A RESONANCE THEORY OF "MICROVIBRATIONS"¹

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A reanalysis of Rohracher's original data shows that the periodic microvibration of the body surface recorded by him does not require the assumption that there exists any physiological event occurring at that frequency. A "resonance" theory concerning the origin of microvibrations is proposed and this suggests that the frequency is determined by the physical characteristics of the particular body-transducer system used for its recording. The microvibration amplitude is shown to be a sensitive psychophysiological measure of muscle tension and gross bodily activity. The implications of the theory with regard to the determination of tremor frequencies are discussed.

Rohracher (1946, 1949, 1952, 1954, 1955, 1958a, 1958b, 1959a, 1959b, 1960) has claimed that the entire surface of the human or homothermic animal body exhibits minute continuous vibrations. During the past several years a number of workers (Denier, 1957; Heller-Jahnel, 1959; Luhan, 1953; Nirrko, 1961; Sugano, 1957; Swarofsky, 1958) have given support to Rohracher's (1954) contention that, with suitable apparatus a system of continuous microscopic vibrations can be demonstrated in the human and animal body. In a healthy human being in the condition of greatest relaxation its magnitude is 1-5μ and its frequency 6-12 vibrations per second . . . we are not concerned with electrical processes but with a microscopically small rhythmic vibration system of the organism [p. I].

Rohracher (1954) has suggested that almost any device which will convert mechanical movements into electrical impulses together with an amplifier and recorder having suitable frequency responses (3-30 cycles per second) can be used to record the microvibrations. Apparently he has successfully used a wide variety of makeshift transducers adapted, for example, from carbon microphones or phonograph pickups. However, for much of his work he has especially favored a commercially designed electrodynamic vibration transducer (Philips Type GM 5520) which, in use, he suspends from a pulley so that a counterpoise may be used to reduce its apparent weight and allow the probe to rest on the subject's limb, etc. with a constant pressure. He scores the resulting alpha-like waveform by measuring its double amplitude and counting the number of apparent peaks occurring during a given interval.

Figure 1 reproduces the waveform obtained by recording the amplified output from a counterbalanced transducer (Acos VP2) resting on the subject's forearm, the general experimental arrangement being similar to that used by Rohracher.

Figure 2 shows our development of Rohracher's original instrumentation: In addition to recording the simple raw waveform (Recorder 2) we have

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added an amplitude-integrated record (Recorder 1) and a frequency analyser record (Recorder 3). The use of these additional recordings is discussed below in the section concerning the experimental validation of the resonance hypothesis.

To the 1954 summary of his earlier publications Rohracher has added much additional material confirming and extending his original findings. While the very extensive work of Rohracher and his collaborators cannot adequately be summarized here,
it is of present importance to restate some of their basic conclusions. The most fundamental of these has been quoted above. Others include the following:

1. While the microvibrations can be detected throughout the body, their origin is in the striped musculature.
2. Contraction of the striped muscles increases the amplitude many times but does not affect the frequency.
3. Within any given recording the frequency is remarkably constant.

Rohracher (1954) concluded that, the body vibrations fulfill two important biological functions with the expenditure of an extraordinarily small amount of energy: Keeping the body of the warm-blooded animal at a constant temperature and keeping the musculature in a constant state of readiness, thereby making possible rapid and positive motor reactions [p. 19].

Both he and others (Nirrko, 1961) have been impressed by the similarity of the EEG alpha and microvibration waveforms and frequencies and have implied the existence of a causal connection. Kennedy (1959) has suggested that alpha rhythm may arise from mechanical oscillation of the gel of the living brain, not necessarily from synchronization of neural activity directly [p. 352].

This viewpoint has been strongly criticized by Oswald (1961) and Rosner (1961).

The purposes of the present paper are to suggest:

1. An alternative hypothesis to account for the occurrence of the microvibration phenomenon.
2. That the microvibration frequency is determined largely by the physical characteristics of the particular transducer system used (and can therefore have no direct relation to the alpha rhythm).
3. That the microvibration amplitude varies according to the amount of energy being imparted to the transducer and has value as a sensitive psychophysiological measure of the degree of muscle tension.

A RE-EVALUATION OF ROHRACHER’S RESULTS

While it is clear that Rohracher has arrived at his final conclusions only after a careful and detailed consideration of his very extensive experimental work, it is unfortunate that, for the most part, his approach has been such as to give qualitative results rather than to provide more than a minimum of quantitative data. (It may be that Rohracher recognizes this when he chooses to state his final conclusions, not as such, but as “hypotheses.”) For this reason, it may be that the most economical method of appraisal would be first to examine the experimental evidence for his basic contention that the striped muscles are the source of microvibrations having a frequency of 6–12 vibrations per second and an amplitude of 1–5 μ, rather than by attempting a critical survey of the very many contributory experiments on which his findings are based.

Of the two dependent variables which he has investigated—amplitude and frequency—his findings about frequency are of central importance to his theories. That muscles exhibit movements of various amplitudes is a truism; that they show continuous periodic movements of a constant frequency is a most important claim with far-reaching implications. Now, it seems that there are three outstanding facts about the frequency:

(a) It always lies within the approximate range of 6–12 cycles per second; (b) within any one record it is strikingly constant; (c) the variation
between records—i.e., between tests given on different occasions, even when these are all taken from the same subject—is apparently random and not correlated with any other variable investigated by Rohracher.

In his attempt to demonstrate a physiological correlate of the frequency Rohracher makes use of only the first two of these observations, arguing that they find a counterpart in several authoritative experimental findings about muscle action potentials. The third he dismisses by assuming that the experimental situation on each occasion is identical and suggesting that because the two series of consecutive daily records taken from each of two subjects were not correlated, the variation must be due to physiological (and not environmental) causes. In fact, he never takes a sufficiently lengthy single record or long enough series of briefly spaced records to relate the second and third of the above observations. He does not formally investigate the reliability of his measures and none of his data can be reanalyzed to provide an indication of this.

If we reject Rohracher's assumption of reliability it is clear that there are at least two possible sources of the variability in addition to the one he suggests: (a) differences in the precise location of the transducer for each record; (b) differences associated with the transducer assembly itself.

Now, these differences would probably reveal themselves most clearly if, in the first case, a number of records were taken from each of several very different sites and, in the second case, a series of records from each of two different transducers were compared. Nothing of this kind has been done in any systematic way:

Nevertheless, in his 1949 monograph, Rohracher does provide us with nearly a hundred reproductions of actual records. An examination of these shows us that the two transducers most frequently used are the electrodynamic and the piezoelectric ones. Moreover, there are several records taken with the one transducer which can be matched (for location) with records taken with the other (see Table 1).

Obviously, there are severe limitations to this kind of retrospective analysis. For example, as the description of each record is not always definitive with regard to either the subject or the transducer used the assumption that the scores are uncorrelated may not, therefore, be altogether justified. In spite of these

<table>
<thead>
<tr>
<th>TABLE 1</th>
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<tr>
<td><strong>COMPARISON OF MICROVIBRATION FREQUENCIES OBTAINED FROM TWO DIFFERENT TRANSDUCERS—ONE CRYSTAL AND ONE ELECTRODYNAMIC</strong></td>
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<table>
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<tr>
<th>Location</th>
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<th>Electrodynamic transducer</th>
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<tbody>
<tr>
<td>Frequency (cps)</td>
<td>Figure number</td>
<td>Frequency (cps)</td>
</tr>
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<td>Forearm</td>
<td>7.0</td>
<td>16c</td>
</tr>
<tr>
<td>7.0</td>
<td>23b</td>
<td>9.5</td>
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<td>7.0</td>
<td>25a</td>
<td>10.0</td>
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<tr>
<td>8.0</td>
<td>26b</td>
<td>13.0</td>
</tr>
<tr>
<td>12.0</td>
<td>36b</td>
<td></td>
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<tr>
<td>Forearm (tensed)</td>
<td>7.5</td>
<td>25b</td>
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<tr>
<td>8.5</td>
<td>26a</td>
<td>9.5</td>
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<tr>
<td>Thigh</td>
<td>7.0</td>
<td>16b</td>
</tr>
<tr>
<td>6.5</td>
<td>23a</td>
<td>9.0</td>
</tr>
<tr>
<td><em>M</em></td>
<td>7.36</td>
<td>10.50</td>
</tr>
</tbody>
</table>

\[ t = 49.45^* \]

Note.—The frequencies were estimated from reproductions of records included in Rohracher's 1949 monograph.

* * *
difficulties, however, the table does tend to support the hypothesis that the frequency is dependent on the transducer assembly used: The distributions of frequencies associated with each of the two transducers do not overlap; the location of the transducer has no obvious effect.

If this analysis is correct, then insofar as we are concerned with frequency we must be dealing with individual differences between two physical systems rather than between two physiological ones (as Rohracher supposed) and it will be necessary to examine such a system in detail.

Resonance Hypothesis

Figure 3 is a schematic representation of a transducer in contact with a vibrating object. The vibrating part of the transducer (mass = $m_1$) is coupled to the stationary part through a spring (spring constant = $k_1$) and the system is necessarily a damped one (damping factor = $r_1$). (In absolute vibration transducers the stationary part is the seismic mass; in relative transducers it is the housing.) It is the movement of the mass, $m_1$, following precisely the movement of the object—which gives rise to electrical changes which can be amplified and recorded in the ways described by Rohracher. If the object were, say, a muscle unit, the transducer would enable its contractions to be recorded accurately, providing that the magnitude of the constants $m_1$, $k_1$, and $r_1$ were very small compared with those of the constants $m$, $k$, and $r$ of the muscle unit. If the constants relating to the transducer were comparatively large, however, a serious reactive error would occur (van Santen, 1953)—a difficulty apparently not recognized by Rohracher.

Further, if an isolated transducer is given a single abrupt movement, the movable part of the transducer will be caused to oscillate with a diminishing amplitude. The initial amplitude of the oscillation will be determined by the amount of energy involved; and the frequency will be determined by the values of all three constants, $m_1$, $k_1$, and $r_1$. If a second movement is imparted to the transducer before the oscillation due to the first has completely decayed and then this is followed by a third and so on, the original oscillation will be maintained with a varying amplitude, the value of which, at any given moment, is a measure of the kinetic energy of the system. It follows from this that the total area of the recorded curve is proportional to the amount of energy which has been fed into the system.

Now, this natural or resonant frequency is of some importance (e.g., the amplitude response is usually linear only at frequencies higher than...
the natural frequency). That for the Philips' electrodynamic transducer is quoted by the makers as being $12 \pm 2$ cycles per second—which is appreciably greater than the mean range of frequencies of body vibrations recorded by Rohracher. Superficially, this would make it appear that the microvibration waveform could not be attributed to any resonance phenomenon associated with the transducer but that it may have a true physiological correlate. However, if we now refer again to Figure 3 and imagine a single movement being imparted in this instance to the object it can be seen that again the natural frequency of the system will be recorded, but in this case it will be the natural frequency of the entire system which is arrived at by considering $m$, $k$, and $r$ as well as $m_1$, $k_1$, and $r_1$ and this frequency will almost certainly differ from that of the transducer alone. More specifically: when a transducer is placed on the surface of the body, the skin undergoes an elastic deformation which introduces the effect of a spring; that part of the body undergoing deformation has a certain mass and damping effect associated with it; the entire physical system, including the transducer, now has a natural frequency determined by the physical characteristics of both the body and the transducer. If a series of aperiodic impulses are imparted to the system a recording from the transducer will show a waveform having a frequency which is that of the combined system and an amplitude which varies according to the occurrence and magnitude of the aperiodic impulses.

It would seem to be reasonable to suppose that the higher the natural frequency of the transducer, the higher would be the natural frequency of the combined body-transducer system. Figure 8 in Rohracher's 1949 monograph is of a record taken by means of a "loudspeaker system with a high natural resonance." The frequency appears to be about 15 cycles per second.

Partly in an attempt to validate his theory Rohracher refers to some experiments which do not make use of electromechanical transducers to record the vibrations and which he regards as confirmation of the existence of microvibrations because of the dissimilarity of the pickup devices. Typical of these experiments is that carried out by Marko (reported in Rohracher, 1952) in which a beam of light passed through a prism placed on the body surface was used as a means of recording the vibrations. Again referring to Figure 3, a resonance theory would suggest that the technique can be analyzed as before: the natural frequency is here determined solely by the constants $m_1$, $m$, $k$, and $r$.

The point has now been reached where it appears that the present hypothesis concerning the origin of the microvibrations may be an acceptable and economical alternative to the explanation put forward by Rohracher. The completion of the argument for the acceptance of the resonance theory necessitates some references to the experimental testing of its validity.

**Testing the Resonance Hypothesis**

In the absence of damping forces the free vibration of a simple mechanical system having one degree of freedom is sinusoidal (Manley, 1945). However, in practice it is usually found that a mass may be capable of vibrating in different directions simultaneously. For example, a cube suitably suspended on springs could be
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capable of assuming six different natural frequencies: three linear along each axis and three torsional about each axis. When a vibrating system possesses more than one degree of freedom, one vibration is likely to influence the others: a phenomenon known as "coupling." The use of a transducer in such a situation would result in the recording of a complex waveform and it follows that this waveform would be the sum (in the direction determined by the placing of the transducer) of the various simple sinusoidal components associated with each degree of freedom.

It is extremely important to note that the final complex waveform does not obviously display the number of component oscillations of which it is the sum, or the frequency or amplitude of those components. For example, in the well-known phenomenon of "beating" which occurs when two sine waves, the ratio of the frequencies of which is nearly unity, are added together, the resultant wave has the same apparent frequency as the component with the greater amplitude and its amplitude varies between the sum and difference of the component amplitudes, the beat frequency being the difference between the frequencies of these components. It can be seen that if this occurrence were transferred to the Rohracher phenomenon it would not be correct, for example, to assume the existence of a physiological correlate of the beat frequency nor the nonexistence of any periodic event other than that indicated by the dominating frequency of the major component. The interpretation of the amplitude of the complex waveform presents similar difficulties. Moreover, the example given is that of one of the simplest situations; the level of complexity of the microvibration waveform investigated by Rohracher precludes even more the acceptance of too facile an interpretation.

It follows from the above that an appropriate experimental validation of the resonance hypothesis would consist of analyzing the microvibration waveform and showing that its periodic components related only to the natural frequencies of the body-transducer system.

It must here be remarked that while, in its simplest form, Fourier's Theorem states that any periodic variation fulfilling certain conditions regarding continuity can be considered as the sum of a number of sinusoidal variations whose periods exhibit a simple relationship, and Riemann's Theorem states that for any given variation the equivalent series of sinusoidal variations is unique, Manley (1945) points out that this does not mean that the original variation must necessarily be regarded as such a series. There are, in fact, a large class of functions (the orthogonal functions) which includes the sine function, and any member of this class could equally well be used as the basis of an alternative series. In some circumstances the choice of sine waves as the basic components of the complex waveform may be difficult to justify other than on the grounds of expediency. Since Fourier's presentation of his first paper in 1807 the assumption has, from time to time, been queried. However, the fact that a simple undamped vibration can be shown to be sinusoidal would appear to make the choice a reasonable one in the present context.

Because of certain difficulties introduced by the fact that the microvibration waveform does not have a precisely regular periodicity (Williams, 1956), it was decided that
although in some circumstances a Fourier analysis might be found to be an appropriately exact and elegant method, here it could give only approximate and unreliable results, and this would not justify the lengthy and elaborate computations involved. Instead, the familiar automatic frequency analyzer expressly designed for the analysis of EEG waveforms was judged to meet the present requirements very fully. This instrument performed a complete frequency analysis every ten seconds and presented it in written form on that part of the microvibration record to which it referred.

In an experimental arrangement resembling that described by Rohracher, eight psychiatric patients provided 2-minute records from each of three transducer systems, the transducer probes being applied in random order to the same point near the middle of the left forearm extensor muscle. The wave analyzer recordings showed unimodal frequency distributions, the modes occurring at different frequencies for each transducer. As the ranges of the distributions could be accounted for by the overlap in selectivity (44%) between adjacent channels of the analyzer it was possible to conclude that in each case there was only one dominant frequency maintained and modulated by aperiodic impulses, or periodic impulses outside the analyzer frequency band.

Having now established the existence of a single periodic frequency within the microvibration frequency range it remains only to show that different transducers having different natural frequencies significantly differ in the frequencies of the microvibration records obtained from them in order to confirm the "resonance" hypothesis and reject Rohracher's assertion that there is a periodic physiological correlate of the microvibration frequency.

Two of the three transducer systems which had already been shown to have unimodal frequency responses were used. These differed only in the method of mounting the transducer (Acos Type VP2) and were chosen on the basis that a noncounterbalanced one would have a larger apparent weight than a counterbalanced one, and, following the previous arguments related to Figure 3, would have a higher natural frequency. At the same time other relevant variables would be kept constant.

Two groups, each of 16 psychiatric patients, matched for age, sex, and diagnosis, were compared:

<table>
<thead>
<tr>
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<th>Mean Frequency</th>
<th>Standard Deviation</th>
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<tbody>
<tr>
<td>Noncounterbalanced</td>
<td>12.1</td>
<td>1.00</td>
</tr>
<tr>
<td>transducer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counterbalanced</td>
<td>7.5</td>
<td>1.06</td>
</tr>
<tr>
<td>transducer</td>
<td></td>
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$t = 12.8 \quad p < 0.001$ (one-tailed test)

This result accords well with the previous reanalysis of Rohracher's data. (See Table 1.)

The obvious experiment of taking simultaneous records from two different transducers placed near to each other on the subject's arm was found to give rise to a curious and misleading result. The records obtained, although not identical, were strikingly similar in form and frequency, the similarity becoming less marked when the transducers were placed further apart. The arm must be responsible for supplying the common factor. The fact that this result does not lend support to Rohracher's hypothesis, however, can be demonstrated by the simple expedient of removing either of the transducers when the other one will immediately provide a record at the expected frequency. The two
transducers, together with the subject’s arm, form a single system, the degree of coupling between the transducers decreasing as the distance between them is increased.

**Sources of Energy of Microvibrations**

Because the microvibrations are due to a physical system being caused to resonate, any mechanical disturbance transmitted to the subject results in an immediately increased amplitude which then decays exponentially to its original level. However, in the experimental arrangement described here, large and frequent impulses are required in order markedly and continuously to increase the amplitude and it is clear that very much the major contribution must be made by the subject.

Again, because any mechanical impulse will increase the amplitude there may be contributions from sources other than the skeletal muscles. Rohracher has, in fact, pointed out that placing a transducer directly over a blood vessel may give rise to modulation by the pulse. A ballistocardiographic effect sometimes occurs; certainly gross limb movements and respiration increase the amplitude.

The most interesting source of energy, however, appears to be the tensed muscle itself. Figure 4 shows two simultaneous amplitude-integrated records (using simple RC integration), the upper from electromyograph electrodes placed over the left forearm extensor muscle, and the lower from the counterbalanced crystal transducer, the probe of which rested between the EMG electrodes. The subject gripped and released a rubber bulb which was connected to a mercury manometer, thereby being enabled more easily to maintain a constant level of tension. The two records are very similar indeed, the main difference being at the point of relaxation. Here there is a sudden increase in the amplitude of the microvibration record which is not paralleled by that of the EMG. From what has gone before it will be seen that this is what would be expected on the resonance theory—*any* mechanical disturbance, including a sudden relaxation, will increase the amplitude of the microvibrations. (Twelve microvibration records taken during changes in the level of tension as indicated by the EMG or mercury manometer showed that on each of the 36 occasions when there was an increase in tension there was also an increase in the microvibration amplitude. On each of the 12 occasions when there was a decrease in tension there was a decrease in the microvibration amplitude provided that the immediate increase in the amplitude due to the sudden relaxation was disregarded, the duration of this increase in part being determined by the degree of damping of the system and the time constant of the integrator.)

Apart from the gross differences at the point of relaxation the techniques themselves differ in two important ways:

1. The amplification required to produce the microvibration record is less than one hundredth of that required for the EMG record. In general the microvibration technique of measuring muscle tension displays the important advantage of requiring relatively simple apparatus.

2. It has been shown how the pulse, respiration, and other remote disturbances affect the microvibration record. It follows that while muscle activity outside the relatively restricted field of the EMG surface elec-
trodes does not contribute to the EMG record, the microvibration record must be produced by the additive effect of many muscles—some quite remote from the transducer. The microvibration record probably approximates to the summed output from many EMG surface electrodes in just the same way that the output of each surface electrode approximates to the sum of many locally sensitive needle electrodes. It has been shown elsewhere (Williams, 1956) how this capability makes it possible to differentiate between different psychiatric groups at a high level of significance.

The similarity of the integrated EMG and microvibration records is not altogether unexpected when one considers that any apparently steady isometric pull by a muscle is obtained by the summation of many muscle units, each in a different phase of activity (i.e., when one group is relaxing, another is contracting, and so on), this circumstance having been brought about by the asynchronous discharge of the cells of the motor neuron pool (Wright, 1961). It is also important to note that, in an isometric contraction, the contractile part of the muscle shortens and thickens while stretching the elastic tissue component. It follows that whereas the surface EMG reflects the electrical aspects of the asynchronous activity, the microvibration resonance can derive energy from the mechanical counterpart. As discussed earlier, gross movements will also contribute to the amplitude of the microvibration record; in fact, attaching a suitable seismic transducer to a subject enables his general activity level to be recorded in a way related to that used to measure the activity of a small animal by suspending its cage from a spring and recording the subsequent oscillations. Figure 5 shows a recording obtained by amplifying the output from a small seismic transducer (M. B. Vibramite Vibration Pickup, Type 11) fastened to the subject's waist. The first and third sections of the record show a pulse-modulated waveform of small amplitude recorded when the subject was standing still;

![Graph](image-url)

**Fig. 4.** Comparison of amplitude-integrated microvibration and EMG records.
the second section shows how the amplitude increased when the subject walked slowly forward. An especially important advantage of this technique is that it requires only the addition of a small transmitter to enable the output from the transducer to be telemetered; the subject then has complete freedom of movement within the range of the transmitter and an easily quantifiable record of his level of activity over many hours can be taken.

One further point arises from this analysis. When a limb or digit is extended and its position maintained only by the balanced contraction of agonist and antagonist, any momentary imbalance in the opposing groups of muscle units will result in a gross movement. Although these slight imbalances may occur erratically, provided that they occur sufficiently frequently we have, according to the resonance theory, all the conditions necessary for the maintenance of a sustained vibration or tremor. The frequency of this tremor would depend on the physical characteristics of the limb rather than reflect the precise time of occurrence of the contractions of the muscle units. That this is so is supported by Hamoen's (1958) experiments which suggested that the frequency of the tremor was correlated with the mass and elasticity of the moving parts.

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