# CARDIOMETRIC STUDIES ON CHILDREN[1]

## I. STETHOGRAPHIC PATTERNS OF HEART SOUNDS OBSERVED IN 1,482 CHILDREN

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### INTRODUCTION

IT IS a well-established fact that more deaths are attributed to a primary breakdown of the cardiovascular system than of any other single organ or organ-system. In 1930, for example, almost 23 per cent of the deaths among the white population of this country were listed as being due to diseases of the circulatory system and to congenital malformation of the heart. It has been repeatedly emphasized, and recently by Hedley (18), that although the bulk of this mortality occurs after middle-age, *all* ages are substantially affected. This is well illustrated by the fact that in 1930, in the white population, a cardiovascular disease was stated to be the principal cause of death of 6 per cent of the infants who died, 5 per cent of the children who died between one and 14 years of age, 12 per cent of the dead persons of age 15 to 49 years, and of 31 per cent of the dead aged 50 years and over. Thus, the official vital statistics show clearly that throughout the whole life span cardiovascular diseases are the primary cause of a considerable proportion of the deaths. This is so because the factors that bring about the breakdown of the heart and vascular system are several and they exert their lethal activities at different periods throughout the span of life.

From the data collected and presented by many investigators [*cf.* Wyckoff and Lingg (44), DePorte (13), Hedley (19)], it is known that congenital defects cause the majority of deaths from heart disease in infancy; the rheumatic manifestations in childhood, adolescence, and early adulthood; while syphilis appears as an important factor somewhat later. However, these conditions produce

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directly only a limited number of fatalities that are attributed primarily to cardiovascular diseases; by far the greatest number of cardiovascular deaths are associated with arteriosclerosis and other so-called degenerative processes that accompany advancing age. It is recognized that the age incidence of the latter forms of heart disease and their associated conditions is not the consequence only of the processes of ageing. Aschoff (1), in discussing the age incidence of arteriosclerosis, remarks (p. 5): "But mere ageing never results in deformation of the vascular wall and the vascular tube which are typical of arteriosclerosis. Therefore, arteriosclerosis is not merely a change or transformation attending the process of ageing; it is not a mere 'infirmity' of old age, but rather a disease of the vessels manifesting itself mainly during senescence." One can add that age *per se* is only a measure of the time interval during which the organism is exposed to the favorable and unfavorable conditions that influence its development and function. As the late T. Wingate Todd (36) wrote (p. 279): "Ageing implies therefore an unending alternation of injury and repair."

When such broad meaning is attached to the phenomenon of ageing it follows that the age incidence of the morbidity and mortality from cardiovascular diseases cannot be identical with the age at which the first injury to the heart and vascular system occurs. Instead, the former is the final expression of the age at which a deleterious agent first comes in contact with the organism, plus the time interval necessary for the agent to produce its injurious effects and, in addition, the length of time it takes the cardiovascular system to manifest its inability to cope with the damage received. Therefore, in the study of the genesis of heart disease these three temporal variables, dependent both on the inherent biological constitution of the cardiovascular system and on the environment, must be considered. Bearing on the validity of this viewpoint is the fact that heart disease resulting from rheumatic manifestations or syphilis may appear long after the rheumatic attack or the syphilitic lesion. Relative to syphilis, the recent authoritative report by Cole *et al* (11) has shown that the clinical signs of cardiovascular involvement can develop as long as twenty years or more subsequent to the infection. With reference to rheumatic diseases, DeGraff and Lingg (12), investigating over 1,500 patients, brought out the important fact that while on the average eleven years elapsed between the onset of rheumatic manifestations and the first signs of cardiac insufficiency, about 20 per cent of their patients developed heart disease twenty years after the initial rheumatic attack and over 10 per cent after thirty or more years. If rheumatic fever and syphilis, each of which produces pathognomonic lesions and is definitely a causative agent of heart disease, take such a varied amount of time to give overt signs of their deleterious effects on the heart and circulatory system, it is possible that the action of whatever factor or factors responsible for the so-called degenerative forms of heart disease may also be manifest in a similar manner.

On the basis of this assumption one can regard the age characteristics of the morbidity and mortality from heart disease as the temporal expression of the resultant of interaction between the biological worth of the cardiovascular system and the cumulative effects of many factors. Some of these, such as syphilis and rheumatic fever and chorea, are well known but there are others that are not specific and therefore have not been definitely recognized. Among the last there is some reason to believe that nutritional deficiencies as well as acute febrile diseases should be included since they are probably more important with respect to heart disease than is generally realized. Weiss (38) and others have noted that lack of vitamin $B_1$ can impair the cardiac function, and that this impairment in turn can be corrected by dietary measures. Heart involvement is also often the immediate cause of death from acute febrile diseases, as is the case in pneumonia, for example [*cf* Stone (32)]. But to what extent these conditions in general predispose to later cardiovascular diseases is not known with any degree of certainty, although some investigators think it is true of a number of the more common major infectious illnesses such as scarlet fever, diphtheria, and typhoid fever. Coburn (10) is of the opinion that scarlet fever is in some way related to rheumatic heart disease, while Nuzum and Elliott (25) report that a history of this disease is found often in hypertensive persons. In the opinion of Butler and Levine (7), diphtheria is a cause of heart block later in life, while Thayer (33), Barach (3), and Walker and O'Hare (37), from the data they examined, believe that typhoid fever is a causative factor in arteriosclerotic and hypertensive diseases. It is well to mention that none of the evidence presented regarding the relation of this group of diseases to cardiovascular failure later in life is conclusive. But when the possibility of such a relationship is borne in mind together with the other facts discussed above, it becomes apparent that to study adequately the genesis of heart disease the attention must be focused not only on the signs and symptoms that accompany it late in life but also especially on the means of discovering the first indications of its presence in the earlier years. Childhood and adolescence would seem to be particularly suited as a starting point of such an investigation for a number of reasons, including the prevalence of rheumatic fever as well as of the numerous exanthemata during this age period. Moreover, from the several surveys made in certain parts of this country it is seen that the incidence of heart disease among children varies from about 0.5 to almost 5 per cent, depending upon locality, age, and social characteristics of the sample studied [*cf.* the reviews of Sampson *et al* (30) and of Bainton (2)]. Sampson *et al* (30) report that in over 13,000 San Francisco school children the percentage of those found affected with all forms of heart disease equaled almost 0.4 per cent. In contrast, Paul *et al* (29), among 332 boys of a poor urban school of New Haven found 4.8 per cent with rheumatic heart disease alone. Thus, from these facts it is further perceived how valuable the period of childhood can be as a point of departure for a study of the genesis of heart disease.

All these considerations have led this office to initiate an investigation that has for its main objectives: (a) to study the characteristics of the cardiovascular activities in children and the factors associated with the related pathological and other changes observed during childhood and adolescence; (b) to formulate a public health program that will serve to facilitate and standardize surveys of the cardiovascular status of school children. To achieve either or both of these purposes requires, first of all, the development of methods of measuring as objectively as possible the cardiac function. Secondly, a more or less precise knowledge must be gained of the significance in terms of health and disease of the observations made. In view of these requirements, the initial step toward the planned objective will be in the direction of seeking and utilizing for the purpose the most adequate instruments that measure the activities of the heart and can be adapted as "screening" devices for the selection of those children with conditions that need intensive clinical study and special care.

Among the clinical instruments that give objective and permanent records of the status of the cardiovascular system, the two that measure more completely the principal cardiodynamic events are the electrocardiograph which records the changes in the electrical potentials of the heart, and the stethograph which registers the sounds resulting from the heart's mechanical activity. The electrocardiograph has long had a definite place in the clinic but has not yet been extensively utilized in the study of children not actually ill with heart disease. There are only a few studies, mainly those of Hecht (17), of Hafkesbring *et al* (16) and of Seham (31), that give data on the electrical characteristics of the cardiac activity of so-called normal children. The information collected by these investigators can in fact serve as standards for determining pathological variations. Use of this instrument in general surveys has been limited, however, probably because of the incidental cost and also because specialized knowledge is required for the interpretation of the records. The second type of instrument, the stethograph, has been developed for practical use only in the last few years although the relation of heart sounds to healthy and diseased conditions of this organ has been definitely recognized for over a century, since Laënnec's invention of the stethoscope. Oriás (27), Braun-Menéndez (6), and others in South America, and McKee (24) in this country have studied the results obtained by the use of this type of instrument on "normal" persons and have pointed out the advantages that derive from it, not the least being that the records obtained can be described in terms corresponding to those used by clinicians when referring to the auscultatory findings on the heart.

In the investigation in progress particular emphasis is being placed on the study of the cardiac activity by means of both types of instruments so as to determine also the relative advantages and disadvantages that might be associated with the use of either as a "screening" device in surveys of school children. In this paper, however, the preliminary results obtained by the use of the stethograph alone will be discussed. This report, which is the first of a series, will describe some of the outstanding characteristics of the heart sound tracings as observed in a sample of 1,482 unselected school children of Hagerstown, Maryland.

## The Stethograph

The limitations inherent in the direct and indirect methods of auscultation are becoming clearer and for some time students have directed their efforts towards developing methods of graphic registration of heart sounds. All the methods employed are based on the same general principle of substituting for the ear either a mechanical or an electrical device which by vibrating in resonance with the heart sounds records them graphically. The first satisfactory stethograph [*cf.* Oriás and Braun-Menéndez (26)] was that described by Einthoven and Geluk (14) in 1894. It utilized an electrical device and consisted of a carbon microphone to which was attached a capillary electrometer. Of the mechanical type was the instrument introduced by O. Frank in 1904. Somewhat modified, this is the type of apparatus with which Wiggers, his associates, and students have contributed so extensively to our knowledge of the physiology of the heart and circulatory system.

Up until the last few years such instruments were designed primarily for laboratory research and only recently has it been possible to obtain stethographs that are precise, compact, portable, and relatively inexpensive. The apparatus used in this survey (the electrostethograph manufactured by the Cambridge Instrument Company) is based on the model described in 1935 by Bierring, Bone, and Lockhart (5). Their report contains the details of the technical and constructional characteristics of this instrument, which is here described only in its essential features.

This stethograph is composed of three basic units: the microphone, the amplifier, and the recorder. The microphone is formed by a piezo-electric crystal element fitted with an open bell. The amplifier contains vacuum tubes which increase the intensities of the sounds received. The recorder consists of a galvanometer, a moving bromide film, a ground glass visualizing screen, and a pair of stethophones. These units operate in the following way: The sounds from the heart reach the microphone and are converted into electrical impulses, these impulses are amplified to the desired levels by means of the vacuum tubes and actuate the recording galvanometer, deflecting a beam of light transversely to the movement of the bromide film. The viewing screen and stethophones make it possible both to observe and hear the sounds as they are recorded.

Through the use of this assembly of electrical and mechanical units, therefore, the sound vibrations from the functioning heart may be perceived in three ways: First, the sounds amplified in intensity may be heard if desired by applying the stethophone unit to the ears. Second, the sounds may be visualized as a moving beam of light upon the ground glass viewing screen. Third, a permanent visual record of the sound waves may be perceived from the tracing made by the beam of light upon the photographic film.

In addition, this instrument is also equipped with a "pelotte" that can be placed over the radial, carotid, or any accessible artery. It consists of a glycerin capsule which transmits the impulses from the artery to a photographic recording unit within the stethograph. With the aid of the pelotte simultaneous arterial pulse tracings and heart sound records can be obtained.

## Material

This report is based on the stethographic records obtained by examining the white children of two public schools of Hagerstown, Maryland. All the children in attendance in the schools on the examination days were taken, without exceptions. Obviously, however, children having serious heart disease or any other disease which prevented their attendance at the schools on those days are not included here. So far as health and disease are concerned, therefore, these records may be said to typify the ones that would be obtained in a routine school health examination.

Two schools, the Antietam Grade School and the South Potomac Junior High School, furnished the 1,482 subjects used. In Antietam School, 779 children were examined and they represent about 25 per cent of the elementary school population of Hagerstown, while the 703 children seen in South Potomac Junior High School represent about 45 per cent of the junior high school population of the City. The Antietam School is limited to the first six grades and draws its pupils largely from the poorer families, many of whom are supported by welfare agencies. On the other hand, the South Potomac School, which contains the seventh, eighth, and ninth grades, draws its students from families that represent fairly well the different socio-economic groups living in the City.

It can be said then that while this material is unselected with respect to heart disease it does not represent a cross-section of the school population either from the standpoint of socio-economic status or from that of age. The last is evident from the following tabulation of the age and sex distributions of the children of this sample. Table 1 shows that 714 boys and 768 girls have been examined and that the mean ages are identical for the two sexes. It will also be noted that for each sex the age distribution is heavily weighted towards the higher ages. This illustrates well the fact that this sample contains a smaller proportion of young children than would be expected in a random sample of school children. This characteristic of the material must be kept in mind when evaluating the findings reported.

Table 1. Age and sex of Hagerstown school children who received a stethographic examination.

| Age (in Years) | Number | |
|---|---|---|
| | Boys | Girls |
| 6 | 40 | 50 |
| 7 | 53 | 49 |
| 8 | 44 | 58 |
| 9 | 47 | 54 |
| 10 | 60 | 55 |
| 11 | 71 | 59 |
| 12 | 99 | 122 |
| 13 | 128 | 129 |
| 14 | 101 | 132 |
| 15 and Over | 71 | 60 |
| Total | 714 | 768 |
| Mean Age | 11.3 | 11.3 |

## The Technique of the Examination

The elements of the examining procedure to which attention must be paid in the case of this test are three: the condition of the instrument, of the environment, and of the subject.

The working order of the stethograph was checked before and during each examination and in addition certain of the instrumental characteristics such as response to frequency of sound waves, the speed of film, and its uniformity were investigated at the United States Bureau of Standards before this work was begun. One of the most important of the instrumental characteristics is the speed and uniformity of movement of the bromide film on which the sound tracing is made. According to the specifications of the instrument, the film moves at a uniform speed of 100 mm. per second. A verification of this fact was attempted by recording and measuring some known pure tones. For example, a tracing was made of a pure tone of a frequency of 100 cycles per second and the total distances occupied by successive series of cycles were measured under magnification with needle-pointed dividers. The results of this work indicated that it was impossible to detect, by the methods used, any significant variation in the speed of the film. At the end of the study the stethograph was again checked by the makers, who detected no alteration in the operating characteristics of the instrument.

Preliminary work with the stethograph brought out the fact that room noises interfere considerably with the satisfactory recording of heart sounds. In particular, it was observed that sufficient amplification of the cardiac sounds to produce good tracings resulted in the frequent appearance of extraneous sound waves. In some instances it was difficult to distinguish on the stethogram between a true cardiac and an interfering sound. The problem which arises from this situation was solved for the present study by making all of the stethograms in a specially constructed sound-insulated booth. This booth, having inside dimensions of 5 x 6 x 6 feet, is made of four thicknesses of one-inch celotex boards, and is so constructed that it can be moved readily from place to place in school or other buildings. The use of the sound-insulated booth, it is believed, has definitely improved the quality of the tracings obtained, and justifies the extra difficulties of working inside the booth.

All the tracings were made in the schools by a carefully trained technician and under the close supervision of one of the authors (B.R.B.). The children, three or four at a time, were excused from their classes and walked to the location of the booth where they were required to sit quietly for periods which ranged from ten to thirty minutes before their stethogram was taken. During this time they were carefully instructed regarding the "test" and assured that it would in no way cause discomfort.

Before entering the booth the boys disrobed to the waist; the girls removed their outer clothing so that they could disrobe to the waist quickly after entering the booth. Work by the technician in the booth was carefully systematized. The child was seated in a standardized semi-reclining position as shown in Figure 1. The microphone, fitted with the large open bell throughout, was placed on the precordium and secured there by a rubber strap encircling the chest. The pulse recording pelotte was adjusted over the radial artery of the left wrist. The adjustment of the pelotte presents no difficulties, and good excursion of the light beam was easily obtained.

The placement of the microphone on three successive areas of the precordium was made carefully as follows:

> Mitral area: Approximately one inch below and one inch inside of the left nipple line. The intercostal space was used and not the rib surface.
>
> Pulmonic area: The second intercostal space immediately to the left of the sternal border.
>
> Aortic area: The second intercostal space immediately to the right of the sternal border.

Slight movement of the microphone around these areas was occasionally necessary in order to obtain the most intense sound and to seal properly the rim of the microphone against the skin.

After the proper adjustment at a particular area had been completed, the technician began to observe closely the respiratory rhythm of the child. As soon as breathing seemed to be regular, and always at a moment of expiration, the child was requested to stop breathing. It was during this period of cessation of respiration, usually made to last for the length of six to eight cardiac cycles, that the heart sounds were recorded.

The total time that each child remained in the booth was always less than ten minutes, and it is believed that fatigue was thus avoided.

## Stethographic Patterns of Heart Sounds in Children

The heart sounds perceived on auscultation result from the propagation to the outer thoracic surface of the vibrations that emanate from the cardiac activity. Apparently a number of heart sounds can be perceived and, in fact, even without electrical amplification Parker (28) has been able to describe five which he says occur normally during the cardiac cycle. The two most easily recognized are the so-called first and second sounds, but in addition there is a third sound which Thayer (34) in 1909 found audible at the apex in 65 per cent of the persons examined, and a fourth sound presumably of auricular origin which Braun-Menéndez (6) discusses and credits Clendenning as having first mentioned in 1840. Parker's fifth sound is not well individualized although it is described as occurring between the first and second sounds of the cardiac cycle.

In general, however, the first and second heart sounds; their occurrence within the cardiac cycle; the changes in their duration, intensity, pitch, and quality have been particularly studied and are regarded of special importance for clinical diagnosis. This description of the stethographic characteristics of the cardiac cycle will therefore give particular attention to these two sounds.

The basic pattern of the cardiac cycle—composed of the first and second sounds—appears on the stethogram in the form illustrated and schematized in Figure 2. As is shown in this figure, on the stethogram the heart sounds are registered as waves, while the period of silence that occurs between sounds is represented by a section of smooth base line. A first series of waves corresponds to the first or systolic sound; it is followed by a segment of smooth base line, the systolic interval. This is terminated by a second series of waves that correspond to the second or diastolic sound which is followed by another period of silence recorded as a segment of smooth base line and termed here the diastolic interval. The first sound together with the systolic interval form the mechanical

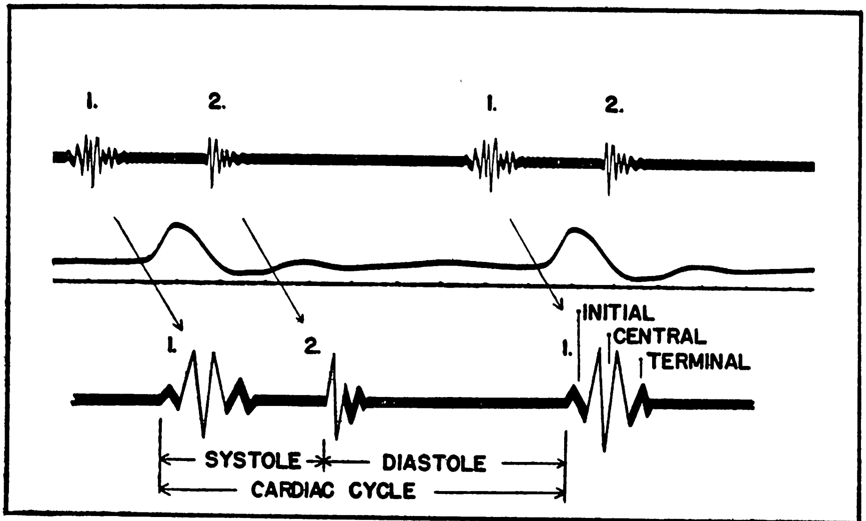


Fig. 2. Stethographic record of the basic pattern of the cardiac cycle and of its principal elements. Above is an actual tracing of two consecutive cycles. The first sound of each cycle is indicated by 1., the second sound by 2. This and all other tracings shown here have been recorded at a film speed of 100 mm. per second. The radial pulse wave recording is also seen and serves to individualize each cycle. Below is a diagrammatic representation of the cardiac cycle to illustrate the basic stethographic pattern of the systole, the diastole, and the three groups of waves constituting the first sound.

systole; the second sound together with the diastolic interval constitute the mechanical diastole.

Schematically such is the stethographic record of the basic pattern of the cardiac cycle, the "lub-dub" of the textbooks. In this paper is given a report on the frequency with which the basic pattern occurs in the sample of children examined and on the number and characteristics of the variations observed. Particular reference is made to the variations that involve the rhythm of the cycle, the pattern of the first and second sounds, the intervals of silence between sounds, and the occurrence of other sounds.

### I. RHYTHM

The frequency and regularity of the cardiac cycle within a given length of time can be measured accurately on the stethogram, since the sounds are recorded on a uniformly moving film. In a subsequent article, the biometric constants of the measurements of the

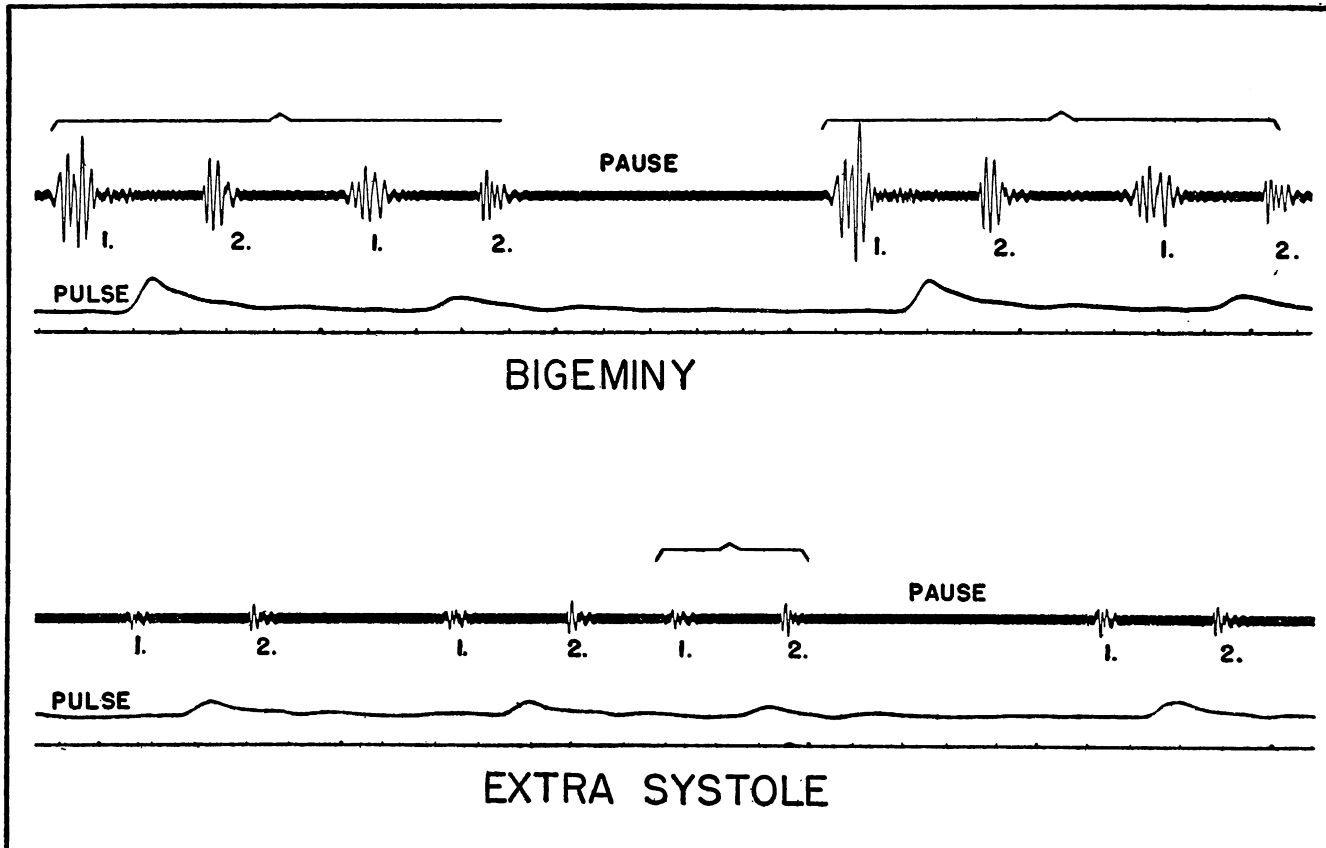


Fig. 3. *Above:* Actual stethographic record of a case of bigeminy or bigeminal rhythm found in one of the children examined. Note the coupling of the cardiac cycles and the long pause between pairs of cycles. *Below:* Actual stethographic record of a case of an occasional extrasystole. The "premature" cycle is shown by the brackets and the "compensatory" pause is also pointed out. In both tracings 1. indicates first sound and 2. indicates second sound.

rhythm and of other quantitative characteristics of the cardiac cycle will be presented, but in this preliminary report only those features of the periodicity of rhythm that are visible on inspection will be discussed.

It is well known that the rhythmic activity of the heart results from the periodic emission of impulses from the sinus node of Keith and Flack (21). The periodicity of impulses is not, however, absolutely uniform but varies perceptibly and continuously due to vagosympathetic [*cf.* Wiggers (41) (42)] and respiratory influences. As a result, the duration of the cardiac cycle—the length of time it takes for the heart to complete its cycle of activity—is not constant but varies from cycle to cycle. This variation in duration of cycle is almost always observed, so much so that some believe that perfect periodicity may be tantamount to a pathological condition. As a matter of fact, in this sample of children none was found that possessed perfect periodicity, or cycles of absolutely constant duration, throughout the period of examination. This is in agreement with the findings of McKee (24) in a sample of 105 children also examined with a stethograph. The extent of the individual variability relative to duration of cycle will be described in a forthcoming publication, and here it is sufficient to note that these findings support the accepted view regarding the rarity of a uniform rhythm of cardiac activity.

Besides the common irregularities or fluctuations of rhythm discussed above, variations in rhythm may have other more striking, and often clinically significant, characteristics. Of such major variations only two kinds were found in this sample: bigeminy and extrasystoles. Bigeminy is that condition in which two heart cycles are "coupled," i.e., follow each other closely, and each pair of cycles is separated from the following group of two cycles by a considerably lengthened diastolic interval (*cf.* Figure 3). This means then that in a group of two coupled cycles the diastole of the first cycle is shortened, whereas the diastole of the second cycle is lengthened. It is a rare condition about which no completely satisfactory physiological explanation has been advanced, although Wenckebach (39), especially, and Kaufmann and Rothberger (20) have formulated hypotheses not yet completely accepted. In this sample of children only one case of bigeminal rhythm was found and is illustrated in Figure 3. This finding is of interest because bigeminy is said to be found in persons with arteriosclerotic and degenerative forms of heart disease or, as Lewis (22) states, in cases of overdigitalization.

The occasional extrasystole is indicated on the stethogram (*cf.* Figure 3) by the occurrence of a cycle having a relatively abbreviated diastolic interval followed by a cycle in which the diastolic interval is of unusual length (compensatory pause). The systole of the second cycle is the extrasystole, the premature appearance of which has apparently shortened the diastole of the preceding cycle. The extrasystoles[2] are distinguished from bigeminal rhythm principally by their infrequent and irregular incidence in a succession of cardiac cycles. This variation of rhythm periodicity was here found in only five boys and four girls so that the relative frequency for the whole sample equals 0.6 per cent. That extrasystoles are found relatively infrequently in children is well recognized. McKee (24) does not mention any in her sample, while Lissner *et al* (23) found only one case in 138 children examined with the electrocardiogram. Lewis (22), Hecht (17), Seham (31), Bass (4), and others have reported extrasystoles rarely in children and then only associated with diseases, although not always heart disease.

### 2. FIRST SOUND

Wiggers and Dean (40) appear to have been among the first to have shown that the waves which represent the stethographic registration of the first sound may be segregated into three distinct groups which they termed introductory, main, and final waves. Succeeding investigators have since adopted other terminologies and today

[2] It should be noted here that on the stethogram it is not possible to determine whether the point of origin of the extrasystole is auricular, junctional, or ventricular.

these three groups of waves are usually called, respectively, initial, central, and terminal. These three groups of waves are shown in Figures 2 and 4 in which the basic pattern of the first sound, i.e., the pattern corresponding to the so-called normal physiological status, is illustrated both schematically and with photographs of actual stethograms. They may be described in the following way:

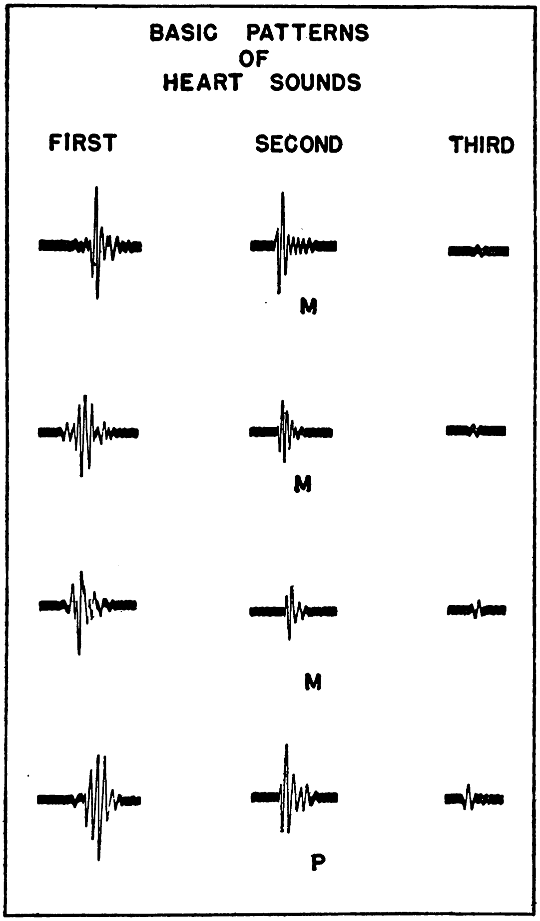


Fig. 4. Examples of the basic stethographic patterns of the first, second, and third heart sounds. M indicates that the record was taken with the microphone at the mitral area (apex) of the heart and P that it was taken at the pulmonic area (base).

(a) The low initial group of vibrations consists of ½ to 3 waves of low amplitude and low frequency. The amplitude may vary from a slight roughening of the base line to a height of several millimeters while the pitch is below that given by 50 double-vibrations per second.

(b) The central group of vibrations consists of from 1 to 5 waves of amplitude and frequency higher than those of the initial set. The amplitude ranges from 5 to 20 mm. in height of wave while the pitch is usually somewhat above 50 double-vibrations per second. It should be noted that occasionally the waves may appear notched or slurred (*cf.* Figure 4) but otherwise with no other modification in their continuity or character.

(c) The terminal vibrations consist of 1 to 3 low amplitude waves whose frequency appears to be essentially the same as that of the central group. The amplitude of these waves decreases rapidly as the end of the sound approaches.

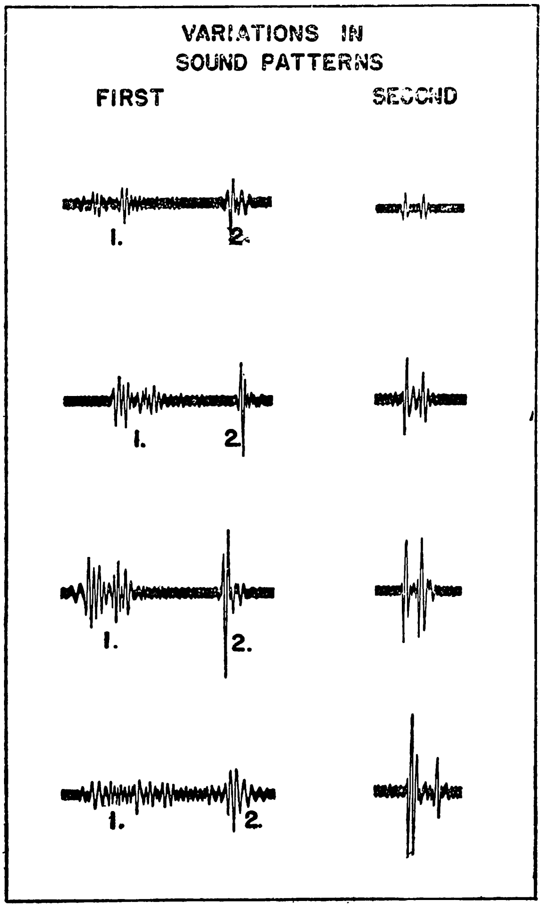


Fig. 5. Examples of variations found in the stethographic patterns of the first and second sounds. On the left, the three upper tracings of the first sound show various degrees of splitting together with prolongation. The bottom sample exhibits marked prolongation of the first sound and no definite termination. On the right, the records of the second sound exhibit various degrees of splitting and both components of the sound have nearly equal amplitude.

The basic pattern of the first sound characterizes almost 98 per cent of the stethograms of the children examined. Variations from this pattern were found in 3.4 per cent of the boys and 1.3 per cent of the girls. These variations consisted in modifications of the duration, intensity, or frequency of one or the other of the three groups of vibrations described. The more common of these variations are illustrated in Figure 5 and are characterized by (1) unusual prolongation, (2) imperceptibility of one or the other of the component sets of vibrations, (3) a distinct splitting and separation of the whole first sound into two groups of waves.

It should be noted that of the thirty-four cases of variations in the pattern of the first sound, the majority, or 62 per cent, were detected at the mitral area alone, 15 per cent could be perceived in all three areas examined, 12 per cent in both the mitral and pulmonic, and 12 per cent in the pulmonic area alone. None was recorded from the aortic area alone. Thus, in order of frequency, the variations described have been perceived first at the mitral area, secondly at the pulmonic, and last at the aortic area.

### 3. SYSTOLIC INTERVAL

In the basic pattern of the cardiac cycle, i.e., in the pattern corresponding to the "normal" physiological state of the heart, there occurs an interval of silence between the termination of the first and the beginning of the second sound. On the stethogram the basic pattern of this systolic interval is represented by a segment of smooth base line as shown in Figures 2 and 4. The basic pattern is not, however, the typical or most common pattern of the systolic interval so far as this sample of children is concerned since it is observed in only 41 per cent of the stethograms.

Interruption of the interval of silence by sounds of varied pitch, duration, and loudness constitute the variations from the basic pattern. These interrupting sounds, the murmurs heard on auscultation, are manifest on the stethogram by waves which replace in whole or part the smooth base line between the first and second sound. It is necessary to point out that not all similar stethographic modifications of the systolic interval can be perceived on auscultation. In fact, Wiggers (41) (42) suggests that in children there may be normally a group of vibrations following the first sound but which are not sufficiently intense to be appreciated by the ear. Since not all of these recorded variations of the systolic interval can be regarded as murmurs they shall be called here systolic vibrations, and thus any implication of pathology that may be read in the word "murmur" will be avoided.

Systolic vibrations were encountered in 59 per cent of the children. In the majority of the cases—78 per cent—they were perceived at all three chest areas examined; in 8 per cent they were perceived in the mitral and pulmonic area only; in 4 per cent at the mitral area alone, and in an equal percentage only at the pulmonic and aortic areas. Thus, while all areas may be regarded as favorable positions to detect systolic vibrations, the mitral (apex) and pulmonic (base) areas are the most favorable. This fact accords well with the conclusion reached by Thayer (35) and by Fahr (15) that the systolic murmurs so frequently observed in children often are due to turbulence of blood-flow and consequently are well heard at the base of the heart.

The intensity of the systolic vibrations can be graded by observing to what degree they replace the base line in each instance. Inspection of the tracing, particularly along its longitudinal axis, reveals that as the amplitude of the group of vibrations increases the base line narrows until there appears to be a loss of its continuity. Therefore, it has been possible to classify the intensity of the systolic vibrations into three grades which, so far as can be learned from this sample, appear to be easily and clearly distinguishable. The three grades of this classification have been termed: perceptible, definite, and marked.

The systolic vibrations are called "perceptible" when the base line maintains its full width but the upper and lower edges have a roughened or saw-toothed appearance (*cf.* Figure 6). "Definite" systolic vibrations are called those in which the saw-teeth are more pronounced and accompany a definite narrowing of the base line which is, however, continuous throughout the interval. The term "marked" is applied when the systolic vibrations replace completely the base line for a certain part of the interval. As the amplitude increases the base line disappears only to reappear when the vibrations decrease in amplitude. In this sample, the perceptible systolic vibrations are the most common, being found in 36 per cent of all the children (61 per cent of all systolic vibrations); definite systolic vibrations were found in 20 per cent of the children (34 per cent of the systolic vibrations), while marked systolic vibrations were found in only 3.0 per cent of the children (5 per cent of all the children with systolic vibrations). It is a well-established fact that during childhood and adolescence systolic murmurs, believed to be functional, are commonly observed. As it has been said, not all cases of systolic vibrations could be perceived as murmurs by auscultation, nor is it desired to imply that the systolic vibrations are identical to murmurs. However, it is with regard to such variations of the basic pattern of the cardiac cycle that objective and permanent records are most useful. When the appearance of the audible murmurs can be definitely identified on the stethogram it is hoped that repeated examinations will allow a clearer understanding of the significance of these variations in relation to health and disease.

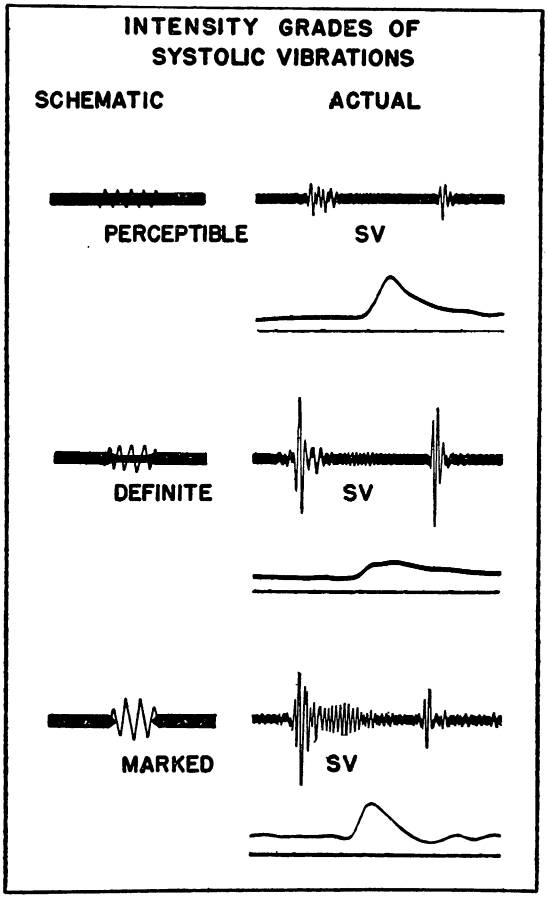


Fig. 6. Schematic representation of the threefold classification of systolic vibrations according to grade of intensity and examples from actual stethographic records. SV means systolic vibrations.

## 4. SECOND SOUND

The second sound is composed of a series of vibrations of shorter duration than the first, and somewhat higher in frequency (pitch). Wiggers says that their wave frequency is from 50 to 70 double-vibrations per second. The onset of the second sound typically is abrupt and the vibrations undergo a rapid decrement to the base line (*cf.* Figures 2 and 4). In general the waves form two distinct groups: one composed of 1 to 2 waves of high amplitude, the other contains 3 to 4 waves of low amplitude. The change from high to low amplitude is abrupt and often marked with a slight slurring or notch at the junction point of the two groups of waves. These are the characteristics of what may be called the basic pattern of the second sound. In this material it was found in 84 per cent of the children.

Variations from the basic pattern of the second sound may occur relative to duration, intensity, and frequency of the sound. In this sample, however, only a modification relative to duration was observed (*cf.* Figure 5). This variation consisted of a distinct separation of the two groups of vibrations, in some cases with a portion of the flat base line appearing between the two groups. In addition, the second group of waves instead of having a low amplitude had one which was almost equal to that of the first group of vibrations. This variation may be regarded as the stethographic equivalent of the clinical "split" second sound. In this sample it has been found in 285 cases, or 16 per cent of the children. In all except twenty-three instances it was detected at the pulmonic area only. This is in agreement with the general view [*cf.* Wolferth and Margolies (43)] that the reduplicated or split second sound is heard best at the base. It should be remarked that in nine children this variation was observed either at the mitral or at the aortic area only.

### 5. THIRD SOUND

Depending upon the point of view and definition adopted, the third heart sound may be regarded as a variation from, or a normal constituent of, the basic pattern of the cardiac cycle. Described in detail first by Thayer (34) who used auscultatory procedures, the third sound has been remarked on the stethograms by Braun-Menéndez (6) and Caeiro and Oriás (8) particularly. It consists of vibrations that are variable in number, duration, and amplitude, although the amplitude is usually low (*cf.* Figure 4). According to Braun-Menéndez (6), the third sound appears in most cases from 0.11 to 0.14 seconds after the beginning of the second sound and coincides with the "r" wave of the venous pulse. In other words, the third sound apparently coincides with the end of the rapid diastolic filling phase.

From the findings in this sample it would seem that the condition is not so rare since it was observed in 13 per cent of the children. In all but seven cases the third sound was detected at the mitral area alone.

The percentage of third heart sounds uncovered here is much lower than that reported by Thayer (34) after examining 231 presumably healthy persons, children and adults combined. In the total sample 65 per cent were found to have third heart sounds, but considering only the children almost 90 per cent had this condition. The large number uncovered by Thayer results from the fact that, as he noted, third heart sounds are heard best with the subject in a dorsal decubitus position. On the other hand, with the subject sitting (and thus in a position more nearly the same as that used here) Thayer was able to hear third heart sounds in only 13 per cent of the children examined. This figure, it will be noted, is identical to the one reported here.

### 6. DIASTOLIC INTERVAL

Above it has been mentioned that following the second heart sound, in the basic cardiac cycle pattern, an interval of silence occurs, terminated by the beginning of the first sound of the succeeding cycle. On the stethogram this, the diastolic interval, is represented by a segment of smooth base line, as illustrated in Figures 2

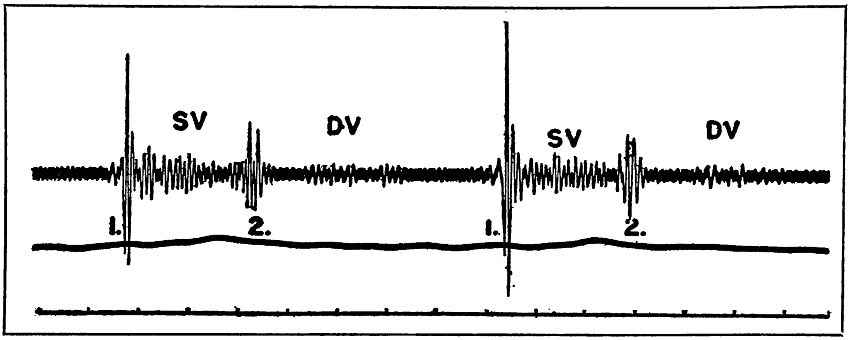


Fig. 7. Actual stethographic record showing diastolic vibrations. In this case marked systolic vibrations are also present. DV means diastolic vibrations, SV means systolic vibrations, 1. indicates first sound, 2. indicates second sound.

and 4. In certain instances and generally associated with frank pathological conditions, the period of silence is interrupted by the presence of so-called murmurs. Corresponding to the murmurs heard by the ear, the stethograph records vibrations which replace[3] in whole or in part the smooth base line. An example of these vibrations, here called diastolic vibrations and regarded as a variation from the basic diastolic interval pattern, is shown in Figure 7. Since the instrument can record sounds which are too faint to be heard by the unaided ear, it must be remembered that, as in the case of systolic vibrations, there may be present vibrations on the stethogram when no murmurs are perceived by simple auscultation.

In this sample of children only seven, or 0.5 per cent, were found to have stethograms showing diastolic vibrations. The small number observed may probably reflect the fact that diastolic murmurs are generally the expression of a diseased state of the heart.

## Frequency of the Basic Pattern and its Variations

The occurrence of the above described variations from the basic pattern is summarized in Figure 8. It is seen that bigeminy, diastolic vibrations, and extrasystoles have been observed in less than one

[3] It has already been remarked that the diastolic interval may be broken by the presence of a third heart sound, but in this case the residual interval is still registered as a smooth base line.

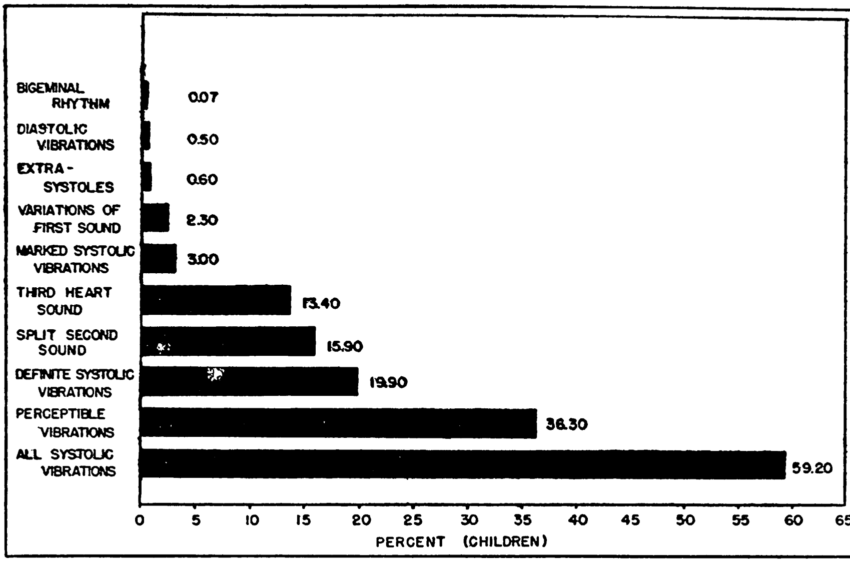


Fig. 8. Per cent of children whose stethographic records show the stated variations from the basic cardiac cycle pattern.

per cent of the children. Variations from the basic pattern of the first sound and systolic vibrations of a marked degree are more numerous and have been noted in 2 to 3 per cent of the sample. Variations characterized by the presence of the third sound, a split second sound, or definite systole vibrations are far more common, being found in 13 to 20 per cent of the children. The most common of all the variations are the perceptible systolic vibrations which occur in over one-third of the subjects. If all grades of systolic vibrations are taken together, then the data show that such variations are present in the stethograms of over half of the children.

It is obvious from the findings discussed above and in the preceding section that the typical stethographic pattern of the cardiac activity of children is not represented by the basic pattern (*cf.* Figure 2) alone but includes one or more of the variations described. This is clearly seen in Figure 9, which presents the percentage of the children whose stethograms show the basic pattern only, of those who have also perceptible systolic vibrations, and so on; the

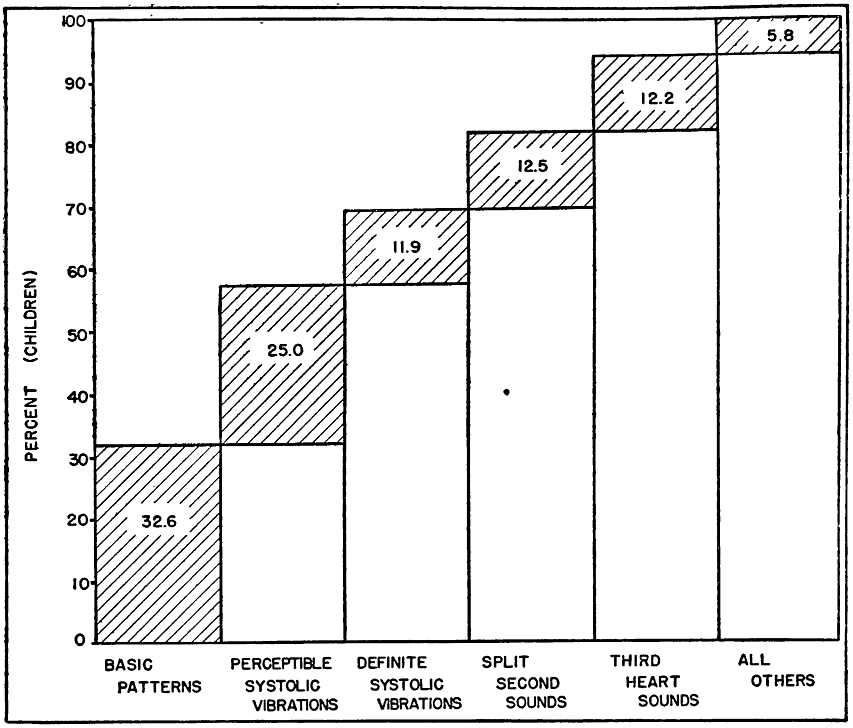


Fig. 9. Per cent of children whose stethograms show: (1) only the basic pattern, (2) a stated variation alone or accompanied by one of more frequent occurrence in the sample (*cf.* Fig. 8). The height of the cross-hatched bar indicates the percentage of children with stethograms showing the stated pattern alone or together with those mentioned to the left on the abscissa. The total height of the bar equals the percentage of children whose stethograms have one or all of the patterns stated so far on the abscissa.

order of the inclusion of the variations being based on their order of frequency in the sample as given in Figure 8. Thus, the data of Figure 9 indicate that less than a third of the children have stethograms that show only a basic pattern. Since altogether in 25 per cent of the cases perceptible systolic vibrations was the only type of variation noted, it means that 57.6 per cent of the children had either a basic pattern alone or one accompanied by perceptible systolic vibrations. Similarly, it is seen that almost 70 per cent of the children gave stethograms that revealed either a basic pattern alone or one that included perceptible and definite systolic vibrations, while in 82 per cent of the cases a split second sound was also observed at times.

In 94.2 per cent of the children there was found either a basic pattern alone or one that contained perceptible or definite systolic vibrations, a split second sound, and a third sound but no other form of variation from the basic pattern of the cardiac cycle.

Without introducing corroborative clinical and laboratory information, no attempt can be made at this time to pass judgment on the pathological significance of these findings unless one assumes, as is too often done, that rarity is synonymous with abnormality. In this paper, purposely limited only to a description of the observations, it is sufficient to remark that the children whose stethograms showed either bigeminy, extrasystoles, splitting, etc. of the first sound, diastolic vibrations, or marked systolic vibrations constitute 5.8 per cent of the sample. It would be expected that in this group are included a considerable proportion of the cases of cardiac dysfunction.

## Sex and Age in Relation to Pattern of Stethographic Records

Since there is a sex difference in the mortality and the morbidity from diseases of the heart and circulatory system [*cf.* Ciocco (9)], it is of particular interest to inquire if in childhood a sex difference in the frequency of the patterns of the heart sounds is to be noted. As a matter of fact, some, although not very striking, differences are demonstrable. The basic pattern of the cardiac cycle was found less often in boys than in girls, the percentages being 28.7 and 36.2 respectively. The difference is statistically significant and indicates that, taking all forms of variations, they occur definitely more often in males than females. Considering individually the more common forms of variations, their higher frequency among the boys is true for all grades of systolic vibrations (boys 61.5 per cent, girls 57.2 per cent), split second sounds (boys 18.6 per cent, girls 13.3 per cent), and for splitting, etc. of first sound (boys 3.4 per cent, girls 1.3 per cent). On the other hand, third heart sounds occur in 14.8 per cent of the girls and only 11.8 per cent of the boys. It is to be

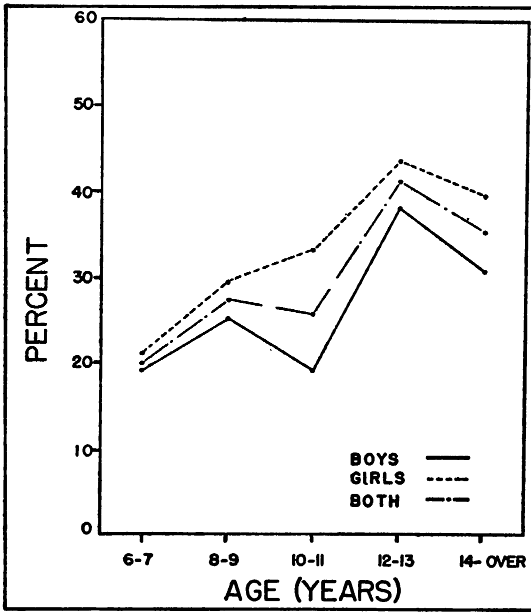


Fig. 10. Per cent of children of stated age whose stethograms show a basic pattern alone.

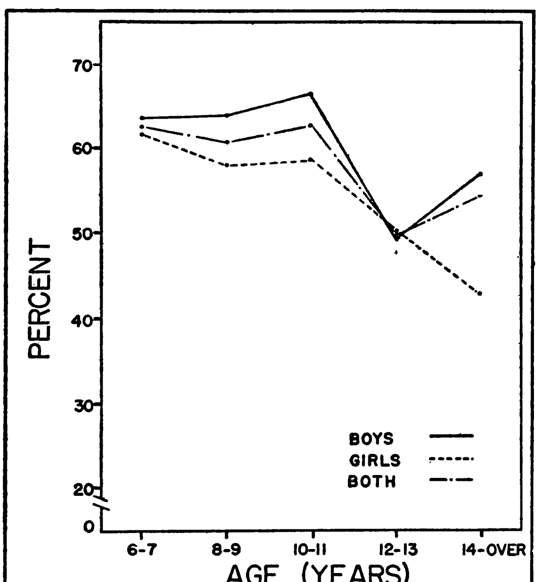


Fig. 11. Per cent of children of stated age whose stethograms have either perceptible or definite systolic vibrations, or both.

realized that for none of the forms of variations mentioned is the difference between the boys and girls sufficiently large to be judged as definitely significant in terms of the sampling error. Altogether they are suggestive, however, and deserve to be investigated further as possible explanations of such sex differences as, for example, the higher incidence of endocarditis in females and of the degenerative forms of heart disease in males.

The higher frequency of the basic pattern of the cardiac cycle in girls is found at all ages. This is demonstrated in Figure 10 in which are given for each two-year age group the percentages of boys and girls whose stethograms showed the basic cardiac cycle pattern only. Moreover, it is seen that for both sexes the percentages tend to become higher with increasing age—relatively more of the older children have a basic cardiac pattern than do the younger ones. Therefore, on the whole, variations are more common in younger than in older children. For systolic vibrations, perceptible and definite combined, the expected age trend is not so regular although from Figure 11 it is apparent that there are relatively less children with these grades of systolic vibrations after 12 years of age than before. The irregularity in the age trend in part may be the result of aggregating all kinds of systolic vibrations, those perceived at only certain chest areas together with those detected at others. In fact, if only the systolic vibrations that were perceived at all three chest areas of the subject are considered, it is found—as will be noted in Figure 12—that the age trend becomes smooth and regular. Among the youngest children systolic vibrations are uncovered over one and one-half times more often than among the oldest. Moreover, it is also seen that with the exception of the 12-13 age group the percentages are higher in the boys than in the girls.

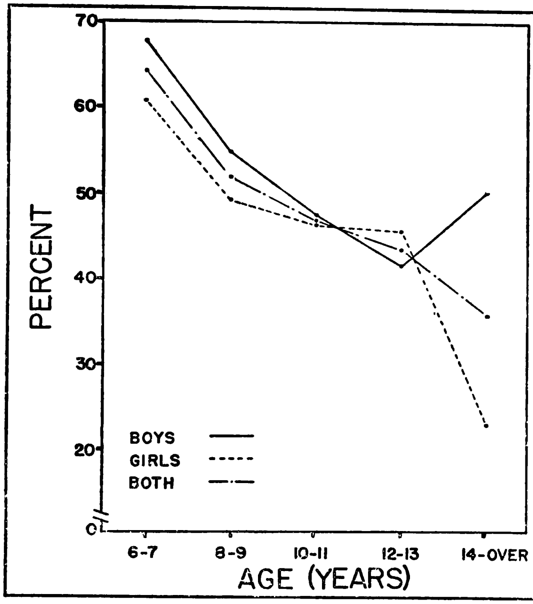


Fig. 12. Per cent of children of stated age whose stethograms show systolic vibrations that were detected at the mitral area only or at the mitral and also at other areas.

Split second sounds also occur somewhat less often in the older than in the younger age groups; however, for the boys particularly the age trend is not consistent in one or the other direction (*cf.* Figure 13). The percentages increase with age until 10-11 years, and

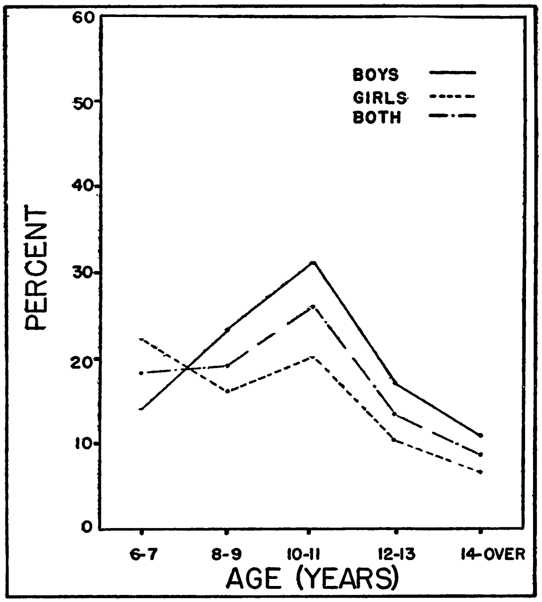


Fig. 13. Per cent of children of stated age whose stethograms show a split second sound.

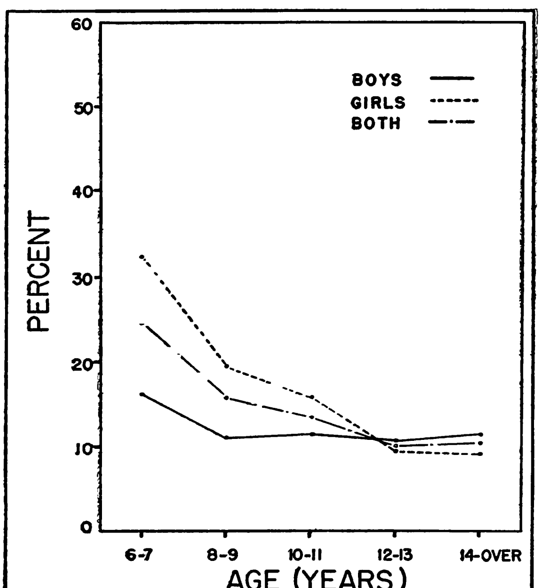


Fig. 14. Per cent of children of stated age whose stethograms show a third heart sound.

then decline thereafter. Although the data for the girls reflect a similar sequence, they appear to show a little more definitely that the frequency of this type of variation from the basic cardiac cycle pattern decreases with increasing age.

A relatively greater number of girls having third sounds is to be found, as illustrated in Figure 14, from the ages 6 to 11 inclusive. Thereafter, there is little sex difference although the percentages are slightly higher in the boys. Taking both sexes together it is seen that the frequency of the third sound also decreases more or less with increasing age, it being found over two and one-half times as often in the youngest as in the oldest age groups. However, when the sexes are considered separately the