Equilibrium of Human Body and Static Functional Tests

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1. Equilibrium of Human Body.

Although the mechanism of equilibrium of body is simple in the low species of animals because it is controlled by a primitive organ, for example statocyst in jellyfish, in human body the maintenance of equilibrium becomes much more complicated because of his erect posture, his erect gait and his need to do complicated actions. According to Fischer (1956)[1], the perception of the vertical line and the presentation of the gravity line of the erect posture is important. If the body is in the position of rest, perception of the physical vertical is sufficient. In active movement, the resultants of mass accelerations are necessary for equilibrium. This resultant is the sum of gravity and all the accelerations resulting from the complicated muscular performance. Abels (1926)[2] calls the physical vertical the static gravity line; the resultant, the dynamic gravity line. The perceived direction of the latter must change with every change of movement in order to maintain equilibrium during every phase.

It is accepted by various researchers that human equilibrium of the body is controlled by a number of impulses, such as 1) labyrinthine discharges, from the macules and cristae, 2) proprioceptive impulses from deep tissues, that is to say, muscles, tendons, joints, neck, trunk, and limbs, 3) exteroceptive impulses from skin and surface and 4) visual impulses from the retina. The correlation of these above mentioned impulses seems to be managed in the higher centers of the central nervous system.

The labyrinth is of importance to control the equilibrium of body and the cerebellum is the main organ to maintain the antigravity muscular activity. The muscular tonus, particularly of antigravity muscles, is responsible to maintain the upright posture. On the other hand, the proprioceptive and exteroceptive functions are essential to the proper correlation of motor acts (Fischer in 1956)[1].

The first neuron of the labyrinth involves the maculae and critstae, the vestibular nerve and ganglion Scarpae. The second neuron involves the central vestibular nuclei and the basal portions of the cerebellum. Secondary fibers pass up and down the brain stem. Cortical centers are considered to be located in the temporal lobe, probably also in the frontal and parietal lobes. According to Wallenberg (1911)[3] the vestibular apparatus is the most important for influencing equilibrium, so that the slightest disturbance of this apparatus is sufficient to upset the statics, On the other hand, the ocular lesions have less effect, and the kinethetic component is the least important.

The anatomical connection with the basal portions of the cerebellum are of special interest to neuroanatomists. The afferent fibers run from vestibular nerve and central nuclei via vestibulo-cerebellalis, to the cerebellum; the efferent from the cerebellar cortex through inferior peduncle to vestibular nuclei; the vestibulo-spinal tracts and the reticular formation of the brain stem. Any lesions within these pathways lead to disturbance of muscular coordination, locomotion, and equilibrium (Fischer in 1956[1]).

Ewald (1907)[4] studied the tonic influence of the labyrinth on the muscles and proposed the tonus labyrinth theory. According to his theory, the impulses emanate from both labyrinths to the muscles of the body and the labyrinth is concerned with the tonus of the homolateral extensors and abductors and with that of the contralateral flexors and adductors. Impulses emanating from the labyrinth are transmitted to the centers and central pathways, thus reaching the muscles. Loewenstein and Sand confirmed Ewald's theory by the electro-physical study. They found out action potentials for normal muscles at all times, even at rest. The tonus changes with movements of the endolymph. The problem of tonus was made clear by intensive animal experiments carried out by Magnus and De Kleyn (1924)[5]. From the results obtained by experimental studies in cats and rabbits, they classified the labyrinthine reflexes into the following groups:

I). Postural reflexes (otolith reflexes)
 1. Tonic labyrinthine reflexes
 2. Labyrinthine righting reflexes
 3. Compensatory eye positions

II). Movement reflexes (semicircular reflexes)
 1. Angular movement reflexes
 2. Linear movement reflexes

III). Reflexes upon inadequate stimuli
 1. Reflexes upon thermic stimuli

2. Reflexes upon galvanic stimuli.

According to Magmus and De Kleyn, postural reflexes produced by the otolithic organ and depend upon the position of the otoliths with respect to the horizontal plane. Postural reflexes in animal are independent of conscious sensation, because complete decerebrated animals are elicitable.

Tonic labyrinthine reflexes seem to be identical with the postural reflexes of Sherrington. These reflexes enablethe individual to bring parts of his body into harmonious positions and to maintain them.

Labyrinthine righting reflexes enable the animal actively to regain its former normal posture and to maintain it, so that these reflexes are of the most importance to maintain a static posture in animals all the time.

Compensatory eye positions such as vertical deviations and counterrollings are elicited by the labyrinth. Vertical deviations are caused by changes in the position of the head over an occipito-nasal axis, counterrolling by changes over a bitemporal axis. Vertical deviations are due to action of the superior and inferior rectus muscles, and on the other hand counterrollings are due to action of both oblique muscles.

Movement reflexes are produced by the semicircular canals and elicited in moving of the body in space. These reflexes are devided into two conditions, such as angular and linear reflexes. For example, when an animal in normal position is turned over the vertical axis in space, nystagmus in a horizontal plane and falling of the body are present.

Reflexes upon inadequate stimuli are caloric and galvanic responses.

2. Righting Reaction in Human Body.

Normal human body in erect posture seems to be stationary in condition. However, it moves slightly all the time and equilibrium of the body is maintained exactly. As above mentioned, equilibrium of the human body is controlled by many impulses, such as labyrinthine discharges, proprioceptive impulses, exteroceptive impulses and visual impulses. Of them, the labyrinthine discharges are most important to control the equilibrium of the body. These labyrinthine discharges in static condition are described as labyrinthine righting reflex or reaction. As our starting point we shall take results from the animal experiments carried out by Magmus and De Kleyn. According to Magmus and De Kleyn, in the animal of unilateral destruction of a labyrinth the reflexes tend to bring the head into such a position that the intact labyrinth lies on top, while the destroyed one is underneath. This is the position in which the labyrinthine righting reflexes are at their minimum. With the opposite position, their maximum is reached, and the animal exerts all its efforts to regain the minimum position, which is the position at rest.

In testing for righting reflexes in animals, the animal is first lift up, held by its haunches. When the trunk is turned to the side, the animal brings its head in normal position. Next the animal placed on a table in lateral position. When the head is held by the examiner's hand, the animal tries to get up in normal head position.

In human subjects, a normal subject in erect position maintains a condition of normal equilibrium, even if the line of gravity deviates to the periphery of the plane of support, immediately after the line returns to the original course. On the other hand, in cases with a destroyed labyrinth, the patient in erect position does not enable to maintain his equilibrium of the body and falls towards the affected side due to some disturbance of righting reaction.

3. Static Function Tests.

Equilibrium of human body in static condition is examined clinically by the following tests: 1. Romberg test; 2. Mann's test; 3. One-leg test; 4. Goniometer test; and 5. Tilt test.

1. Romberg test.

Although Romberg test is rather classical, this test is performed from choice by otoneurologists up-to-date because of a simple and excellent procedure in the light of present. Usually for this test the subject is required to stand on the flat floor with both feet close together to eliminate the proprioceptive factor as far as possible and with eyes closed to eliminate the visual factor. This test method is available to examine whether labyrinthine righting reaction is normal or not. In my opinion (S. Honjo) human equilibrium in static condition is maintained by a synthetic reaction of labyrinthine righting discharge, proprioceptive impulse and visual impulse. Therefore, at first, in order to examine the synthetic reaction of equilibrium the subject should stand in natural posture without any requirement as to his posture. Then the subject keeps his feet close together and eyes closed. The examiner observes and records tendency to fall, direction of falling and body swaying.

2. Mann's test.

In Mann's test the subject in erect posure is required to stand with one foot in front of the other, so that the heel of the anterior foot touches the toe of the posterior foot. Mann's position is rather unstable than Romberg's position, so that in our experiences the normal subject, particularly old woman, shows sometimes body-sway. It should be kept in mind that results from Mann's test is difficult to understand equilibrium function exactly.

3. One-leg test.

The subject in erect posture is required to stand on one leg alternately. In this test it is necessary that the supporting leg keeps extend and the raised leg flexes maximally at the knee. In our experience equilibrium responses in static condition represents most sensitive in the test, particularly with eyes closed.

4. Goniometer test

It is to credit of Von Stein to have demonstrated in 1882 that goniometer test is useful for examining static function of human body. Thereafter method of advancing technique and clinical use of such tests have been sought by many authors. Judging from their reports one can conclude that the results obtained by the methods heretofore in use show a large individual variation in normal subjects and a wide range even in the same subjects at different times. It is, therefore, difficults to distinguish between normal and pathological date because the equipment employed by the above mentioned authors was a hand-machine. This is a reason why a large variation occurs.

To remedy this defect electrically driven equipment, or goniometer, was devised by S. Honjo. Fig. 1 shows the electeical goniometer which inclines from horizontal plane to 30° at angular acceleration of 1.4°/sec^2 and a constant angular velocity of 1.0°/sec. From the normal erect posure

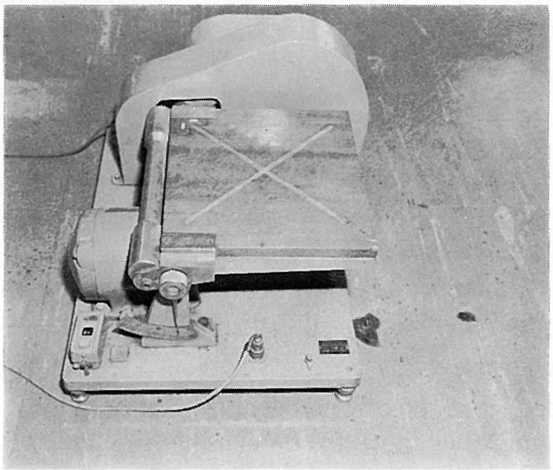

Fig. 1. Electrical goniometer (Honjo).
A plank of this instrument inclines from horizontal plane to 30° at angular acceleration of 1.4°/sec^2 and a constant angular velosity of 1°/sec by electric motor.

on the horizontal plank of the goniometer each subject is inclined forwards, backwards and to both sides. During the inclination the subject keeps his eyes open or closed. An angle of fall we record the angle at which the subject falls from the plank.

5. Tilt test.

McNally is the first to describe the tilt test. The subjects rests with his knees and hands as the same posture to a frog on the tilt table. The table is tilted over a frontal or longitudinal axis. Normal subject and cases with cerebellar ataxia and tabes maintain equilibrium by shifting the trunk towards the raised part of the table, and on the hand cases with labyrinthine lesion on both sides lose balance.

4. Recording Methods of Static Function tests.

Since ancient times attempts have been made to record the results of static function tests in order to take an objective view of equilibrium responses of human body in static condition.

1. Cephalography.

At the beginning, cephalography was used for recording the results of the static function tests. In cephalography the minute movements of the subject's body in erect posture are recorded as a cephalogram on the surface of a flat paper covered with soot, with the sharp needle being attached to the top of the subject's head. In this way, cephalogram shows a locus of body movements, and in normal subjects a range of the locus is limited to a small circle while in cases with disequilibrium a locus is described over a wide range.

2. Photography (Motion picture).

Motion picture of the human subjects in erect posture has been taken for recoding the static function tests. Recently our colleague, Y. Takata, studied the static function of the normal subjects by using 16 mm high speed motion picture camera-HYCAM (K200-Red Lake Laboratory, Ltd). Motion picture of the subjects in erect posture was taken from a distance of 9 meters with film speed of 150F/sec and the films were analyzed by means of a Filmotion analyzer (Bell & Howell).

3. Electromyography.

It is accepted that electromyography is excellent to analyse the actions of muscular fiber and to determine the characteristics of the reflexes caused by various stimulus. Therefore this method has been used to study the static function and by using this method a number of reports have been presented by many authors.

4. Acceleration registography (Kitahara).

In general, mechanical-electrical transducer enables to change a mechanical quantity into a electrical quantity. Recently by utilizing this principle, in order to record the body movements of human subjects, various kinds of transducer have been used by many investigators. For example, Coats (1973)[6] recorded body sway of human subjects in both anteroposterior and lateral planes using a standard precision potentiometer connected to the subject. In addition, the principle of the strain-gage as a transducer was discovered by Load Kelvin in 1856. Strain-gage has been applied not only in measuring the strain and stress of material under test, but in constructing many kinds of transducers in technology. Since then strain-gage-type transducers have been introduced into the medical studies, for example blood and intra-ocular pressure have been measured and masticatory force has been measured by Katsuki et al (1957) Jonkees and Groen about twenty years ago recorded acceleration components of the head movements in walking of human subjects by using an induction-type accelerometer as a transducer.

Kitahara (1965)[7] was the first to describe an acceleration resistrography. He studied equilibrium of human subjects and recorded the body movements of human subjects in erect posture by using an unbonded resistance wire strain-gage type linear accelerometer as a transducer. We propose to explain mechanism of this accelerometer. This accelerometer placed on the top of the subject's head enable to change mechanical quantity of body movements into electrical quantity of resistance. This accelerometer consists of two pairs of resistance wires suspending the inertia mass. These two pairs of resistance wires are

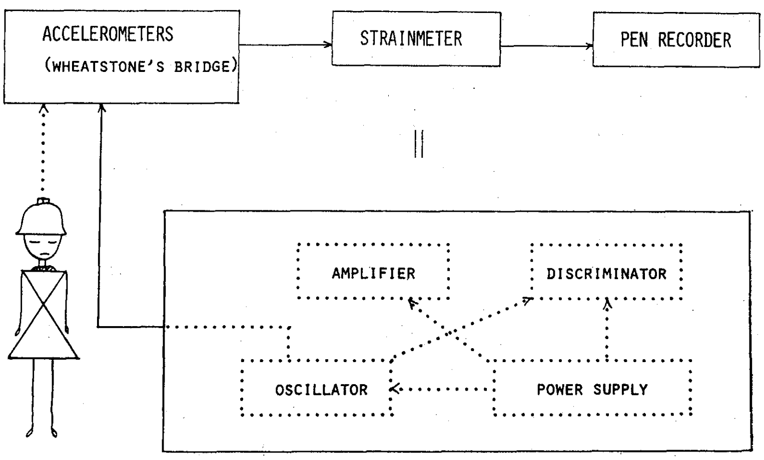

Fig. 2. Block diagram of subject position and instruments.

connected in Wheatston's bridge. If the deviation of the inertia mass occurs on account of head movements, the tesion of one pair of resistance wire is increased, while that of the other is decreased. In this condition, electrical resistance changes and consequently potential is generated in the Wheatston's bridge. The bridge is activated by an oscillator, so that the sine wave of the oscillator frequency is modulated by the signal wave. The output of the bridge circuit is applied to an amplifier and then to silicon diode discriminater. The output of this discriminater is then led to a pen writing recorder as shown in Fig. 2. The output of these instruments is potential which is proportional to the head movements.

In order to measure body movements of subjects, two accelerometers of which directions of action are lateral or anteroposterior planes are used. These accelerometers are fixed on the top of a light helmet which is fastened firmly to the head of the subject, so that when the subject body moves they inclines.

According to Kitahara, curves obtained by acceleration resistrography are named "acceleration resistrogram", and curves on the resistrogram are divided into two types: 1. a high frequency wave; and 2. a low frequency one. The high frequency wave is caused by any kind of linear accelerations, be it the gravitational acceleration or the acceleration of non-uniform movements. An amplitude of this wave is considered to be an index to the amount of head swaying. The low frequency wave is also caused by any kind of linear accelerations as well as the former wave.

5. Results From our Present Studies of Static Function Tests in Normal Subjects and Cases with Disturbances of Equilibrium.

In the last decade, the researches of static function tests have been engaged in our Department of Yamaguchi University and a number of papers have been reported by our colleagues.

In order to measure the body movements of subjects, an unbonded resistance wire strain-gage type accelerometer (Kyowa Dengyo AS-1C) was used. Mechanical characteristics of the accelerometer used are as follows: 1. Capacity, 1g; 2. Frequency range, 0-57 Hz; 3. Input resistance, 121.7 Ohm and output resistance, 121.7 Ohm; 4. Sensitivity of output, Full scale 0.4605 mA/V (Strain 921×10^{-6}); 5. Non-linearity, 1.0% Full scale. A dynamic strain amplifier (Kyowa Dengyo DPM-110A) was used as an oscillater, amplifier and discriminater. The output of the dynamic strain amplifier is led to a pen writing recorder (Fig. 2).

Methods of static function tests in our studies were 1. Romberg test, Mann's test and goniometer test with eyes open and closed.

1. Tsujikawa (1965)[8] studied the human equilibrium by static function

tests in 20 normal adults by using acceleration resistrography. According to his descriptions, the waves of acceleration resistrogram in Romberg test were composed of waves of short amplitude (less than 0.1 g) without respect of eyes open or closed. The waves in Mann's test were mainly composed of waves of short amplitude, occasionally a few waves of medium amplitude (0.1–0.25 g), particularly with eyes closed. The waves in Goniometer tests were composed of mainly short amplitude, while a few waves having medium amplitude were recongnized. The influence of vision upon the waves of acceleration of resistrogram in Romberg tests was hardly proved, and great influence of vision upon the waves was clarified in Mann's test and Goniometer test.

2. Nishimura (1967)[9] performed on static function tests in 86 cases with complaining vertigo using acceleration resistrography. All 86 cases tested were divided into the following groups: 1). 6 cases with circumscribed labyrinthitis; 2). 13 cases with Meniere's disease; 3). 8 cases with head trauma; 4). 28 cases of congenital deafmute; 5). 2 cases with sudden deafness; 6). 3 cases with streptomycin poisoning; 7). 2 cases with labyrinthine syphilis; 8). 3 cases of cervical vertigo; 9). 1 case with spinal ataxia; 10). 5 cases with epilepsy; 11). 5 cases with congenital nystagmus; and 12). 9 cases with cardiovascular diseases. The methods of static function tests were Romberg test, Mann's test and Goniometer tests. In cases with unilateral lesion of the labyrinth, for example circumscribed labyrinthitis or Meniere's disease, waves of the affected side in Mann's test and Goniometer test revealed more irregular than that of normal side. In cases with head trauma, the waves presented some different pattern from the normal. In cases with deafmute there were three types in the waves of accelerogram: 1. the same to normal pattern; 2. Moderate deviation; and 3. severe deviation. In cases with cardiovacular disease there was no deviation in waves.

3. Ishihara (1975)[10], and Honjo and Ishihara (1971)[11] carried out static function tests in 54 cases with complaining vertigo by using acceleration resistrography. All subjects tested were in erect posture and Romberg test, Mann's test and Goniometer test were performed. Acceleration resistrograms obtained by the above mentioned methods were divided into six types in comparison with those of normal subjects (Fig. 3).

Type I. The waves of acceleration resistrograms obtained by three tests were within normal limits with eyes open or closed.

Type II. The waves of acceleration resistrograms obtained by Mann's test and Goniometer test with eyes closed showed larger than those of normal in frequency.

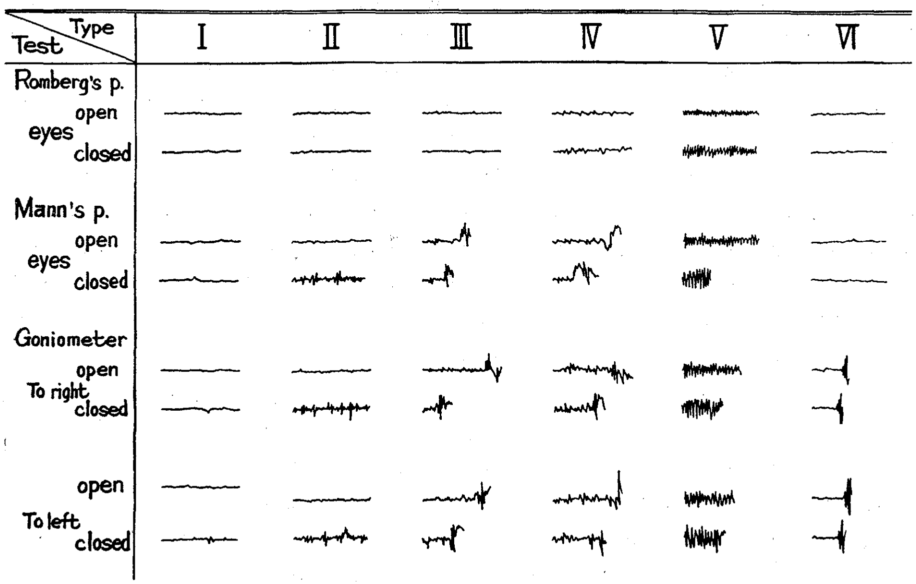

Fig. 3. Patterns of acceleration resistrogram. They are classified into six types.

Type III. The waves of acceleration resistrograms obtained by Mann's test and Goniometer test with eyes open and closed showed larger than normal in frequency, notwithstanding normal by Romberg test.

Type IV. The waves of acceleration resistrograms obtained by three tests showed larger than those of normal in frequency.

Type V. The waves showed abnormal peculier spike in all tests.

Type VI. The waves obtained by only Goniometer tests showed larger than normal in frequency with eyes open and closed.

4. The author and Shimamoto recently have engaged in a statistical analysis of results obtained by static function tests, such as Romberg test, Mann's test and Goniometer test in cases with complaining vertigo performed on tests at our Department.

The total number of the cases is 220. Age and sex incidence are given in Table I. The cases have been divided into six types in the manner designed by Ishihara[10] as shown in Fig. 3. The analysis is present in Table II. The diagnostic categories in the cases tested are given in Table III, IV and V.

5. Goniometer Test.

In order to examine the righting reaction in erect posture of human body, static function tests, such as Romberg test, Mann's test, One leg

Table. 1. Age & sex distribution in 220 cases of our study

	(Total)	0–19	20–29	30–39	40–49	50–59	60–69	+70
Male	112	2	13	23	26	23	19	6
Female	108	5	14	25	23	22	18	1
Total	220	7	27	48	49	45	37	7

Table. 2. Patterns of accerelation resistrogram (Ishihara and Honjo) in cases with complaining vertigo

Type	Number of cases	
I	69	31.4%
II	80	36.4%
III	19	8.6%
IV	37	16.8%
V	5	2.3%
VI	10	4.5%
Total	220	

Table. 3. Classification in 220 cases with vertigo (1)

	Total	I	II	III	IV	V	VI
Meniere's disease	43	22	18	1	1		1
Vestibular neuronitis	15	6	6	1	2		
Dead labyrinth	10	4	1	2	3		
Benign positional nystagmus	6	3	3				
SM intoxication	4	2	1		1		
Circumscribed labyrinthitis	3		1	1	1		
Harada's disease	3	1	1	1			
Sudden deafness	3		2		1		
Motion sickness	1		1				
Vegetative dystonia	6	6					
Hormonal disorders	5	1	2	1			1

test and Goniometer test. It is needless to say that Goniometer test is different from the other tests as to purpose of examination.

The purpose of goniometer test is to examine how a subject keeps up his body posture during passive movement carried out by inclining the plank of goniometer. On one hand Romberg test and the others are

Table. 4. Classification in 220 cases with vertigo (2)

	Total	I	II	III	IV	V	VI
Cerebral vascular lesions	42	9	17	5	7	1	3
Head trauma	19	6	5	1	6		1
Cervical vertigo	10	1	7		2		
Hypertension	8	2	3		2		1
Brainstem lesion	6	1		1	3	1	
Hypotension	5	2	2	1			
Mercury poisoning	5		1	1	2	1	
Spinal ataxia	3				3		
Cerebellar ataxia	3				2	1	
Brain tumour	2			1			1
Post-op. brain tumor	2		1		1		

Table. 5. Classification in 220 cases with vertigo (3)

	Total	I	II	III	IV	V	VI
Post-meningitis	2		2				
Thinner intoxication	1	1					
Philopon intoxication	1			1			
Organic phosphate poisoning	1		1			1	
Tabes dorsalis	1						
Acoustic neuroma	1		1				
Wallenberg syndrome	1	1					
Epilepsy	1	1					
Amenia	4		3	1			
Ophthalmologic diseases	2		1				1
Mitral stenosis	1				1		

performed on in exactly static posture in condition without any passive movement. Furukawa (1957)[12] studied goniometer test and reported extensive results obtained by using an electrical goniometer devided by Honjo and Furukawa.

In order to determine the most available angular velosity for differentiating normal from lesions of vestibular system, subjects were inclined by six kinds of angular velocity, such as 1°, 3°, 5°, 10°, 15° and 20°/sec. For this study 280 normal subjects and 118 patients with vestibular disturbance were tested. From results obtained by the above mentioned study, Furukawa concluded that an angular velocity of 1°/sec is the most available for goniometer test. In addition, he studied goniometer test as to some influences of visual factors and electromyographical findings on the legs and trunk.

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REFERENCES

1) Fischer, J.: *The Labyrinth.* Grune & Stratton, London, 1956.
2) Abels H.: Die Seekrankheit. *Handbuch* d. *Neurol. d. Ohres,* 3 : 601, 1926.
3) Wallenberg, A.: *Deutsche Ztschr. f. Nervenh.*, 41 : 8, 1911.
4) Ewald, J.: *Der Labyrinthtonus. Cong. internat. de psychiat.* (Amsterdam), 1907.
5) Magnus, R., and De Klyen, A. Experimentelle Physiologie des Vestibularapparates. *Handb. d. Neurol. d. Ohres,* 1 : 465, 1924.
6) Coats, A.: Effect of varying stimulus parameters on the galvanic body-sway response. *Ann. Oto., Rhino., Laryngol.*, 82 : 96, 1973.
7) Kitahara, M.: Acceleration resistrography. *Ann. Oto., Rhino. Laryngol.*, 74 : 203, 1965.
8) Tsujikawa, O.: Human equilibrium in standing position. *Jap. J. Otol., Tokyo,* 68 : 1016, 1965.
9) Nishimura, M.: Clinical experiences of the acceleration resistrogram. *Jap. J. Otol.. Tokyo,* 70 : 1847, 1967.
10) Ishihara, K.: Clinical study on the righting responses. *Jap. J. Otol. Tokyo,* 78 : 26, 1975.
11) Honjo, S. & Ishihara, K.: Some problems on the static function test: Part II. *Otolaryngology Tokyo,* 12 : 981, 1971.
12) Furukawa, R.: Electrical goniometer test. *Otorhinolaryngologia Kyoto,* 50 : 45, 1957.