Mechanism of Mechanical Vibrations in Living Body and Its Application to Various Fields

Toshitomo Usui, Kazuyoshi Sakamoto, and Hiroshi Okuno
Department of Industrial Management Engineering,
Faculty of Electro-Communications,
The University of Electro-Communications,
1-5-1, Chofugasaka, Chofu-City, Tokyo, 182 Japan.

There are various kinds of mechanical rhythms in living body as shown in Table 1. The mechanical vibration is not strange phenomenon but important significance as rhythm in living body. The important two hundred literatures related to the mechanical rhythms from the first stage of study to the recent development are here selected. The history, the mechanisms proposed, and many results for the respective mechanical rhythms were checked.

The classification of mechanical rhythms are denoted as follows. Shivering is visible vibration of the local part of body or the whole body. Tremor is invisible vibration of body part like finger or hand by involuntary or voluntary muscular contraction, accompanying with electromyogram (EMG). The tremor is classified by (i) normal tremor (involuntary vibration), (ii) intention tremor (voluntary vibration), (iii) pathological tremor like Parkinson disease with frequency 5 Hz, and (iv) high pressure nervous syndrome (HPNS) tremor (Zaltzman, 1961 and Bachrach & Bennett, 1973). Main frequency of normal tremor for finger, hand wrist, and elbow present (25 Hz, 10 Hz), (9-10 Hz), and (2 Hz, 10 Hz), respectively. The common frequency is 10 Hz and the other peak frequencies depend on the mass of the body part. Microvibration (MV), which was discovered by Austrian psychologist H. Rohracher, is invisible vibration not of body part but on skin surface in motionless body part, and EMG is not detected during the measurement of MV. Although there is no strict discrimination between the above mechanical vibrations, these mechanical vibrations have been distinguished expeditiously by the part (i.e., local or whole body part or skin surface) observed and by the magnitude of the vibrations. These three mechanical vibrations, that is, shivering, tremor, and MV, have the frequency

<table>
<thead>
<tr>
<th>Mechanical Rhythm</th>
<th>First Investigator</th>
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<tbody>
<tr>
<td>(1) Shivering</td>
<td>whole body: 1924 Sherrington, C.S.</td>
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<tr>
<td>(2) Tremor</td>
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<tr>
<td>(a) Physiological tremor</td>
<td>1876 Beaunis (see Friedlander, W.J., 1956)</td>
</tr>
<tr>
<td>(b) Pathological tremor</td>
<td>1817 Perkins, J.F.</td>
</tr>
<tr>
<td></td>
<td>(see Jenker, F.L. and A. Ward, 1953)</td>
</tr>
<tr>
<td>(3) Microvibration (MV) or Minor Tremor (MT)</td>
<td>1944 Rohracher, H.</td>
</tr>
<tr>
<td></td>
<td>(see ibidem, 1955)</td>
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<tr>
<td>(4) Ballistocardiogram (BCG)</td>
<td>1905 Henderson, Y.</td>
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<tr>
<td></td>
<td>(see Starr et al., 1939)</td>
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<tr>
<td>(5) Whole Body Microvibration (WB-MV) at standing posture</td>
<td>1959 Corti, U.A.</td>
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<td></td>
<td>(see Bircher, M. et al., 1978)</td>
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</table>
component of about 10Hz as common feature; They show alpha rhythm as well as electroencephalogram (EEG) in rest state gives the same rhythm.

As for ballistocardiogram (BCG), the generation is clear to be heart beat. Whole body microvibration (WB-MV) is the fluctuation of whole body. The main origin is attributed to the central nervous system. Therefore, the mechanism of the two mechanical vibrations, that is, BCG and WB-MV, is clear and they are not the object of study for mechanism treated here.

There have existed a long history in the study of mechanical vibration, especially tremor and MV. As the origin of generation of the mechanical vibrations, four factors, that is, (a) the central nervous system, (b) the spinal reflex, (c) the autonomic nervous system, and (d) the ballistocardiogram by heart beat have been always treated in the development of these studies. Moreover, in the study of both tremor and MV, the mechanical model was presented that the vibration generated by heart beat was modified by the muscle which played the role of low pass filter. In the study of shivering, the central nervous system is considered to be predominant origin (Ohye, 1981). In tremor (especially physiological tremor), γ-loop in stretch reflex played an important role (Lippold et al., 1957; Lippold, 1970). However, further studies claimed that the other components (i.e., (a), (c), and (d) shown above) should be connected to the mechanism (Elble & Randa11, 1976; Rack et al., 1978). In the study of MV, heart beat is predominant component of generating mechanical vibration (Ozaki et al., 1962).

Tremor has been studied chiefly in foreign countries, but MV has not been studied since 1950 except for Japan. Although the reason is not clear, the researchers in foreign countries seemed to regard MV as the same phenomenon of tremor. They were also much interested in the theory of stretch reflex proposed by Lippold et al. (1957 & 1970) for the tremor, so that they studied chiefly the physiological tremor and they seemed not to take interest in the study of the vibration on skin surface, that is, MV. On the other hand, Japanese researchers disputed for long time (1957-1977) about the mechanism on MV: That is, Sugano and Inanaga (1957 & 1958) proposed the role of γ-motor system, and Ozaki (1962, 1977b, & 1980) insisted BCG component as the origin of MV. The historical developments of the studies are given in Table 2. Fundamental results of MV are also listed in Table 3. Since the detailed points of disputes for MV were reported, the main points are collected in Table 4. Each proposed theory was retorted by other proposed theories. Therefore, the uniform mechanism for MV has not been yet obtained, but MV was applied to various fields (especially, clinical medicine and psychology) and MV played the important role especially in autonomic nervous function and psychosomatic disorder as shown in Table 5. What the mechanism proposed could well explain the many experimental facts (Tables 3 to 5) should be more important than which mechanism is right or predominant.

Examining many results of MV listed here, we considered not one factor (i.e., heart beat) but many factors (i.e., heart beat, spinal cord, central nervous system, and autonomic nervous system) as the mechanism of MV. Our proposed mechanism of MV is shown in Fig.1 and the mechanism well explains many points of contradictions and controversies for the mechanisms presented in Table 4. The mechanism in Fig.1 will give the suggestion for establishing the mechanism for other mechanical rhythms in living body.
Table 2. Development of study of mechanism for mechanical vibrations

<table>
<thead>
<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1935</td>
<td>Denny-Brown, D. et al.</td>
<td>cooling; Cephalic part (bulbar reticular formation) produces shivering.</td>
</tr>
<tr>
<td>1945</td>
<td>Perkins, J.F.</td>
<td>role of proprioceptor.</td>
</tr>
<tr>
<td>1959</td>
<td>Lippold, O.C.J. et al.</td>
<td>negation of the origin of central nervous system.</td>
</tr>
<tr>
<td>1974</td>
<td>Shimamura, M.</td>
<td>spinal reflex (γ-loop); proprioceptor. review.</td>
</tr>
<tr>
<td>1981</td>
<td>Ohye, C.</td>
<td>central nervous system; classification of shivering.</td>
</tr>
</tbody>
</table>

(2) Tremor (Physiological tremor and pathological tremor)

(a) Spinal reflex

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<thead>
<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1886</td>
<td>Horsley, V. &amp; Schäfer, E.A.</td>
<td>first measurement of tremor for human.</td>
</tr>
<tr>
<td>1957</td>
<td>Lippold, O.C.J. et al.</td>
<td>correlation between elementary EMG and tremor; disappear of tremor by complete deafferentation.</td>
</tr>
<tr>
<td>1970</td>
<td>Lippold, O.C.J.</td>
<td>stretch reflex theory (a established theory for 1970); represent of tremor amplitude.</td>
</tr>
<tr>
<td>1976</td>
<td>Elble, R.J. &amp; Randall, J.E.</td>
<td>stretch reflex; Recurrent inhibition rebound (Renshaw cell) determines tremor frequency (8-13Hz).</td>
</tr>
<tr>
<td>1983</td>
<td>Gottlieb, S. &amp; Lippold, O.C.J.</td>
<td>reconsideration of Lippold's stretch reflex theory: Three factors (stretch reflex, central nervous system, and mechanical movement of muscle) are important.</td>
</tr>
</tbody>
</table>

(b) Central nervous system

<table>
<thead>
<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>1931</td>
<td>Travis, L.E. &amp; Hunter, T.A.</td>
<td>three bands (8-13Hz, 40-50Hz, and 100-150Hz) similarity of EEG and tremor</td>
</tr>
<tr>
<td>1938</td>
<td>Jasper, H.H. &amp; Andrews, H.L.</td>
<td>no relation between EEG and tremor</td>
</tr>
<tr>
<td>1939</td>
<td>Schwab, R.S. &amp; Cobb, S.</td>
<td>no relation between EEG and tremor</td>
</tr>
<tr>
<td>1941</td>
<td>Lindqvist, T.</td>
<td>electric stimulation of bulbar reticular formation.</td>
</tr>
<tr>
<td>1953</td>
<td>Jenkner, F.L. &amp; Ward, A.</td>
<td>no correlation between visual feedback loop and voluntary muscular contraction.</td>
</tr>
<tr>
<td>1974</td>
<td>Stephens, J.A. &amp; Taylor, A.</td>
<td>hyperbaric condition; guinea pig; Two peaks (4-8Hz and 10-18Hz) originate from central nervous system (thalamo-cortical and olivo-cerebellar).</td>
</tr>
<tr>
<td>1978</td>
<td>Gruenau, S.P. &amp; Ackerman, M.J.</td>
<td></td>
</tr>
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(c) Mechanical model

<table>
<thead>
<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>1956</td>
<td>Marshall, J. &amp; Walsh, E.G.</td>
<td>low-pass filter of muscle (less than 15Hz); aging; cooling; negation of servo-loop theory (i.e., existence in spite of deafferentation).</td>
</tr>
<tr>
<td>1967</td>
<td>Stiles, R.N. &amp; Randall, J.E.</td>
<td>relation between tremor frequency and mass of body part; sitting posture; (1/\text{(tremor frequency)}^2)-a \cdot (mass)+b.</td>
</tr>
<tr>
<td>1970</td>
<td>Fox, J.R. &amp; Randall, J.E.</td>
<td>Forearm tremor (3.3Hz) was determined by mechanical factor of body part.</td>
</tr>
</tbody>
</table>
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1974 Rietz, R.R. & Stiles, R.N. inertic and stiffness factor; independent of denervation; negation of Halliday & Redfearn's result (1956) and Lippold's one (1957).

1976 Stiles, R.N. viscoelastic-mass mechanism.


(d) component of ballistocardiogram (BCG) by heart beat.

1960 Wachs, H. existence of tremor in spite of section of spinal cord.

(see Brumlik, J., 1962)

1962 Brumlik, J. component of BCG and EMG; voluntary contraction; lower frequency in children (aging).

1962 Buskirk, C.V. & Fink, R.A. Tremor is not neurologic problem; no existence of tremor by removing heart; existence of tremor in spite of section of spinal cord in dog.

1967 Yap, C.B. & Boshes, B. MV is the same as physiological tremor.

(3) Microvibration (MV).

1944 Rohracher, H. (see ibidem, 1955) discover of MV; autonomic nervous system (body thermo-regulation); existence of MV in warm-blooded animal.

1957 Sugano, H.; 1958 Sugano, H. spinal reflex including γ-motor system.

& Inanaga, K.

1961 Yoshi, N. et al. Main factor was muscle, but influence of heart beat was recognized.


1962 Yamauchi, I. no relation between EEG and MV by cross sectional study.


1960' to recent many applications of MV to various clinical fields in Japan, in spite of establishing no uniform mechanism!

1960' to recent

Table 3. Results of fundamental experiments for MV

(a) Frequency at various body parts
dependency of distance from apical area of heart except for thenar (Inoue, 1960; Nomura, 1967); independence of muscle size (Sato & Tsuruma, 1967).

(b) Posture (Yoshii et al., 1961)

(c) MV pattern
Aging (Nakazawa, 1961; Ueno, 1959)

(d) Respiration
no relation (Sugano & Inanaga, 1958); hyperventilation: increase of amplitude and invarianbleness of frequency (Sugano & Inanaga, 1958); increase of φ (4-8Hz) (Yoshii et al., 1961); respiratory fluctuation (Ozaki et al., 1975a).

(e) Enteric (or bowel) movement
no relation (Sugano, 1957).

(f) Fatigue
physical and mental fatigue, sports, overwork: increase of φ (Yamaoka, 1972; Inoue, 1960; Ohara, 1960b); fatigue in middle stage: increase of β (13-20Hz) (Yamaoka, 1972); work in night shift: decrease of α (8-13Hz) (Inanaga, 1961a)

(g) EEG
relation between sleep stage and MV (Itoh, 1967; Usui et al., 1984).
(b) Autonomic nervous system
seasonal change (Yamauchi et al., 1964)
cooling and warming (Sugano, 1957; Sato & Tsuruma, 1967; Usui et al., 1979)

(i) Emotion
photo-stimulation (Itoh, 1967)
hypnosis (Inanaga & Kurauchi, 1959)
anxiety (Sugano, 1964; Inanaga, 1966b)
angry (Inanaga, 1960)
Suggestion (Sugano & Inanaga, 1960; Ohara, 1960a & 1960b)
music: change of \( \alpha \) (Yamaoka, 1972; Homma & Nao, 1967)
color: blue (\( \theta \) for male), red (\( \beta \) for female) (Yamaoka, 1972)
psychological test: relation to stable time of MV (Sasaki, 1976)
autogenic training: no effective (Tebecis et al., 1976/77)

(j) Drug
(Sugano, 1957; Sugano & Inanaga, 1958; Inanaga & Kurauchi, 1959; Inoue, 1960)
influence of dosage (Ozaki, 1972a; Sato & Inanaga, 1959)
atropine: small (0.2-0.5mg/kg) increase of amplitude
large (5-20mg/Kg) decrease of amplitude
alcohol: small increase of \( \alpha \) (excitation of central nervous system)
large no increase of \( \alpha \) (inhibition of central nervous system)
increase of amplitude
central analeptic (e.g., metrazol, aminocordin)
muscle analeptic (e.g., Ba)
decrease of amplitude
anesthetic (e.g., pentathal, procaine, xylocaine)
alcohol, muscle relaxant (e.g., Ca, mephenesin)
inhibition of central nervous system (e.g., urethan, methyl hexabital, morphine)
ganglioplegic (tetraethyl ammonium bromide, nicotine)
increase of frequency (\( \beta \) band)
parasympathomimetic (e.g., pilocarpine)
decrease of frequency (\( \theta \) band)
parasympatholytic (e.g., promethazine hydrochloride)
sympathomimetic (e.g., adrenaline, noradrenaline)
increase of \( \alpha \): inhibition of central nervous system; comfortable circumstance; rest state.
decrease of \( \alpha \): mental tension; anxiety; mental excitation; stress in experiment.

Table 4. Proposed Mechanisms of MV

<table>
<thead>
<tr>
<th>foundation</th>
<th>phenomenon/experiment</th>
<th>counter view</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Thermo-regulation</td>
<td>existence of MV in only warm-blooded animal (Rohracher, 1946 &amp; 1955)</td>
<td>no differentiation of ( \gamma )-motor system in cold-blooded animal (Kasagi, 1977)</td>
</tr>
<tr>
<td>(ii) Influence of temperature</td>
<td>seasonal change (Yamauchi et al., 1964)</td>
<td>In cold stimulation, amplitude cannot explain the response to elevate body temperature. (Sugano &amp; Inanaga, 1958)</td>
</tr>
<tr>
<td></td>
<td>warm water (50°C): increase of ( \beta )</td>
<td></td>
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<tr>
<td></td>
<td>cold water (0°C): increase of ( \theta )</td>
<td></td>
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<tr>
<td></td>
<td>and decrease of amplitude</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Sugano &amp; Inanaga, 1958)</td>
<td></td>
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Electric stimulation of body temperature center in cat (Sugano, 1963)

<table>
<thead>
<tr>
<th>Excitation of autonomic nervous system</th>
<th>Adrenaline (sympathetic): increase of $\theta$ (Inoue, 1960)</th>
<th>Promethazine hydrochloride: decrease of $\beta$ (Inoue, 1960)</th>
<th>irritable colon syndrome: irregular type of MV (Kawakami et al., 1971)</th>
</tr>
</thead>
</table>

| Other | close relation between MV pattern and Mecholyt test (i.e., performance test of autonomic nervous system) (Kuroki, 1972) |

(b) $\gamma$-motor system
Sugano, H., 1957; Sugano & Inanaga, 1958.

<table>
<thead>
<tr>
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<th>counter view</th>
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<tbody>
<tr>
<td>Negation of BCG origin</td>
<td>continuation of MV for 30 min. after extraction of heart in rabbit and dog; decrease of amplitude but inchangeability of frequency (Sugano, 1957).</td>
<td>disappear of MV by extraction of heart (Konda et al., 1970).</td>
</tr>
</tbody>
</table>

Influence of central nervous system

| Amplitude at sleep in one third at awake due to muscular relaxation (Sugano, 1964). Stimulation of motor area and auditory area depresses MV. Stimulation of hypothalamus increases MV (Sugano, 1957). |

No existence of MV in smooth muscle (Inanaga, 1966a).
(c) Ballistocardiogram (BCG) origin

<table>
<thead>
<tr>
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<th>counter view</th>
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</thead>
<tbody>
<tr>
<td>stimulation of parasympathetic nervous system → brady cardia → increase of stroke volume → increase of MV amplitude (Tomonaga, 1965).</td>
<td>no relation to heart beat (Rohracher, 1955).</td>
</tr>
<tr>
<td>A-V block patient: decrease of MV amplitude (Ozaki et al., 1969).</td>
<td>existence of MV by extraction of heart in rabbit and dog (Sugano, 1957; Sugano &amp; Inanaga, 1958; Sugano, 1964; Yoshii et al., 1965).</td>
</tr>
<tr>
<td>Parietal MV resembles closely to BCG (Ozaki et al., 1970).</td>
<td>influence of tilting of body related to stroke volume (Ozaki et al., 1971).</td>
</tr>
</tbody>
</table>

Table 5. Application of MV to clinical medicine

(a) Autonomic nervous function test (Mecholyt test)
Mecholyt test (Oknaka method) relates closely to NADL classification which is evaluated by change of MV in time course. (Doubeta et al., 1970; Kuroki, 1972; Ohno et al., 1976; Kasagi, 1977; Ozaki, 1978; Sato et al., 1978; Takeya et al., 1979; Hasegawa et al., 1982; Teshima et al., 1982).

(b) Dysautonomia
Effect of clinical treatment is examined by MV. (Doubeta et al., 1970; Tsutsui et al., 1976)

(c) Orthostatic dysregulation
Effect of BCG component on MV is examined by parietal MV (Igarashi, 1970 & 1971).

(d) Substitute for BCG measurement of child; parietal MV.
(Ozaki et al., 1970; Igarashi, 1974).

(e) Psychosis; photo-evoked MV
anxiety neurosis $\theta > \alpha > \beta$ (Ohara, 1960a).
schizophrenia $\beta > \alpha$ (Inanaga, 1961a; Morisaki, 1972).
depression; increase of $\alpha$ by clinical treatment (Ishibashi, 1961; Kimura et al., 1972; Hirotu et al., 1977).

(f) Psychosomatic disorder; eyelid MV
Time required for the formation of stable MV pattern extends three times to the normal. (Doubeta et al., 1970; Kawakami et al., 1971; Kuroki, 1971; Nozawa, 1975; Sasaki, 1976).

(g) Depth of anesthesia; detection of muscular hypotonia and change of cardiac impulse (decrease of amplitude) (Murayama, 1960; Kiyohara et al., 1963).

(i) Heart disease
evaluation of cardio-function; parietal MV.
(Igarashi, 1975 & 1976; Ozaki, 1977a)

(j) Obstetrics (relaxation in the first stage of labor).
relation between relaxation and MV pattern
(Ueno, 1959; Kakizaki & Guohisa, 1982).

(k) Cancer; cheek MV
(Kawata et al., 1964).

(l) Otology; Ménière’s syndrome
(Kawata, 1961).

(m) Dental; mandibular movement, facial expression
(Noda et al., 1976 & 1979).

(n) Ophthalmology; effect of contact lens in rabbit. Evoked MV by photo-stimulation
(Naito et al., 1979).

(o) Myogenic dystrophy
(Sakuma et al., 1984).

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![Diagram](image)

**Fig. 1** Proposed Mechanism of MV: Thickness of arrow into MV depends on the degree of contribution to MV amplitude (Usui and Sakamoto, 1983).
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e of the gaseous medium. Leningrad (English
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(3) Microvibration (MV)


Urban & Schwarzenberg, Wien.
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Yasuhsara, A., A. Yamada, T. Sugimoto, T. Matsu-

(4) Ballistocardiogram (BCG)
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