OSCILLATORY PROPERTIES OF THE HUMAN BODY

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Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 55, No. 6, pp. 65-69, June, 1963
Original article submitted July 13, 1962

Analysis of the fading of oscillations in the human body caused by the brief action on it of forces (impulses) can give various items of information regarding the oscillatory properties of the organism. Such information has already found wide application on ballistocardiography — a procedure involving recording of body oscillations caused by internal forces arising from the action of the circulatory apparatus. Examination of the physical properties of the human body may be of value in other cardiological procedures, such as cardiography, phonocardiography, dynamocardiography, and others.

Because of the elastic properties of the tissues of the human body, it may be regarded as being a kind of oscillatory system. If a person is lying on a rough surface, this system may be represented by a model (Fig. 1). A body of mass m is connected to a resistance by an sisodromic device, consisting of a spring (S) and a damper (D). It is evident that when a force of short duration acts on the body in the direction S–D, it will begin to execute free, diminishing oscillatory movements about the position of rest, or, more precisely, about the point of stable equilibrium (0-0').

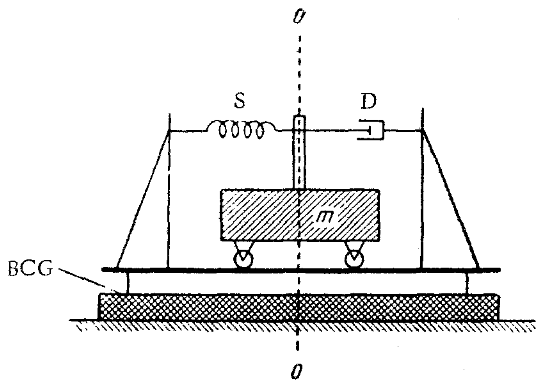

Fig. 1. Model for analysis of oscillatory properties of a body

Curves recording decay of body oscillations were obtained in the following way. The subject is placed on the platform of a high-frequency ballistocardiographic table, and a force of brief duration is applied along the long axis of the body (a gentle push on the shoulders or head). The resulting oscillations are recorded on a ballistocardiogram (Fig. 2).

Direct and ultra-low frequency ballistocardiographs were formerly used for recording intrinsic oscillations of the body. M. I. Tishchenko [3] has shown that high-frequency ballistocardiographic tables may be used for this purpose.

We applied this technique to the examination of 135 persons, aged from 18 to 67. The weight of the subjects ranged from 40 to 1?2 kg.

Analysis of the oscillation decay curves permits, in the first place, of determination of the frequency of intrinsic oscillations of the human body (f_0), in c. p. s.:

$$f_0 = 1/T, \qquad (1)$$

where T is the period of oscillation, in seconds (see Fig. 2).

Our observations showed that, for healthy individuals, the value of f_0 varied within a relatively narrow range (3.3-2.5 c. p. s.), the mean value being 4.36 c. p. s. (see the table). These findings are in agreement with published ones [5-8].

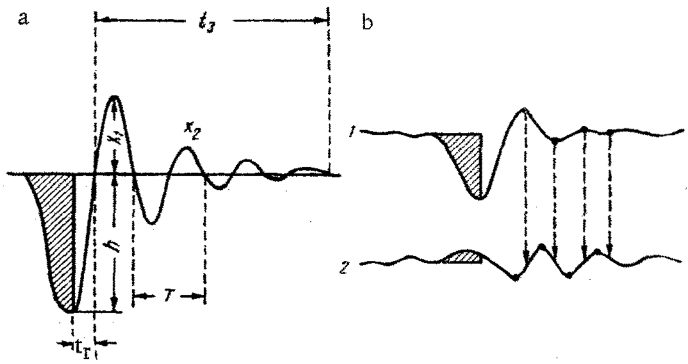

Fig. 2. Curves representing diminishing oscillations of the human body to which an impulse has been applied along its long axis. a) Longitudinal diminishing oscillations; b) longitudinal (1) and transverse (2) diminishing oscillations (the arrows demonstrate that the curves are out of phase). The shaded areas indicate displacement of the body during application of external force.

Low values of f_0 are frequently encountered in morbid conditions. It is noteworthy that low frequencies of intrinsic oscillations of the body are found in patients suffering from severe (and chronic) impairment of motor activity. Thus, in a group of patients suffering from a serious complication of myocardial infarction—cardiac aneurism, and who had been treated as semi-ambulant cases for a long time, the values of f_0 varied from 2.5 to 4.9 c. p. s., mean value 3.64±0.13 c. p. s. It may be supposed that the lowering of f_0 in individuals with restricted motor activity is due to lowering of the tonus of the musculature and of the subjacent tissues.

Schroeder and Wendhut [7] demonstrated an age dependence of the value of f_0; the frequency of endogenous oscillations of the body was higher for aged people than for younger ones.

The attachment of the body to the resistance has a significant effect on the value of f_0 [5], and this applies in particular to the connection of the lower extremeties to the resistance [1,3,5]. It was found that the firmer the attachment, the higher was the value of f_0, and vice versa. This is what might be expected from the basic formula:

$$f_0 = \frac{1}{2\pi} \cdot \sqrt{\frac{K}{m}}, \tag{2}$$

which establishes a direct dependence between the frequency of intrinsic oscillations of the body (f_0), its mass (m), and the firmness of its attachment to the resistance (K).

It could be supposed, on the basis of equation (2), that the value of f_0 should depend on the mass of the body (m). We found, however, that f_0 was so weakly correlated with m that statistically significant changes in the values of f_0 could not be discerned before and after removal of ascites fluid from patients (up to 10 liters from patients of body weight 60-70 kg).

Knowing the mass of the subject, and the frequency of intrinsic oscillation of his body, the value of K may be derived from equation (2). This value may arbitrarily be termed the elasticity coefficient of the underlying tissues. Analysis of the model (see Fig. 1) shows that the magnitude K characterizes the force required to lengthen the spring S by 1 cm, and is expressed in 1-cm units. Noordergraaf [5] and Corti [4] have made a study of K. We found that its value varied from $3 \cdot 10^7$ to 10^8 dyne/cm, with a mean of $5.07 \cdot 10^7$ dyne/cm (see the table).

For the characterization of the extinction curve of body oscillations it is evident from the laws of mechanics that the logarithmic decrement of extinction (B) needs to be derived:

$$B = \ln x_1/x_2 = \alpha T, \tag{3}$$

where x_1 and x_2 are the amplitudes of corresponding phases of oscillation (see Fig. 2), and α is the extinction coefficient.

Normal Standard Indices of Oscillatory Properties of the Human Body

Index	M±m
Frequency of oscillations of the body (c. p. s.)	4.36±0.04
Elasticity coefficient of underlying tissues (10^7 dyne/cm)	5.07±0.21
Logarithmic decrement of extinction	0.84±0.03
Time of extinction of oscillation (seconds)	0.56±0.02
Time of return (seconds)	0.075±0.002
Oscillation index (%)	51.0±2.6

The logarithmic decrement of extinction of the subjects varied from 0.4 to 1.5, mean 0.84.

The above specified indices may, with full justification, be termed classical indices of the oscillatory properties of the body. We think that three other indices might be added, and that their addition would contribute substantially to our knowledge of the oscillatory properties of the body. These indices have been taken from the theory of automatic regulation. The following concepts were used in the formulation of these indices.

It was noticed that the curves of the transition process of so-called isodromic regulation were identical with those representing body oscillations following application of an impulse. Examination of the model of the system "body–resistance" shows that this similarity is not fortuitous–the attachment of the body to the platform of a ballistocardiograph is of the nature of an isodromic device.

We have called the first of our proposed new indices the time of extinction of oscillations (t_e). As is shown in Fig. 2,a, this time is the interval between the beginning and the disappearance of the intrinsic oscillations of the body. The value of t_e varied from 0.3 to 1 second for the individuals examined by us, but was 0.4-0.7 seconds for most of them. Since the value of t_e is to some extent dependent on the strength of the displacing force (shaded area of Fig. 2), it is desirable to record the diminishing oscillations following application of a standard external force. The extinction time bears a certain relation to the frequency of intrinsic oscillation of the body (Fig. 3,a).

We have called our second new index the time of return (t_r). As is indicated in Fig. 2,a, t_r is the time interval between removal of the external force and transit of the body through its equilibrium point (the continuous horizontal line shown in Fig. 2). The time of return is a characteristic of the elasticity of the underlying tissues of the human body. For the subjects examined by us t_r varied within the limits 0.02-0.15 seconds, mean value 0.075 seconds (see the table).

We thought it would be profitable to study the oscillation coefficient (σ), which is analogous to the transregulation coefficient of the theory of automatic regulation. This coefficient is derived in the following way:

$$\sigma = x_1/h \cdot 100\%, \quad (4)$$

where x_1 is the amplitude of the first oscillation, h is the amplitude of displacement of the body by the externally applied force (see Fig. 2,a). Instead of h we may use the area below the curve expressing displacement of the body by the externally applied force (shaded in Fig. 2).

The value of the oscillation coefficient varied within the range 20-60% for most of the observations, mean value 51%. Its value was found to be reciprocally related to that of the time of return (Fig. 3,b).

We shall, in conclusion, discuss some of the problems of the kinematics of a body lying on a plane. Although the external force was applied to our subjects strictly in the direction of the long axis of their body, oscillatory movements of the latter were observed not only parallel to this axis, but also transversely to it. The amplitude of the transverse oscillations amounted usually to 10-30% of that of the longitudinal ones. It is of interest that about the same ratio is found between the amplitudes of longitudinal and lateral ballistocardiograms [2] as between the amplitudes of the longitudinal and transverse oscillations following application of an external force.

It was frequently found that the curves recorded synchronously for longitudinal and transverse oscillations following application of an external force of short duration were out of phase (Fig. 2,b). Such recordings were taken either on a multicomponent ergometric table, which permitted of the registration of the separate components of the movements of the body in space, or by recording the oscillatory curves on a high-frequency ballistocardiograph and a

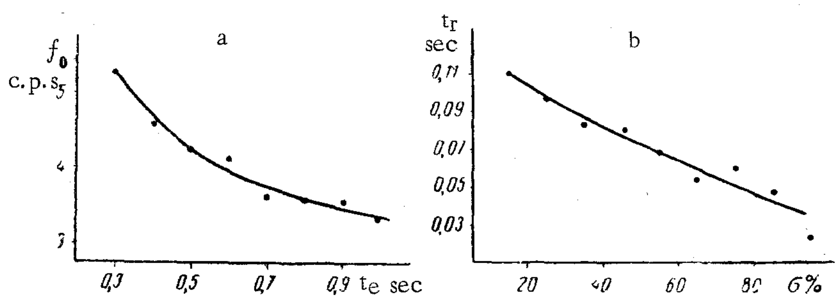

Fig. 3. Dependences of the frequency of intrinsic oscillations of the human body (f_0) on the time of extinction of oscillations (t_e), (a); and of the time of return (t_r) on the oscillation coefficient (σ), (b).

transversely directed direct displacement counter. This observation is analogous to what is frequently seen in longitudinal and transverse ballistocardiography, that the peaks of the waves of the two recordings are not synchronous.

The resemblance between the kinematics of the body due to externally or internally applied forces permits of the use of the former as models of the latter; this is of both theoretical and practical importance.

SUMMARY

The frequency of body oscillations caused by application of single impulses to a number of supine subjects has been measured, as well as the elasticity coefficient of their underlying tissues, and the logarithmic decrement of extinction of oscillations. The following additional indices of the oscillatory properties of the body are proposed: time of extinction of oscillation (t_e), time of return to the equilibrium point (t_r), and the oscillation index (σ).

Both longitudinal and transverse damped oscillations were observed following application of a strictly longitudinal directed impulse; these oscillations were in many cases out of phase.

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