The energy spectrum of this flux is similar to that of the sun, but in an expanding steady-state universe [suggested by the theory of Bondy and Gold (*8*)], the energy distribution is still lower as a result of the Doppler shift. One gets a reaction rate $\Im\ \sigma < 10^{-38}$ ν sec^{-1} for this flux, which is certainly a very small value. The antineutrino flux can be neglected.

If, on the other hand, the birth of heavy nuclei took place in an early, compressed state of the expanding universe, one would expect much more intensive neutrino radiation. In the highly compressed state of matter most of the nucleons had to be in a neutron-rich state, and during the formation of the proton-rich state of today, also an antineutrino flux of relatively high energy distribution and of relatively high intensity had to be emitted: $\Im \approx 10^{7}$ $\bar{\nu}$ cm^{-2} sec^{-1} [that is, the density of the neutrinos has to be comparable to the proton density (*9*)]. This corresponds to a detecting reaction rate $\Im\ \sigma \approx 10^{-35}$ $\bar{\nu}$ sec^{-1}. If the compressed state of matter were connected with a high temperature, a thermal neutrino and antineutrino radiation of considerable density also would have originated. Thermodynamic equilibrium between neutrinos and atoms can be attained in a state of nuclear density in microseconds; in a state of stellar density, in years; and in a state of the average density of today, in about 10^{30} years. This means that after a certain stage of expansion no interaction takes place any longer and the hot neutrino-antineutrino gas "freezes"; the intensity and spectrum of the gas are no longer regulated by the atomic interactions but by the adiabatic expansion. According to the laws of thermodynamics, experimental detection below a neutrino temperature of 10^{8}°K is not possible. An observed equal intensity of neutrino and antineutrino flux would be explicable on the basis of an origin connected with thermodynamical equilibrium. There seems to be only one other explanation: If celestial bodies built up from common matter and celestial bodies built up from antimatter are isolated from each other and occur in the universe in equal abundance—that is, if not only the physical laws but also the physical state of the universe are invariant with respect to PC transformation, being neutral with respect to electric charge and baryonic charge at the same time, the average neutrino and antineutrino density would be equal everywhere (*7*).

The answer to the question of whether the detection of neutrinos will make it possible to decide between the different cosmogonical views depends on whether the detection threshold attainable today, $\Im\ \bar{\sigma} = 10^{-30}$ $\bar{\nu}$ sec^{-1}, can be diminished by several orders of magnitude. The most difficult problems of decisive importance are that of eliminating the much more dominant neutrino radiation emitted by the sun and that of the antineutrino flux of terrestrial radioactivity; this background intensity is of a greater order of magnitude than the cosmic flux to be detected. Neutrinos of high energy distribution are emitted in the atmosphere also by the decaying mesons generated by cosmic rays, but the total intensity of this radiation is nevertheless negligible as compared to the neutrino fluxes mentioned above. The anisotropic angular distribution of the electron emission in certain neutrino capture reactions would serve as a useful basis for the construction of a "telescope" differentiating neutrinos of terrestrial or solar origin and neutrinos of stellar origin, respectively. The differential cross section of the capture reaction is as follows:

$$\sigma(\theta)\, d\Omega = \frac{f^2}{16\pi^2\hbar^4c^3}\left\{\left|\int 1\right|^2\left(1+\frac{v}{c}\cos\theta\right)+\left|\int \sigma\right|^2\left(1-\frac{1}{3}\frac{v}{c}\cos\theta\right)\right\} pE\,d\Omega$$

where θ denotes the angle between the direction of the captured neutrino and the emitted electron. In the case of reaction 1, the angular dependence of $\sigma(\theta)$ does not exist, but, for example, for the pure Gamow-Teller transition

$$\bar{\nu} + D \rightarrow n + n + e^{+} \qquad (3)$$

(energy threshold 4 Mev) one can draw conclusions about the direction spectrum of the incoming antineutrinos from the angular distribution of the positrons. Naturally this makes the telescope method applicable only for high-energy neutrinos and makes the possibility of detection much further away than is suggested by the accuracy $\Im\ \sigma = 10^{-30}$ $\bar{\nu}$ cm^{-2} sec^{-1} obtainable today. Another possibility would be that offered by measuring the neutrino energy spectrum—namely, by comparing the absorption rates in nuclei with different energy thresholds.

GEORG MARX
NORA MENYHÁRD

Institute for Theoretical Physics of the Roland Eötvös University, Central Research Institute of Physics, Budapest, Hungary

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Computer Analysis of Reflex Control and Organization: Respiratory Sinus Arrhythmia

Abstract. Respiratory sinus arrhythmia in waking man is described by differential equations which relate thorax circumference acceleration to instantaneous heart rate. Consequent experiments show that the arrhythmia is initiated by stretch receptors within the thorax rather than by hemodynamic or central factors, and that it is due mainly to superimposed biphasic inspiratory heart rate transients of about 15 seconds' duration. Analysis of respiration heart rate reflex provides a new quantitative physiological tool.

The changes in heart rate produced through changes in vagus inhibition, which accompany respiration, present both a varied and regular picture. The regularities appear as waves in the heart rate of the same frequency as the respiration. As a result of this regularity it has usually been assumed that a causal relation exists between inspiration and cardiac acceleration, and between expiration and deceleration (*1*). Certain investigators have observed, however, that the wavelike changes in the heart rate often show the opposite phasic relation to respiration (*2*). Recent work displays what appeared to look like a lag of one cycle between the respiration and the heart rate waves (*3*).

The irregularities in the heart rate trace have been difficult to relate to respiration. How much of the unwavelike and apparently irregular changes may be due to respiration as compared with other causes has remained undetermined. In order to investigate these conflicting results, we have applied the method of dynamic analysis as developed for automatic control system theory (*4*). Simulation by analog computer techniques, in experiments designed with the aid of control system theory, with unanesthetized human subjects, shows several results.

1) Two different biphasic reflexes are the main causes of changes in heart rate produced by respiration. One of these is produced only by inspiration and the other only by expiration. The two reflexes are both biphasic in the same direction. Each reflex first causes acceleration and then deceleration of the

heart rate. The time course of the reflex is of the order of 4 seconds for the accelerated phase and 10 seconds for the decelerated phase, making a total of 14 seconds for the complete transient. The expiration transient differs to some extent in shape from the inspiration transient, being usually of smaller amplitude and having a somewhat longer acceleratory phase, but it is in no way in the opposite direction from the inspiration transient, but clearly in the same direction.

2) The observed patterns of heart rate changes produced by respiration are the result of the superposition of biphasic heart rate transients which may or may not have time to complete themselves before the onset of the next transient. Because of the diphasic nature of these transients and the fact that both the inspiration and expiration are in the same direction, the wavelike patterns observed bear a different phasic relation to respiration depending on how fast the respiration rate is.

3) For respiration rates of about 4 per minute and slower, sufficient portions of the transients can complete themselves to give the effect of twice as many heart rate waves as respiratory waves. If one employs a method of step-wise breathing—that is, inspiration in several steps and likewise with expiration—then one obtains a biphasic heart rate transient for each step in respiration. In this way one can obtain any whole number relation between respiration and heart rate waves.

4) The time course of basic inspiration heart rate transients is independent of the degree of normal activity or rest, and thus of blood flow. The time course of the reflex in a given individual does not change regardless of initial heart rate.

5) Atropine in doses sufficient to reduce materially the amplitude of the heart rate transient (0.6 mg, intravenous) changes the time course of the transient, producing considerable slowing. As recovery from the effect of atropine takes place, the time course returns to its normal relationship and even temporarily becomes faster than the normal value of about 14 seconds. Both the time course of recovery and the extent of changes are dissimilar for the two reflexes.

6) Positive- or negative-pressure artificial respiration produces heart rate transients similar to those of natural respiration for similiar respiratory maneuvers.

7) Of 50 subjects tested, every one showed the two basic biphasic reflexes. Individuals showed considerable differences in amplitude and lesser differences in duration of reflex.

8) The mathematical expressions for the changes in vagus inhibition producing these heart rate changes are given by Eqs. 1 (for $dR/dt > 0$) and 2 (for $dR/dt < 0$).

$$\frac{\mathcal{V}}{\mathcal{R}} = \frac{-ks^2}{(1 + T_1 s)\ (1 + T_2 s)} \qquad (1)$$

$$\frac{\mathcal{V}}{\mathcal{R}} = \frac{k's^2}{(1 + T_1 s)\ (1 + T_2 s)\ (1 + T_3 s)} \qquad (2)$$

These are the transfer functions relating changes in vagal inhibition to respiration. (Transfer functions are convenient means of handling linear, high-order differential equations in terms of Laplace transforms.) V is the vagal inhibition (as a firing rate) and R is the circumference of the thorax (the Laplace transforms of V and R are $\mathcal{V}$ and $\mathcal{R}$, respectively); s is the Laplace operator; T_1, T_2, and T_3 are time constants; and k and k' are sensitivity constants. The parameters for the inspiratory reflex are thus k, T_1, and T_2. For the expiratory reflex they are k', T_1, T_2, and T_3.

These transfer functions (Eqs. 1 and 2), written in the usual differential equation form, become Eq. 3 (for $dR/dt > 0$) and Eq. 4 (for $dR/dt < 0$)

$$\frac{d^2V}{dt^2} + \frac{T_1 + T_2}{T_1 T_2}\frac{dV}{dt} + \frac{V}{T_1 T_2} + \frac{k}{T_1 T_2}\frac{d^2R}{dt^2} = 0 \qquad (3)$$

$$\frac{d^3V}{dt^3} + \frac{T_1T_2 + T_2T_3 + T_3T_1}{T_1T_2T_3}\frac{d^2V}{dt^2} + \frac{T_1 + T_2 + T_3}{T_1T_2T_3}\frac{dV}{dt} + \frac{V}{T_1T_2T_3} - \frac{k'}{T_1T_2T_3}\frac{d^2R}{dt^2} = 0 \qquad (4)$$

Note that the respiration enters the equations only as a second derivative, or acceleration, of thorax circumference; the switching of equations depends on the sign of the motion.

The differential equation relating calculated vagus inhibition changes to heart rate is

$$\frac{1}{4\pi^2 r_0^2 - (V_0 + \Delta V)}\frac{d^2y}{dt^2} + y = 0 \qquad (5)$$

Parameter r_0 corresponds to the heart rate with complete absence of vagus inhibition, V_0 to the normal vagal tone, and ΔV the changes in vagal tone

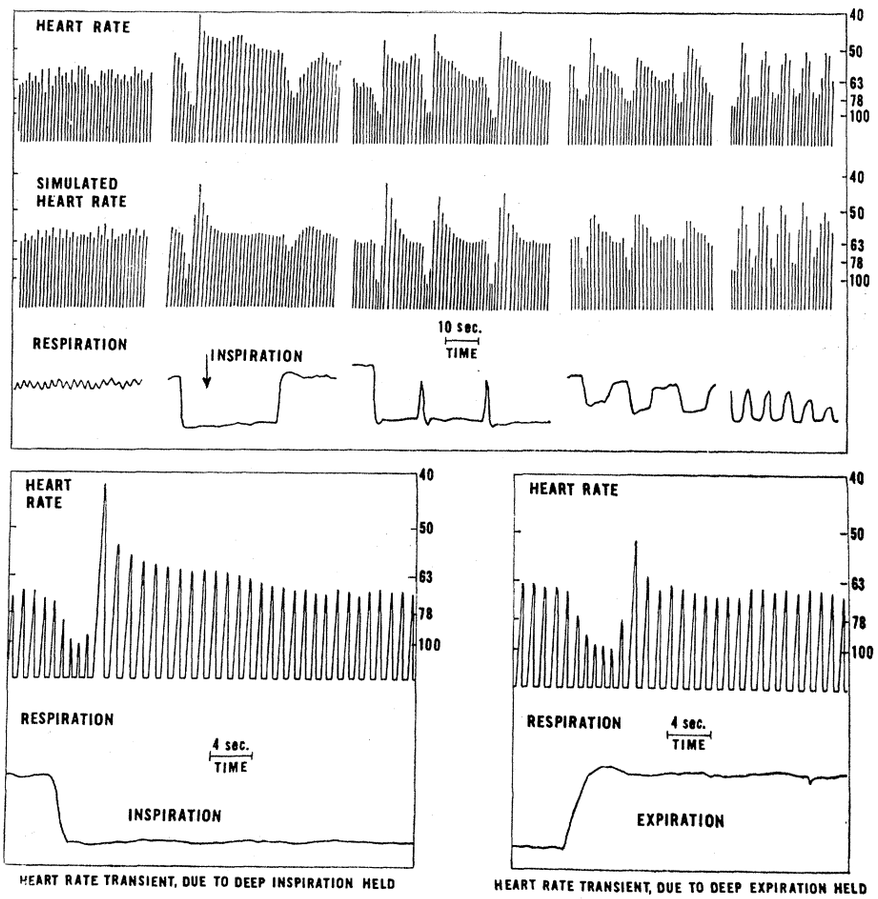

Fig. 1. Simulated and actual heart rate patterns for various modes of breathing; basic RHR (respiratory heart rate reflex) transients are shown in lower portion of figure.

caused by respiration; y is the output of the pacemaker and has a periodic solution. The maxima of y are considered to correspond to the times of firing of the pacemaker.

Comparison of the predicted and actual heart rate changes has been carried out successfully, showing a good correspondence for a wide variety of breathing modes.

Figure 1 shows a portion of a half-hour simulation record showing heart rate, simulated heart rate, and respiration for various modes of breathing. The simulated heart rate was computed by the analog computer and simultaneously recorded with the actual heart rate (*5*). The only signal entering the computer from the subject was the subject's respiration in the form of an electric signal proportional to thorax circumference. The actual and simulated heart rate are recorded above each portion of the respiration record. The record was taken with the subject in a resting state, supine; the subject was a 26-year-old male. Each ordinate represents the time between two consecutive heart beats, measuring from R to R peak of the QRS complex of the electrocardiogram. Thus a long line represents a slow heart rate, a short line a fast heart rate. The basic inspiratory and expiratory heart rate transients are shown in the lower parts of the figure.

Parameters of the differential equations represented by the computer remained unaltered during the course of the simulation. Note the correspondence between actual and simulated heart rates. Since the measure taken of respiration is the external circumference of the thorax, some amplitude dissimilarities between the stretch experienced by the organic receptor and our recording device is to be expected. Some nonlinearities in this regard are likely.

Note that a slight dissimilarity is actually theoretically required, since each cardiac cycle in the simulated circuit does not begin synchronously with the actual heart. Consequently, a deep inspiration, for example, does not necessarily begin at the same point in the cardiac cycle in the simulated circuit as in the real heart, thus causing a minor deviation in the transient. Some steady state changes in heart rate with extent of chest expansion are also sometimes found in addition to the transient changes described.

It may be concluded that in the unanesthetized human being, respiratory sinus arrhythmia (the heart rate changes caused by respiration) is initiated by stretch receptors located within the chest and is not primarily caused by hemodynamic factors or central influences. The paradoxical findings regarding the phasic relation between heart rate and respiration are resolved by showing that the heart rate waves observed are in fact superpositions of biphasic transients of definite shape and duration. As a result of the mathematical analysis, in terms of nonlinear differential equations, it is possible to predict the heart rate changes (both regular and irregular) due to respiration for any manner of breathing in the given subject.

MANFRED CLYNES
Rockland State Hospital,
Orangeburg, New York

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Solid-Counting of Octadecane-1-H^3

Abstract. A solid sample of octadecane-1-H^3 was found to show a fairly good proportionality of the counting rate to the amount of the sample. Taking account of the synthetic process, nonvolatility, and spreadability of octadecane, this compound offers a possibility of being used as a standard sample for counting the radioactivity of tritium.

Many investigators have attempted to count the radioactivity of tritium, which emits extremely soft β-rays, by gas-phase (*1*) and liquid scintillation (*2*) counting. However, these methods require some special and expensive equipment and complicated procedures. Moreover, it seems inevitable that these methods should suffer from some difficulties—for example, memory effect for the former method and limited applicability for the latter—in performing the measurement. To avoid the memory effect, attempts were successfully made to perform the solid-counting of vegetable oil (*3*) and *p*-aminosalicylic acid (*4*), both tagged with tritium. A weakness of the use of these two substances, however, arises from limited applicability: The first must be synthesized by adding tritium as a gas to unsaturated oil; the second, by a gas-exposure method in which carrier-free tritium gas is used (*5*).

Because of these difficulties, it seems desirable to change a sample of organic compound tagged with tritium to a standard form through a common process such as

$$H^3\text{-tagged organic compound} \xrightarrow{\text{burn}} H^3{}_2O \longrightarrow \text{standard substance to be counted}$$

To practice good solid-counting, the final product should be (i) prepared easily and quantitatively from $H^3{}_2O$, (ii) nonvolatile at room temperature, and (iii) uniformly spreadable on a suitable surface. Octadecane, synthesized by the reaction of tritiated water and excess octadecyl magnesium bromide, satisfies the first two conditions, and, when it contains a small amount of amphipathic compound, it may also satisfy the third. Thus, this compound seems to be suitable for a standard sample to be counted.

In the present experiment, octadecane-1-H^3, synthesized by the above reaction and containing a small amount of octadecanol, was used. A portion of this substance was spread from benzene solution onto the bottom of a stainless steel pan (24.5 mm in diameter), and the radioactivity was determinated by using a 2π flow counter (Aloka, type DC-1001). Commercial propane was used as a flow gas (*6*).

Figure 1 shows a dependence of the counting rate upon the sample thickness. The calculation assumes uniform spreading of octadecane over the bottom of the pan, though this is not always valid. In spite of this rough assumption, the counting rate increased proportionally with the increase of the sample thickness, when the amount of the sample was less than that corresponding to the maximum range of β-rays. Within this region, the counting rate was reproducible for a given amount of the sample, irrespective of distribution of the sample over the bottom of the pan. Beyond this region,

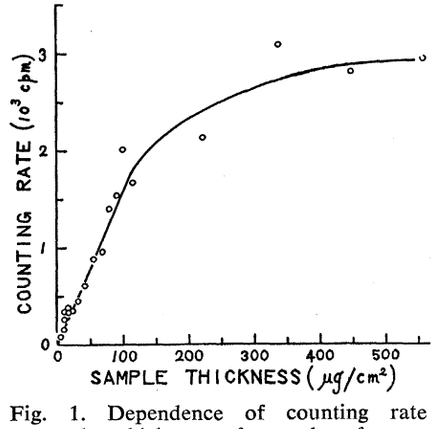

Fig. 1. Dependence of counting rate upon the thickness of sample of octadecane-1-H^3.