A Ballistocardiographic Study of Healthy Young Adult Males

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Ballistocardiograms were obtained from 319 well-screened young soldiers on an electrically equalized electromagnetic ballistocardiograph. The records were analyzed for the basic pattern and for variations. The conventional criteria of normal were confirmed. The most frequently observed variation consisted of changes in complexes written during expiration which, when of sufficient degree, resemble those described as abnormal. Prominent L waves were also common. Variations of the J and K waves were rare. A grade 1 or 2 abnormality was noted on 22 records, but when respiration was suspended, only three remained questionably abnormal.

It has been established that there is a high degree of correlation between abnormalities of the ballistocardiogram and the presence of heart disease.\textsuperscript{1-25} The ballistocardiograph, therefore, has been recommended as a diagnostic tool in the evaluation of the cardiovascular system. In order to define the normal and to test the reliability of the ballistocardiogram as an indicator of heart disease, a number of surveys of apparently normal subjects have been undertaken.\textsuperscript{2, 11, 14, 15, 16, 18, 20, 26} In subjects over the age of 40, abnormal records are common. From 10 to 20 per cent of individuals in the fifth decade, 22 to 43 per cent in the sixth decade, and 50 to 90 per cent in the seventh decade and older are reported to have abnormal records. It is suggested that these percentages correspond to the expected incidence of subclinical cardiovascular disease in these older subjects and, therefore, these abnormal tracings may be true records and not variations due to age.\textsuperscript{14, 25, 26, 27} It follows that the definition of the normal and normal variations must come from a study of young individuals. The reports indicate that none to 10 per cent of normal subjects under the age of 40 have abnormal ballistocardiograms. Although the ballistocardiographic deflections have been approximated experimentally,\textsuperscript{28} the present criteria of normal are largely empiric. There is confusion however, because these criteria have been described for four different types of ballistocardiograms,\textsuperscript{2, 27, 29, 30, 31} each of which introduces its own distortions. Recently it has been proposed that the most reliable records are obtained with a displacement (photoelectric) type of direct body pickup.\textsuperscript{35, 32} An electromagnetic (velocity) ballistocardiograph will provide a practically identical record if electrically equalized.\textsuperscript{25, 22, 33}

It seemed of value, therefore, to obtain ballistocardiograms with such an apparatus from a large group of healthy young subjects. The presence of an Airborne Division at this Post created an opportunity to do this. Records were obtained from 319 of these select soldiers after extensive studies confirmed their good health. Attention was primarily directed to the characteristics of the basic pattern and variations from this pattern as obtained on this simple, inexpensive and accurate instrument.

Materials and Methods

The subjects were 319 soldiers mostly from an Airborne Division. A few were post complement personnel. The troops had reported to the Physical Examination Section of this hospital for processing necessary for separation from the service, re-enlistment or eligibility for Airborne training.

The processing consisted of: (1) a complete clinical history, (2) a physical examination, including a blood pressure recording, (3) a chest x-ray study, (4) a serologic test for syphilis and (5) urinalysis. Only individuals in whom these studies were normal were included in the survey. The subjects were of ages 19 through 29 years. The average age was 23.4 years.

The men were directed not to smoke for four hours prior to the test. The recordings were made...
at least two hours after eating. The cardiovascular system was again reviewed with each subject prior to the test.

The apparatus employed was a Dock model, portable, electromagnetic ballistocardiograph. *Electrical equalization was effected by having a 20 mifarad capacitor across the coils as recommended by the manufacturer and by Dock. Thus, this electromagnetic transducer of body motion actually writes a displacement curve, has an essentially flat frequency response in the range of the ballistic waves, but attenuates respiratory motion more than if a condensor of larger capacity is used.  

The tracings were recorded on a Cambridge Simpli-Scribe Electrocardiograph with the standardization set at 5 mm. equals 1 mv. A fluoroscopic table provided a solid base. Records were obtained during normal respiration and with the breath held in midrespiration, deep inspiration and deep expiration. Care was taken to avoid an inadvertent Valsalva maneuver.

The ballistocardiograms were analyzed according to the usual criteria as described by Starr, Brown, Hoffman and de Lalla, Dock, Mandelbaum, and Mandelbaum, Pordy, Taymor, Moser, Chesky and Master, Gubner, Rodstein and Ungerleider, Scarborough, Mason, Davis, Singewald, Baker and Lore and Thompson, Rappaport and Sprague.

Each test was witnessed by one of us (W.B.A.) and if a record appeared to vary from the normal, an electrocardiogram was obtained. Only one abnormal electrocardiogram was obtained and that subject's ballistocardiogram was eliminated from the study.

**RESULTS**

1. Two hundred and seventy-three of the ballistocardiograms were of the usual basic normal pattern (fig. 1). Each complex consisted, in order, of a low upright H wave, a short, negative I wave that was clearly below the baseline; a prominent positive J wave, the tallest component; a prominent negative K wave, the deepest component; and an upright L wave which was shorter than the J wave but usually taller than the H wave. These waves could easily be identified without a marking system. Essential features of the normal are clean, unslurred lines, sharp acute angles and uniformity of all the complexes.

2. The most frequently observed variation from the basic pattern was that associated with respiration and involved, for the most part, complexes written during expiration. The variation presented itself in a range of degrees. The least degree was noted on a large number of tracings and consisted of a reduction in amplitude with maintenance of form (figs. 1 D; 2 A and B). This is described as a normal finding but in some records the I waves are noted to be disproportionately reduced. Further shortening of the I waves produced high HIJ complexes which made the K waves appear deep (fig. 2 C, D and E). If the L waves of these variant expiratory complexes were also prominent, the "abnormal" high HIJ-deep K-prominent L pattern described by

* Manufactured by the County Surgical Company, Brooklyn, N. Y.  

*Fig. 1. Typical normal ballistocardiograms. Description in text. These tracings typify the pattern noted in 273 of the 319 records.*  

Starr, Brown, Hoffman and de Lalla, Dock, Mandelbaum and Mandelbaum resulted (fig. 2 F, G and H). This type of change is also similar to that described by Brown, Hoffman and de Lalla. This variation was noted on less than half the complexes recorded during normal respiration on 10 records and a grade 1 classification of Brown was therefore assigned (fig. 2 C, D, E and G). On five records more than half the complexes were so altered and these were graded 2 (fig. 2 H and F). In every case normal ballistocardiograms were recorded in one or more of the three positions of held expiration [fig. 2 C (2), D (2), F (2), G (2) and H (2)].
3. On most records there was some weaving of the base line due to respiratory motion. This rarely interfered with the interpretation (figs. 1 C and 3 A). Six tracings, however, were distorted by this effect (fig. 3 B). This variability differed from that described above in that there was no appreciable change in amplitude and the form reflected the site on the base line the complexes fell, not the phase of respiration. If the breathing was quieted or held, clearly normal ballistocardiograms were obtained (fig. 3 B (2)).

4. A distortion similar to the high HIJ-deep K-prominent L pattern described above also appeared on most tracings which also showed a heart rate of 100 beats per minute or more (fig. 4 A and B). This effect did not disappear when the breath was held [fig. 4 B (2)], unless the rate also slowed [fig. 4 A (2)]. The degree of abnormality was considered grade 3 for five records, grade 2 for three records and grade 1 for six records. This effect is attributed to the superimposition of the HIJ deflections on after waves of the preceding complexes. These records emphasize that tachycardia so distorts the ballistocardiogram that interpretation is precluded.

5. The H waves varied from relatively tall [fig. 5 A (1)] to absent [fig. 5 A (2)]. On one record the H waves in a few expiratory complexes were as tall or taller than the J waves (fig. 5 B). This did not occur when the breath was held [fig. 5 B (2)]. On another tracing a few complexes with exceptionally large H waves were noted (fig. 5 C). These two tracings were classified as possible grade 1 abnormal records.

6. The I wave variations were considered in paragraph 2. The J and K waves were very stable. Minor notching of the J waves was
Fig. 5. Variations of the H waves: A (1), normal tall H waves. A (2), small or absent H waves. B (1), note the unusually tall H waves in the second and seventh complexes. B (2), same subject with respiration held; the tall H waves are not seen. C, note the very large H waves in the first, fourth and tenth (inserted) complexes. The age, height, weight and blood pressure of these individuals were: A (1), 23, 67 inches, 145 pounds, 110/64; A (2), 24, 69 inches, 210 pounds, 108/70; B, 24, 67 inches, 140 pounds, 120/74; and C, 24, 62 inches, 150 pounds, 116/70.

Note on two records (fig. 6 C) but this practically disappeared when the breath was held [fig. 6 C (2)]. A persistent small single notch of most K waves was observed on two other tracings [fig. 6 A (1)]. On one record some of the K waves were shortened and notched [fig. 6 A (2)], but this disappeared when respiration was suspended. These five tracings are probably normal, but if strictly interpreted, the two with notched K waves would also be graded 2 and the one with shortened K waves would be graded 1.

7. The L waves were quite inconstant, varying in size and angularity (figs. 1 A and B, 6 B). Nineteen tracings were normal except that the L waves were as tall or taller than the J waves (fig. 6 C, D). Since relatively tall L waves are a characteristic of records obtained with this type of ballistocardiograph, and since many of the L waves on the 273 clearly normal ballistocardiograms were only slightly less prominent, these records were considered normal.

8. The 22 subjects whose ballistocardiograms were considered abnormal did not differ at all from the group as a whole in age or in the height of the blood pressure. However, their average height was 67 inches as compared to 69 inches for the total group, and their average weight was 6 pounds less than the average of 167 pounds for the entire series. These differences were not statistically significant.

SUMMARY AND CONCLUSIONS

1. The basic characteristics and variability of the ballistocardiogram as obtained from a well screened young population on an equalized portable electromagnetic ballistocardiograph have been described.

2. The most frequently observed variation involved changes in the expiratory complexes which, when of sufficient degree, have been considered abnormal. Ten (3.2 per cent) records were classed grade 1 and five (1.6 per cent) were classed grade 2 abnormal tracings for this type of change.

3. Variations of the H, J and K waves add a possible three (1.0 per cent) grade 1 abnormal records and four (1.3 per cent) grade 2 abnormal records.

4. The distortion due to tachycardia was described, and it is clear that such ballisto-
cardiograms cannot be interpreted. These records were not included in these percentages.

5. Tall L waves were noted in 19 (6.2 per cent) of the records and were not considered abnormal.

6. This study confirms the authenticity of the widely described criteria of normal, but demonstrates that variability sufficient to invoke a classification of grade 1 or 2 abnormality may occur in a small (7.2) percentage of clearly normal subjects. When respiration was suspended, only three (1.0 per cent) of these ballistocardiograms remained questionably abnormal.

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SUMARIO ESPAÑOL

Se registraron balistocardiogramas en 319 bien seleccionados soldados en un balistocardiógrafo electromagnético electricamente igualizado. Los trazados fueron analizados para los patrones básicos y para variaciones. El criterio convencional de lo normal se confirmó. La variación que se observó con mayor frecuencia consistió en los cambios de los complejos registrados durante expiración, que cuando de suficiente grado se asemejaban a las variaciones descritas como anormales. Ondas L prominentes se observaron comúnmente. Variaciones en las ondas J y K fueron raras. Una anormalidad grado I o II se notó en 22 trazados, pero cuando se abolió la respiración, solamente tres persistieron discutiblemente anormales.

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