. The cardiac diagnosis was established in each instance by complete diagnostic examinations on the respective services; many of these patients had been followed in cardiac clinics for a number of years. All of the patients were re-evaluated by us\textsuperscript{16} before being included in the present study. None of them had clinically significant skeletalmotor disability, or pulmonary, endocrine or hematologic disease.

Patients with all etiologies of heart disease and functional classification I through III were included (Table 1).

**Table 1.—Distribution of Cardiac Etiologies and Functional Classifications in 51 Cardiac Patients**

<table>
<thead>
<tr>
<th>Cardiac Etiology</th>
<th>No.</th>
<th>Functional Classification</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arteriosclerotic</td>
<td>10</td>
<td>Class I</td>
<td>12</td>
</tr>
<tr>
<td>Hypertensive with or without</td>
<td>12</td>
<td>Class II</td>
<td>23</td>
</tr>
<tr>
<td>arteriosclerosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rheumatic</td>
<td>17</td>
<td>Class III</td>
<td>18</td>
</tr>
<tr>
<td>Syphilitic</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congenital</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other†</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>Total... 53*</td>
<td></td>
</tr>
</tbody>
</table>

* Two patients evaluated at two different times.
† This group includes indeterminate etiology, nonspecific pericarditis, constrictive pericarditis, possible and potential heart disease, and doubtful rheumatic-type heart disease.

As part of the cardiac evaluation, ballistocardiograms were recorded routinely on all patients in the resting state, after lying in bed or on the ballistocardiographic table for at least 10 to 15 minutes. The Dock type electromagnetic instrument was employed in conjunction with a direct writing electrocardiograph, and in most of the records simultaneous QRS complexes (lead I or II) of the electrocardiogram superimposed on the ballistocardiographic tracing were recorded by the method of Gubner\textsuperscript{19} for the purpose of observing time relationships.

Many workers in clinical ballistocardiography have reported records taken at rest and after exercise. In the present study, ballistocardiograms were not recorded after exercise for the following reasons: (1) Following completion of the exercise (step-walking) the patient returned to rest in a sitting position and remained connected to the respirometer for another 6 to 10 minutes while recovery phase oxygen consumption was being recorded. This precluded, for technical reasons, the recording of postexercise ballistocardiograms. (2) Experience has indicated that immediately after exercise artefactual distortion of the ballistocardiographic record is very common, probably due to the
increased amplitude and frequency of the respiratory excursions of the thorax and diaphragm. (3) Finally, it was our purpose to determine the usefulness of the resting ballistocardiogram as a simple clinical tool and as a possible replacement for the performance of stress tests in cardiac patients. Therefore, it is to be emphasized that mention of ballistocardiographic records herein indicates those taken in the resting state.

Step-walking was performed on a conventional staircase six steps high with a total height of 42 inches at the rate of six round trips (up and down) per minute (except for one slower test). This rate of work is approximately equivalent to six times the energy cost of the average resting metabolism.\textsuperscript{15} The graded activities consisted of the following tests: six trips in one-and-a-half minutes (slow “six-trip”); six trips in one minute (“six-trip” test); nine trips in one-and-a-half minutes (“nine-trip” test); 12 trips in two minutes (“12-trip” test); 18 trips in three minutes (“18-trip” test), and 24 trips in four minutes (“24-trip” test). The “nine-trip” test is approximately equivalent to a standard Master “two-step” test (21 trips) in terms of the rate and the vertical distance through which the subject lifts his own weight.

The step-walking tests were usually performed in the morning during the fastiging state or at least two hours after breakfast. Except in those instances where the patient’s ability to perform the test was poor, two or three morning sessions on separate days were required to complete the tests. When patients manifested symptoms of angina, dyspnea, or moderate weakness in any test, the series was discontinued at that point, and the most strenuous test completed was designated the maximum work performance of the patient.

During the performance of these tests, the subject was breathing 100 per cent oxygen through a closed system respirometer and oxygen consumption (corrected to normal temperature and pressure) as a measure of the energy cost of the activity was calculated from the respirometric records.\textsuperscript{13, 15} Since the work done by each subject varied directly with his weight, the energy cost was calculated in relation to the body weight (milliliters per kilogram).

There were thus available for comparison simultaneous data of the patient’s ability to do work of graded intensities, the energy cost, and the resting ballistocardiogram. These data were examined for the existence of any correlation between the normality of the ballistocardiogram and the amount of work that the patient could perform. To maintain objectivity, the ballistocardiograms were analyzed and interpreted without original reference to the patient’s energy expenditure or maximum work performance.

**Interpretation of Ballistocardiograms**

Since the ballistocardiograms recorded by the Dock type instruments do not allow critical quantitative measurements, interpretation depends on a qualitative study of the ballistic forms or wave patterns. The unquestionably normal ballistocardiogram can easily be identified. The pattern is regular and repetitive and the H, I, J, and K waves are sharply defined and easily identified. Where the pattern is so grossly distorted and bizarre that the wave forms are indistinguishable, abnormality is obvious. There are, however, patterns of fairly regular and repetitive complexes which many believe are also abnormal.\textsuperscript{2, 4, 5, 7, 8, 16, 17, 18} These include (1) an H wave amplitude equal to or taller than the J wave; (2) marked diminution in amplitude or absence of the I wave; (3) late notching or double-peaking of the J wave; (4) an excessively deep (and often late) K wave associated with a relatively small HIJ complex; (5) an absent K wave.

It should be noted that such qualitative terms as “marked diminution in amplitude” and “excessively deep” are used in describing criteria of abnormality, and this allows for certain differences of opinion in interpretation and the designation of “borderline” tracings. It is hoped that this shortcoming of a method which is at present qualitative rather than quantitative, will be obviated with further refinement of the ballistocardiographic technic.

Although most of the ballistocardiograms in the present series were recorded in various phases of respiration, it was noted that the best tracings were obtained with respiration held at the end of a normal expiration. Other investigators\textsuperscript{5b, 16} have attached great significance to the variations occurring with the phases of respiration, but during this study similar variations in many normal persons were observed and it is believed that the present state of knowledge does not allow any particular significance with respect to cardiac function to be attributed to the respiratory variations.

**Results**

Fifty-one cardiac patients were studied for a total of 53 tests (two patients were studied
at two different times) and a summary of the results is given in table 2. The data are tabulated to indicate the maximum work performance, the mean energy cost in terms of oxygen consumption (milliliters per kilogram of body weight in excess of resting at normal temperature and pressure) for each category of work and their correlation with the resting ballistocardiogram.

Table 2.—Comparison of the Resting Ballistocardiogram with the Maximum Work Performance and Mean Energy Cost of Each Category of Work Performance in 53 Cardiac Patients

<table>
<thead>
<tr>
<th>Category</th>
<th>A*</th>
<th>B†</th>
<th>BCG Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Slow “6-trip”</td>
<td>22.7</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>“6-trip”</td>
<td>21.5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>“9-trip”</td>
<td>30.7</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>“12-trip”</td>
<td>40.0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>“18-trip”</td>
<td>57.0</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>“24-trip”</td>
<td>72.5</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Totals . . .</td>
<td>24</td>
<td>23</td>
<td>2</td>
</tr>
</tbody>
</table>

* Column A indicates the various categories of maximum work performance. Maximum work was determined by a series of step-walking tests of increasing energy costs continued to the point of first manifestation of symptoms.

† Column B gives the mean energy cost for each category of work performance in terms of oxygen consumption (milliliters per kilogram of body weight, at standard temperature and pressure, dry) in excess of resting metabolism.

In 24 patients, normal resting ballistocardiograms were obtained and all of these subjects were able to complete the “nine-trip” test, the performance of which resulted in a mean energy cost of 30.7 ml. per kilogram; this is nine times the resting metabolism for one minute (3.39 ml. per kilogram per minute for 50 cardiac patients in this study). Eighteen of these patients (75 per cent of those with normal ballistocardiograms) were able to do the “18-trip” test, or better, with a mean energy cost of 57.0 ml. per kilogram, or greater, an increase of at least 16.8 times above the requirements for one minute of resting.

Of 23 patients with abnormal resting ballistocardiograms, five could not complete the regular “six-trip” test (mean energy cost of 21.5 ml. per kilogram) and only four (17.4 per cent of those with abnormal resting ballistocardiograms) were able to do the “18-trip” test, or better, with a mean energy cost of 57.0 ml. per kilogram.

Two patients with borderline tracings were able to do the “12-trip” and “18-trip” tests, respectively. In four patients the ballistocardiogram was considered as indeterminate. These tracings were taken early in the course of the study before simultaneous electrocardiograms were recorded and there was some question about the identity of segments of the complexes. All four completed the “18-trip” test (mean energy cost of 57.0 ml. per kilogram).

The chi-square test for homogeneity was applied to the data, excluding borderline and indeterminate cases, and chi-square was found to be highly significant, with p, the probability if chance alone were operating, less than 1 in 1000.*

When the data were grouped in a two-way classification, they showed that 21 out of 24 in the group with normal and only 7 out of 23 in the group with abnormal ballistocardiograms had a work performance of over nine trips. The difference between these two proportions was tested statistically and was found to be highly significant with p for chi-square less than 1 in 1000.

Discussion

The results indicate that a normal resting ballistocardiogram in a known cardiac patient is associated with the ability to perform work of a moderate to marked increment in energy cost (from 9 to 16.8 times, or greater), above the resting level during a relatively short period of time.†

The significance of this lies in the fact that very few working activities other than heavy

* We are indebted to Dr. Donald A. Mainland, Professor of Biostatistics, Department of Preventive Medicine, New York University College of Medicine, for review of the statistical data.

† Unpublished data from this laboratory indicate that in a group of about 50 normal persons, in general, the mean energy expenditure for the performance of the identical tests is not significantly different from the values herein reported for the cardiac patients.
manual labor require a sustained output of more than two to four times the resting energy expenditure. It has been pointed out\(^3^9\) that work may be considered moderate when its cost is three times that of the basal rate and strenuous when the cost increases to eight times the basal rate. Therefore, it may be postulated that these patients have a good to excellent potentiality for work of moderate energy costs, other factors being equal. On the other hand, according to the data in this study, an abnormal resting ballistocardiogram is not prognostic of the patients' work performance, for such patients fell into all categories of maximum work performance and energy cost from the least to the greatest.

A comparison of the 24 patients with normal resting ballistocardiograms, and the 23 patients with abnormal resting ballistocardiograms, reveals a similar distribution of the various cardiac disease etiologies in each group (table 3). However, it also reveals a significant difference in the mean ages of the two groups; namely, 37.0 years for the "normals" and 50.5 years for the "abnormals." It has been demonstrated that the incidence of abnormal ballistocardiograms increases with each decade of advancing age,\(^4^,\) \(^2^1\) and there seems to be little doubt that extracardiac factors related to aging are important in producing many of the abnormalities of the ballistocardiogram in older persons. However, this age difference would not seem to invalidate the present conclusions, since in no case was a normal resting ballistocardiogram (six were found in patients over 45 years of age) associated with a poor work potentiality, but it does suggest a practical limitation to

### Table 3.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Etiology of Heart Disease</th>
<th>Functional Class*</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As</td>
<td>Hyper or $%$ As</td>
<td>Rheum</td>
</tr>
<tr>
<td>With Normal BCG</td>
<td>5</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>With Abnormal BCG</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

* Where available, the functional class was obtained from the cardiac clinic record of the patient; otherwise it was determined by us after evaluation of the history and physical examination of the patient.

The data with reference to functional classification offer additional support for the usefulness of the ballistocardiogram. Clinical experience with cardiac patients indicates that the assignment of a specific functional classification is often conditioned by the physician's own

fears and prejudices about the patient's ability to do work, to say nothing of the latter's anxieties and exaggeration of symptoms. The frequency with which disabling cardiac neurosis (superimposed on nondisabling organic disease) is met in the cardiac clinic is proof enough of this and is one of the greatest obstacles to the rehabilitation of the cardiac patient. What is sorely needed is an objective means of functional classification and the present data indicate that the resting ballistocardiogram may offer assistance in this regard. In table 3, it can be seen that 16 patients were assigned the functional classification III, on the basis of history, physical examination and the usual cardiac laboratory data, by competent cardiologists. This means that these 16 patients were considered to be relatively severely disabled, since, according to the criteria of the New York Heart Association,\(^2^2\) class III patients are defined as those who are comfortable at rest,
but have discomfort in the form of undue fatigue, palpitation, dyspnea or anginal pain caused by less than ordinary activity. Actually, the present studies demonstrated that in work performance, 12 of them were able to perform the "nine-trip" test, or better, with a mean energy cost of 30.7 ml. per kilogram, or greater. In five of these patients (two completed the "18-trip" test, two the "12-trip" test, and one the "nine-trip" test), the resting ballistocardiogram was normal. It is evident that the ballistocardiogram is a better indicator of work performance (functional capacity) than the history and physical examination in at least 5 of the 12 patients.

Such considerations have bearing on our particular interest in the problem of the rehabilitation of cardiac patients, and it may be seen that these preliminary findings have special significance, for they suggest that the resting ballistocardiogram may be a useful tool in evaluating the functional or work capacity of a cardiac patient without subject to a series of tests calculated to "titrate" work capacity. In this connection, it should be noted that there are those who feel that exercise tests carry with them an attendant hazard. The present findings also indicate that the resting ballistocardiogram may be used as a screening device for finding those cardiac patients who have the functional capacity to perform certain jobs whose energy requirements are known or can be estimated by physical demands analysis, and in whom the extremely important factors of motivation and other psychologic considerations are not a barrier to useful employment.

It is of special interest that in the series of 24 patients with normal resting ballistocardiograms there are five who had sustained one or more myocardial infarctions and all were able to complete the "18-trip" or "24-trip" tests, activities with a high energy cost. All were placed in selected jobs and are now working full time supporting their families.

**SUMMARY**

1. In 51 known cardiac patients of all etiologies and functional classification I through III, a comparison was made of the resting ballistocardiogram and the ability to do work and expend energy as determined by a series of step-walking tests of graded intensities, while oxygen consumption was measured in a closed system respirometer.

2. The results indicate that under the conditions studied, a normal resting ballistocardiogram in a known cardiac patient is very frequently associated with the capacity for moderate to marked energy expenditure. An abnormal resting ballistocardiogram gives no consistent information about the patient's work capacity. Statistical analysis of these correlations is highly significant.

3. Furthermore, the resting ballistocardiogram, *when normal*, appears to be a more accurate indicator of the functional classification of a cardiac patient than the assignment of a classification on the basis of the interpretation of the cardiac history and physical examination.

4. This suggests that the resting ballistocardiogram (a) may be a useful tool in evaluating the functional or work capacity of a cardiac patient for rehabilitation purposes and vocational guidance, and (b) may serve as a screening device for finding those cardiacs, other things being equal, who possess the functional capacity to perform jobs or activities whose energy requirements are known or can be estimated. However, in view of the relatively higher incidence of abnormal resting ballistocardiograms in persons in the older age groups, for practical purposes this usefulness of the ballistocardiogram may be limited to the cardiac patient under the age of 50 years.

**ADDENDUM**

In a recent study and review which appeared while the present paper was in press, W. R. Scarborough and co-workers (Am. Heart J. 44: 645, 910, 1952) indicate a limitation to the usefulness of the ballistocardiogram in diagnosing coronary artery disease in patients over the age of 50 years, which is similar to the limitation we found in its usefulness for evaluating functional capacity.

**ACKNOWLEDGMENT**

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Sumario Español

Estudios correlativos del ballistocardiograma en reposo y la habilidad de usar energía en pacientes cardíacos indica que el ballistocardiograma en reposo puede ser un instrumento provechoso en la evaluación funcional o de capacidad de trabajo de un paciente cardíaco para propósitos de rehabilitación y guía vocacional, y además puede servir para encubrir cardíacos que poseen la capacidad funcional de trabajar en oficios o participar en actividades cuyas demandas de energía ya se saben o se pueden estimar. Sin embargo, en vista de la incidencia relativamente alta de ballistocardiogramas en reposo anormales en el grupo de edad avanzada, el uso provechoso de ballistocardiograma para propósitos prácticos se debe limitar a pacientes cardíacos de menos de 50 años de edad.

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