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EVALUATION OF OTOLITH ORGAN FUNCTION BY MEANS OF OCULAR COUNTERROLLING MEASUREMENTS*

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SUMMARY PAGE

THE PROBLEMS

1. Does ocular counterrolling represent a specific and valid indicator of otolith function?

2. What are the diagnostic parameters of the ocular counterrolling response?

3. Can otolithic function be predicted from the results of functional tests of the other two auricular organs?

FINDINGS

When certain critical procedural requirements are met, ocular counterrolling can be used as a specific and valid indicator of otolith function. The photographic method affords high precision of mensuration which extends the usefulness of this eye reflex in assessing otolith function of individuals with severe macular destruction as well as normals subjected to conditions which act to reduce otolith activity, including near weightlessness as experienced in aerospace flight. The average magnitude of the counterrolling response (Counterrolling Index) provides a measure of the general functional level of the otolith apparatus, although the limits of normal function need to be better defined. Diagnosis of unilateral loss of otolith function as reflected in an asymmetrical counterrolling response to rightward and leftward tilt appears possible. Loss of otolith function cannot always be predicted from the results of tests of hearing or the semicircular canals.

INTRODUCTION

The reflex act of the eyes rolling conjugately about their lines of sight appears to be the most valid of all known indicators of man's otolithic activity since it occurs in systematic relation to the magnitude and direction, with respect to the head (otolith organs), of the acting inertial force. The potential value of using this external indicator, the so-called ocular counterrolling reflex, to assess otolith function was recognized by earlier researchers in this field (1-5). Its use, however, as a clinical test method was restricted, and interest in it eventually waned, probably because the various methods available were difficult to employ and yielded less precision than desired. The measuring error of those methods, which at best was approximately one degree, was significant in terms of the typically small amount of counterroll manifested even by a healthy person with his head positioned so as to evoke a maximal response. Physiological variability in torsional position added to the difficulty of obtaining a reliable indication of otolith activity.

In response to the need for greater precision in mensuration, a method utilizing photographic recording of natural iris landmarks was developed which provides great accuracy (about ± 5 minutes of arc) and has provided the opportunity to appraise precisely the otolith function of both normal and labyrinthine-defective individuals under a variety of experimental conditions (6).

The purpose of this paper is: 1) to present the current standard test method initiated at the Naval Aerospace Medical Institute for measuring ocular counterrolling, and 2) to summarize the results of certain studies which have led to the development, validation, and confirmation of the clinical need for this method of evaluating otolith function.

MEASUREMENT OF OCULAR COUNTERROLLING BY THE PHOTOGRAPHIC METHOD

The basic solution to the problem of measuring very small amounts of eye roll was found in simply magnifying natural iris landmarks which are recorded photographically. In this procedure, a 35-mm film image of the iris is enlarged 300 times its actual size by projection onto a screen. Measurement of angular torsional movement around the center of the pupil is then accomplished by superimposing upon each test image in succession a second projected image of the subject's eye that serves as a standard of comparison. More complete details of this measuring technique are available in other publications (6-8). Control of this stimulus to the otolith organs and reduction or elimination of extralabyrinthine factors which influence the torsional eye position are provided by a counterrolling tilt device (Figure 1) which was developed at this laboratory. The subject is restrained within this device in a standing position, and his head and body are tilted as a unit to eliminate cervical reflexes that are evoked when the head is tilted by bending the neck. The subject's head is fixed by a dental bite and placed so that the center of the eye being recorded falls on the axis common to tilt and to the camera optical system; while properly viewing the fixation target, he is made to

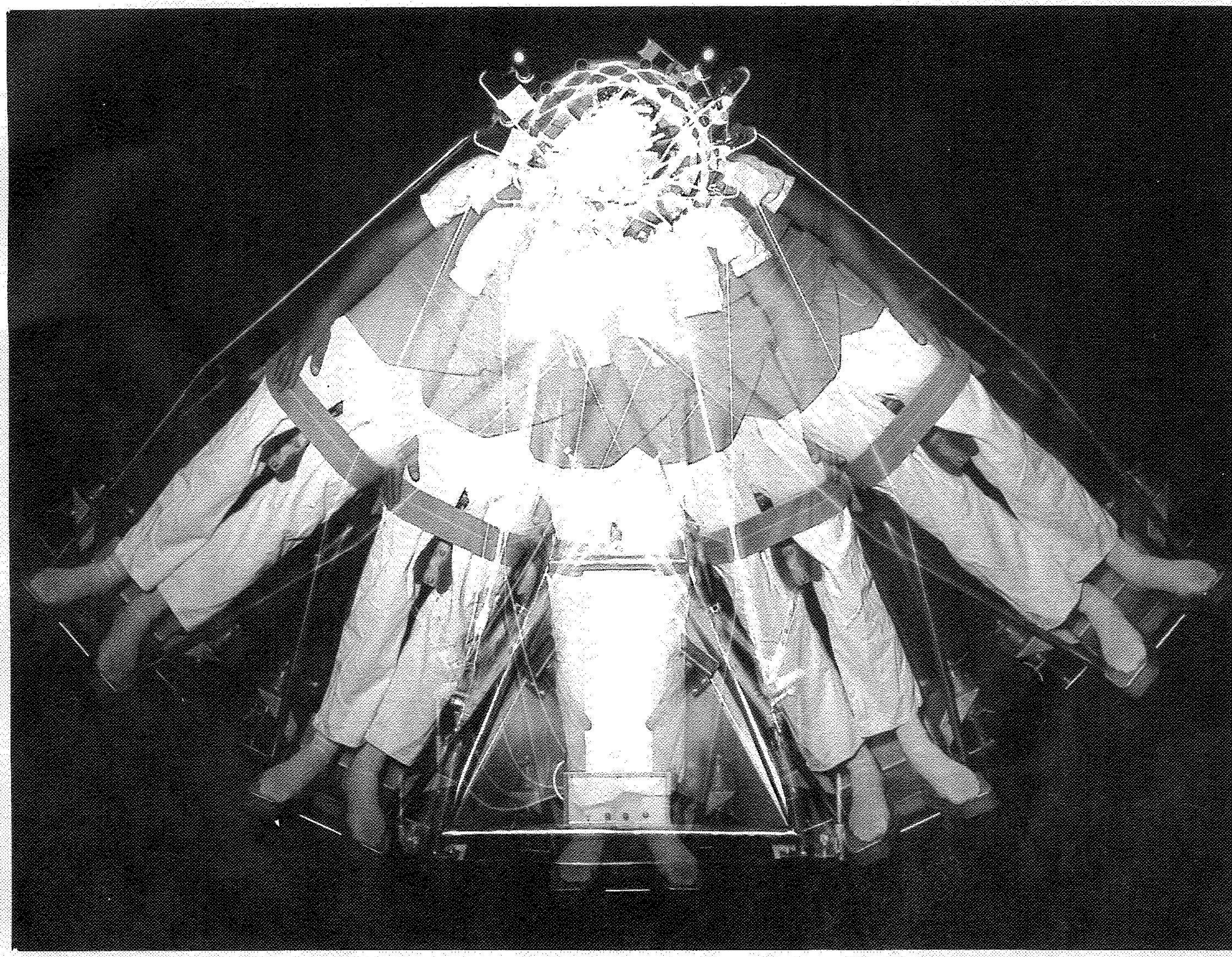

Figure 1

Multiple Exposure View of Counterrolling Tilt Device Showing Subject Positioned Upright and Tilted ± 25° and ± 50°

tilt around his line of sight. Throughout the test the experimenter verifies the subject's fixation as well as the correctness of the focus, as indicated on the ground-glass screen of the camera system. An electronic flash provides the necessary illumination for proper exposure, and its corneal reflection "marks" the film image of the iris for final verification of ocular fixation. The eye not being photographed is covered with an opaque patch, and the test is conducted in a completely dark room to eliminate any visual stimuli which might affect extraocular muscle tonus.

Several minutes before the test one or two drops of Pilocarpine hydrochloride are instilled in the eye being tested to reduce the size and physiological oscillations of the pupil. The photographic recording of the smaller and relatively constant pupil size has been found to increase the ease with which the test and standard film could be superimposed and aligned, although the accuracy was not appreciably improved by this procedure. A considerable amount of variability among individual measurements of ocular counterrolling which is far greater than the measuring error has been found in almost every subject tested, indicating that a certain amount of physiological unrest also exists with respect to the anteroposterior axis of the eye. This variability has been observed by several authors (3,6,7,9,10) using various measuring techniques and points up the need for taking several measurements at each tilt position. In the shortened test now used as the standard one, at least six records are made at each tilt position.

In an earlier extensive study of counterrolling in which measurements were made at every 15 degrees within the frontal, sagittal, and two intermediate planes, it was found that maximum compensatory torsional eye movement occurred in the frontal plane, somewhat less in the intermediate plane, and not at all in the sagittal plane (6). Ocular rolling, as the term counterrolling implies, was always found to occur opposite the lateral component of the head tilt and to increase fairly rapidly up to a maximum at a head inclination between 60 and 90 degrees; from this point on counterrolling decreased but at a lesser rate than it increased, reaching about zero when the head was tilted vertically downward. The data points in Figure 2 represent the average of several values obtained at each tilt position. Data obtained on other normal individuals tilted in the frontal plane usually revealed the same general response curve with a relatively high ratio of counterrolling to small amounts of body tilt from upright; this ratio tended to decrease with greater amounts of tilt.

The eye roll response to moderate body tilts as measured by the photographic method predicts well the overall counterrolling response and is therefore sufficient in most cases to calibrate the functional status of the otolith organs. For this reason, the standard screening type test of counterrolling as it is currently used at this laboratory involves recording at only five positions (upright, ± 25°, ± 50°). Besides the greater economy of time, the advantages of the shortened version of the test include greater suitability for testing less than robust individuals, and probably less influence of extralabyrinthine factors in counterrolling.

A variant of the screening test is the so-called "clinical" version in which the tilt positions of ± 17.5, ± 37.0, and ± 64.0 degrees are added to the standard ones. These

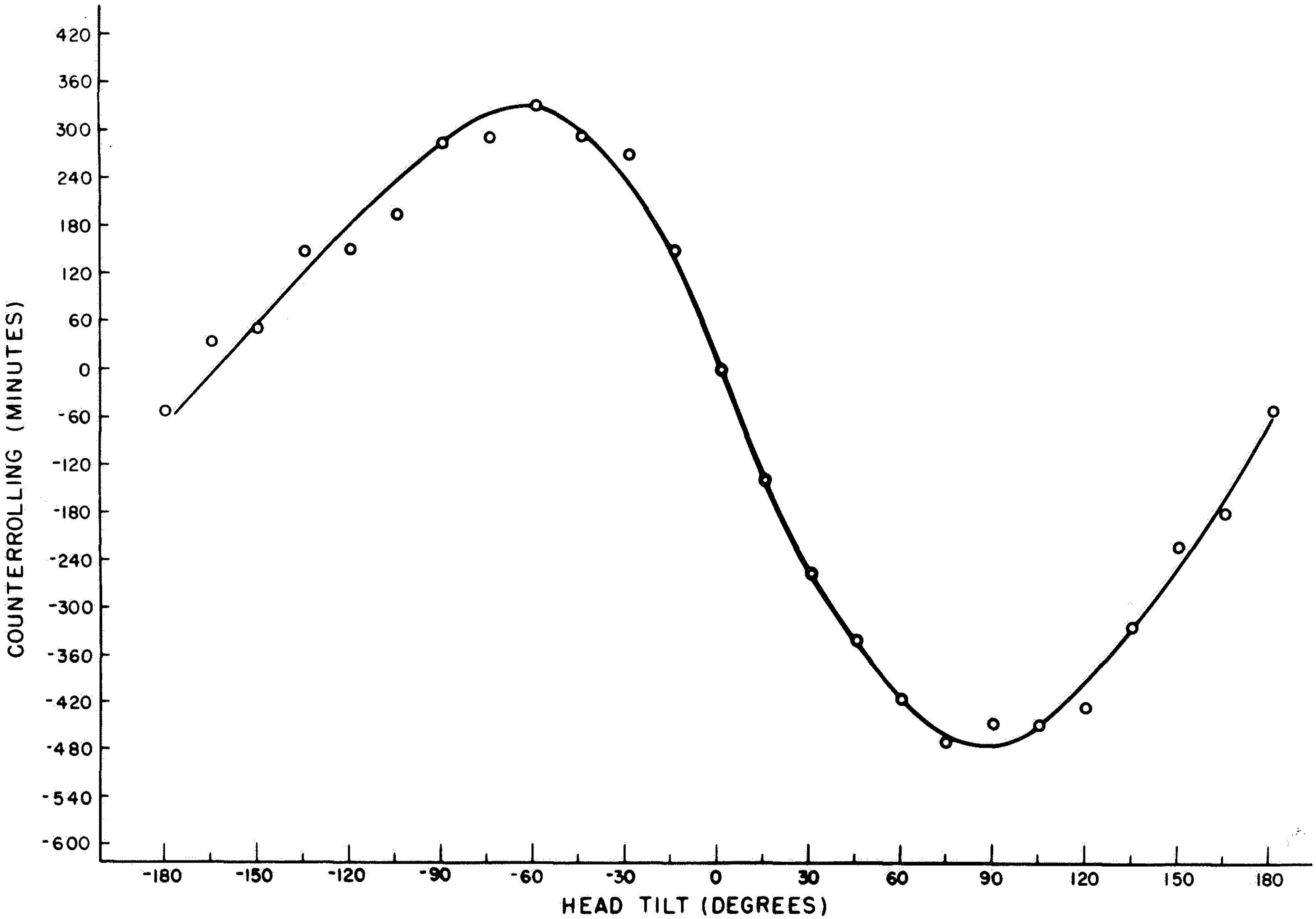

Figure 2

Counterrolling as a Function of Lateral Head Tilt additional data points give better delineation of the response and allow a more comprehensive evaluation of various parameters of counterrolling. Therefore, the clinical method is used to test a person with known or suspected labyrinthine disorder or to retest one who manifests unusual counterrolling as recorded by the screening method. The longer method is particularly useful when counterrolling values before and after surgery involving the labyrinthine organs are to be compared.

VALIDITY OF USING COUNTERROLLING AS AN INDICATOR OF OTOLITH FUNCTION

In several experiments involving special aircraft equipped to fly Keplerian trajectories the normal gravitational pull of the Earth was counteracted partially or completely in specific amounts (11, 12). In this way it was possible to investigate the effect of reducing the adequate stimulus to the otolith organs and thereby to test the general validity of recording eye roll as a means of measuring otolithic activity. Several persons with complete or severe functional loss of the auricular organs on both sides were used as control subjects. It was found that otolith activity as indicated by counterrolling decreased in a regular fashion as the force was reduced. In the weightless condition in which the otolith organs were physiologically deafferented, tilting the normal individual had no appreciable effect upon the activity of the otolith organs, as indicated by the absence of counterrolling. The labyrinthine-defective subjects manifested a greatly reduced pattern of change in response which resembled that of the normals (Figure 3). This could be interpreted either as an actual change in the small residuum of otolith function which these subjects probably possess or as an effect of stimulation of extralabyrinthine sources of tonic innervation to the extraocular muscles. Figure 4 summarizes the data which relate otolith activity to the logarithm of the gravitational stimulus. Although the absolute threshold is apparently only a very small fraction of the normal gravitational pull, the curves of this figure reveal that as the g-load is increased above threshold, otolith activity is initially raised only slightly and increases steadily in ever-increasing amounts as a direct function of g-load. Above approximately 0.6 g, otolith activity becomes linearly related to the g force, at least up to 1.0 g and probably beyond (13).

COUNTERROLLING RESPONSE PARAMETERS

In assessing otolith activity by means of the ocular counterrolling measurements, it is useful to consider at least two response characteristics: 1) magnitude and 2) symmetry. The magnitude of the counterrolling response (Counterrolling Index) is calculated as one-half the maximum average roll measured for right and left tilt and which usually occurs at the greater tilt angle (± 50 degrees) used in the standard test procedure. Figure 5 depicts the distribution of Counterrolling Index values among a normal population (N = 550) (unpublished observations) that consisted mainly of military personnel, ranging in age from 17 to 52 years, who were free from any disease, defect, or disorder, and among ten labyrinthine-defective subjects, ranging in age from 20 to 43 years, who are discussed in the next section of this paper. Although it is impossible at this time to divide the normal population into two groups, those with normal and those with defective

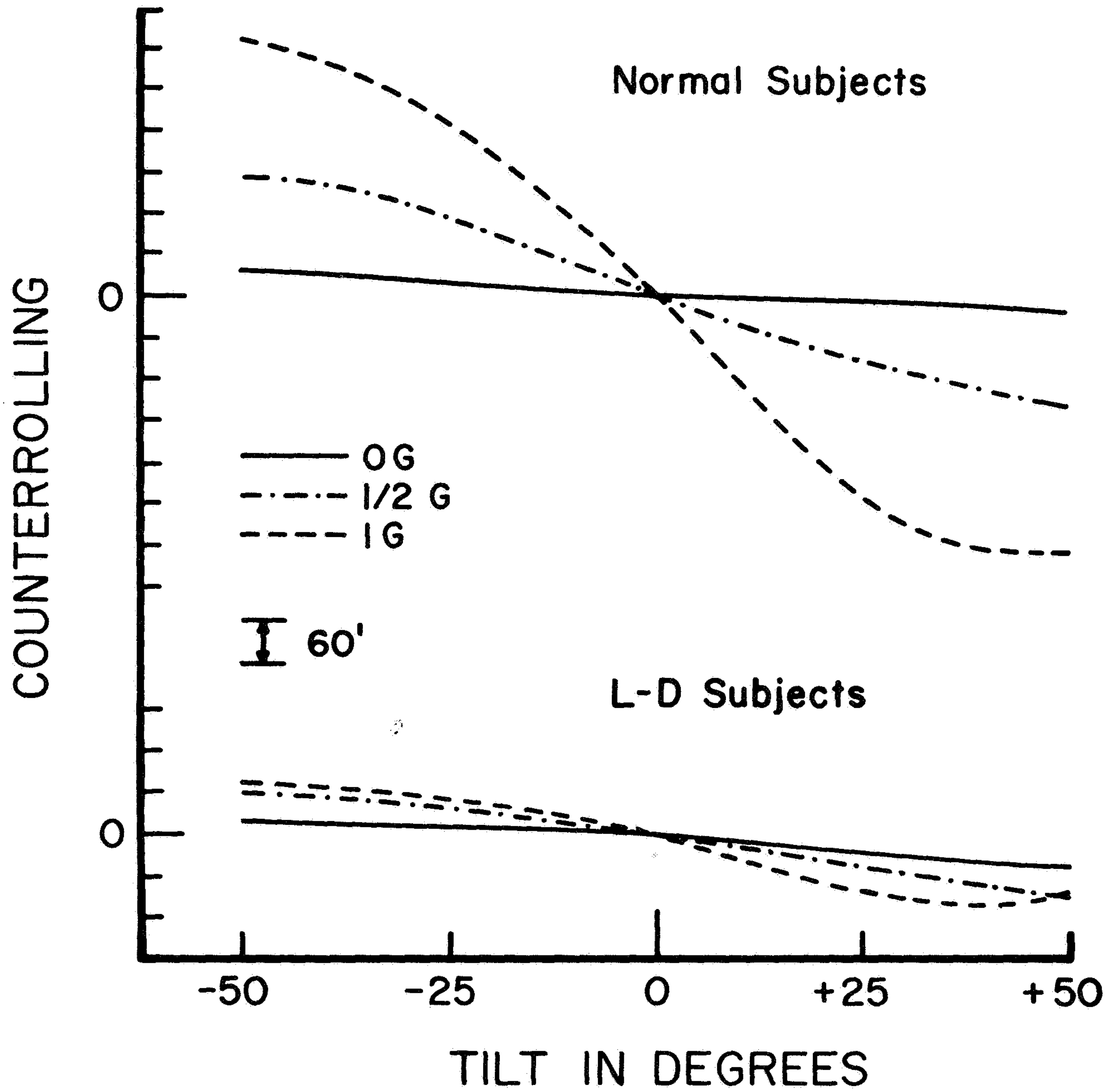

Figure 3

Counterrolling as a Function of Magnitude of Gravitational Force and Body Position with Respect to Direction of Force in Normal and Labyrinthine-Defective Subjects

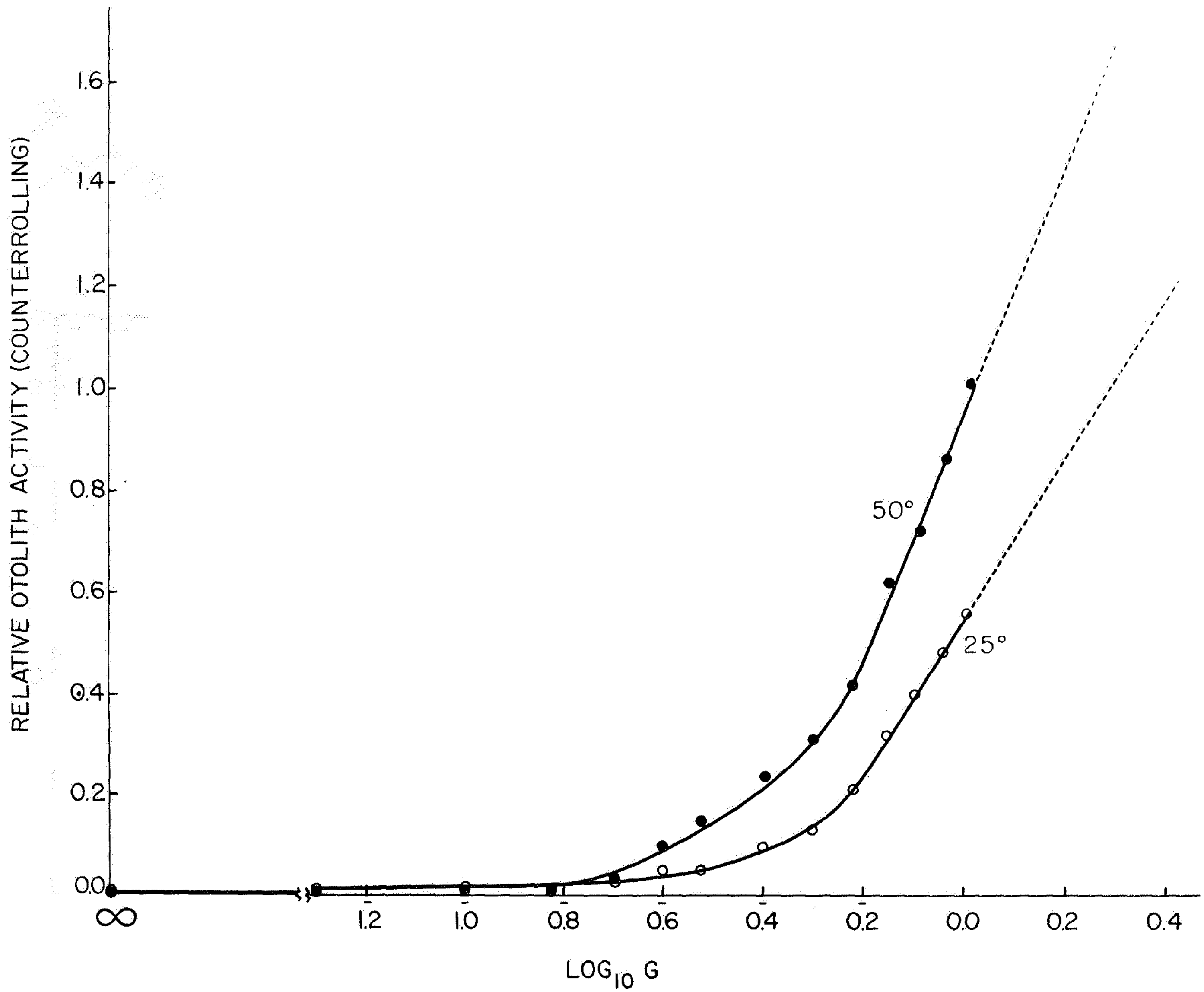

Figure 4

Relation of Otolith Activity to the Logarithm of the Gravitational Stimulus

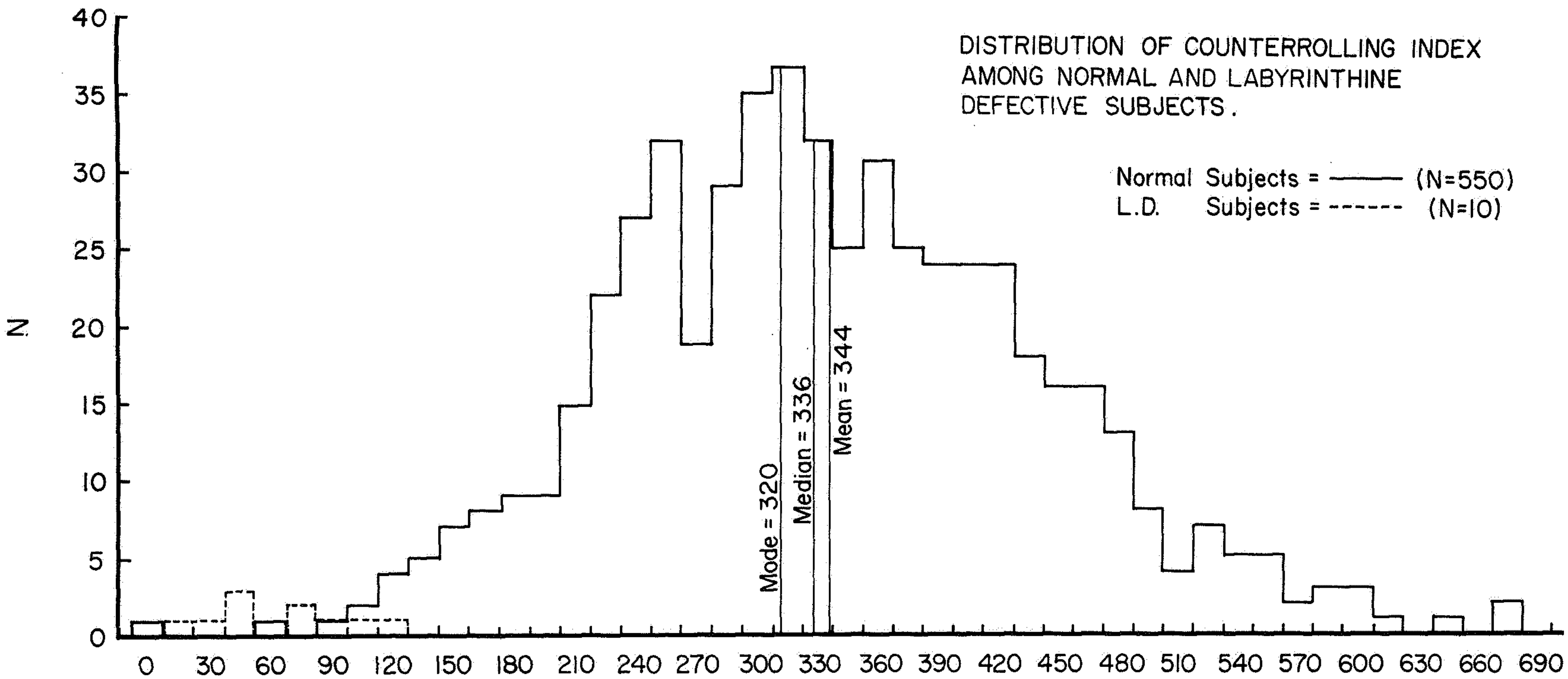

Figure 5

Distribution of Counterrolling Index Among Normal and Labyrinthine-Defective Subjects

otolith organ function, an index in a subject which is less than approximately 120 minutes of arc is a strong indication of otolithic impairment since that is within the range of counterrolling indices of the labyrinthine-defective group of subjects. Further investigation is required to define the probable range of physiological variation of counterrolling response in the positive as well as in the negative direction of deviation from the mean.

In addition to interindividual differences in magnitude of response, it was found early in the testing program that occasionally an individual would manifest a difference in the amount of counterrolling when he was tilted rightward and leftward. In quantifying this right-left difference another index (Asymmetry Index, AI) was adopted. This index is the ratio (in per cent), expressed in absolute terms, of the larger to the smaller sum of counterrolling values (Σ CR) measured for all angles of right-left tilt (clinical counterrolling test) of the subject:

$$AI = \frac{\Sigma CR_1}{\Sigma CR_2} - 1.00 \times 100,$$

where $CR_1 > CR_2$. The direction of the asymmetry is denoted by R or L which indicates the direction (right or left) of tilt that yields the greater counterrolling.

Other possible parameters of ocular counterrolling are now under study.

SELECTIVE LOSS OF OTOLITH FUNCTION

There is evidence that the level of otolith organ function cannot always be deduced from the results of testing the other auricular sensory organs. The following examples of differences in response measured by specific tests of the inner ear illustrate that selective loss can occur in various degrees.

1) Bilateral deafness and loss of semicircular canal function: Tests of a group of completely deaf subjects with severe or complete bilateral loss of the semicircular canals revealed curious counterrolling patterns (Figure 6). The magnitude of response was in all cases less than what could be considered as normal; in some instances there was no definitive evidence of counterrolling, in others it was limited to one direction, and in still others there was a small but regular amount of counterroll with successive increase in bodily tilt in both directions. The differences in counterrolling among these individuals can be explained by the various amounts of otolith function which have withstood the disease (infantile meningitis).

2) Normal or partial loss of hearing with various amounts of suppression of semicircular canal function: Figure 7 summarizes the results of the counterrolling test on four patients who several years previously had been given streptomycin sulfate parenterally in the treatment of Ménière's disease (14). Inasmuch as similar measurements were not obtained prior to streptomycin therapy, the relative etiological significance of the disease process and the drug in causing any reduction in otolith function is

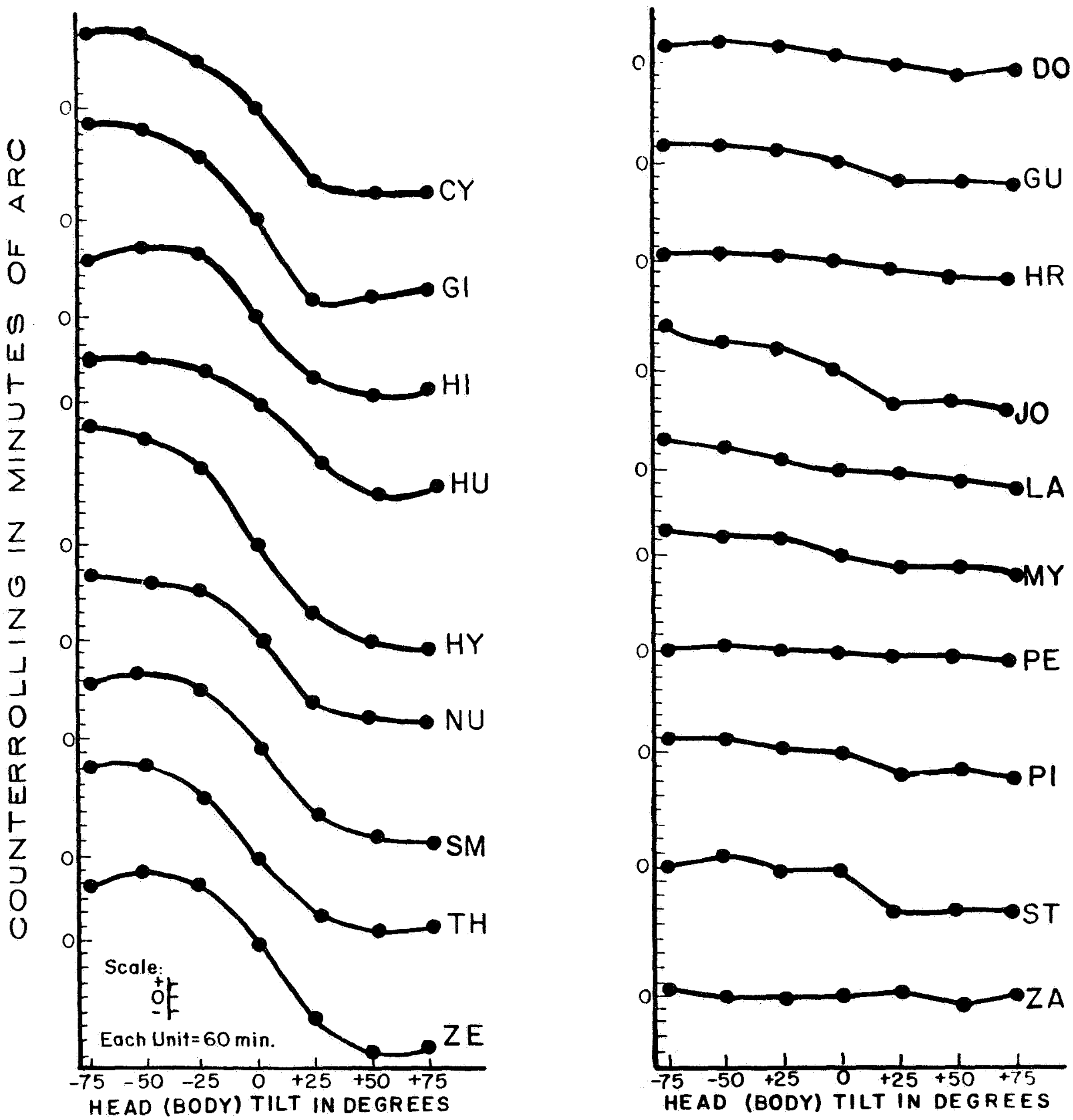

Figure 6

Comparison of Counterrolling Values Between Normal and Labyrinthine-Defective Subjects. Left: Normals Right: L-D's

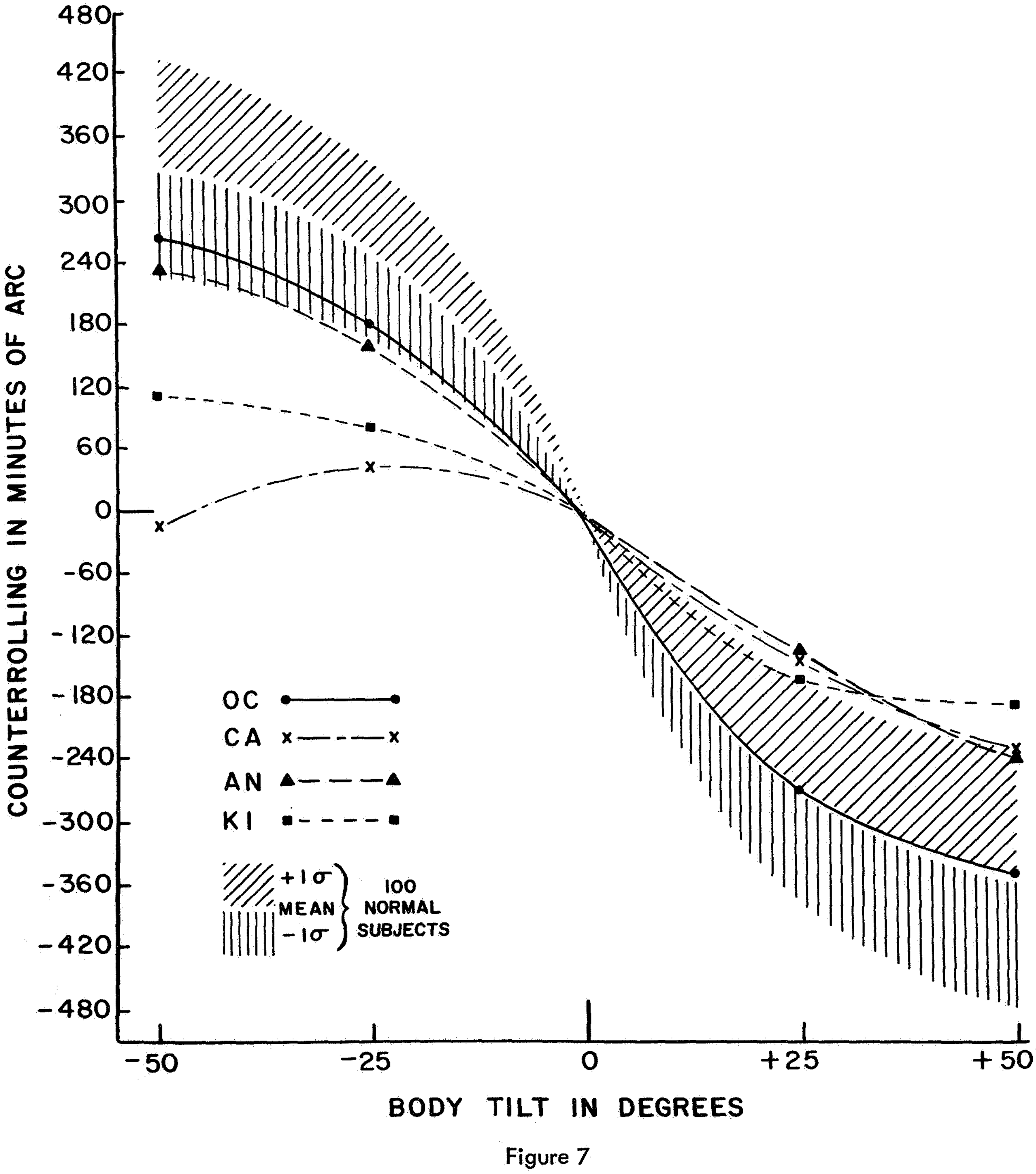

Figure 7

Counterrolling Values of Four Subjects with Ménière's Disease
Treated with Streptomycin Sulfate

unknown, and the probable loss of otolith function must be based upon deviation from the average response of the normal subjects tested. Even so, these patients exhibited various levels of function of the semicircular canals and organ of Corti in their normal and diseased ears with which to compare otolith organ function. Patient KI, for example, with bilateral disease and hearing loss, after therapy revealed complete suppression of response to caloric testing on the left and greatly reduced response on the right. His counterrolling index (CI = 149) indicated that his otolith function was bilaterally reduced below normal, and particularly when he was tilted leftward. According to the inward shearing theory (6) of otolith stimulation, this left asymmetry (AI = 79 L) correlates with greater otolithic loss in his left ear; i.e., theoretically greater counterrolling will occur when a person is tilted toward his defective (in this case, more defective) side. Among the remaining three patients who were affected by the disease injury and drug toxicity on one side only, OC manifested "normal" counterrolling (CI = 305) for both directions of tilt with only slight asymmetry (AI = 38 R), indicating a relatively small loss of otolithic function compared to the great loss of function of the other two auricular organs of the same diseased right ear; CA revealed substantial bilateral reduction in counterrolling (CI = 127) as well as great asymmetry (AI = 277 R), indicating severe yet incomplete loss of otolith function of his diseased right ear; the counterrolling of AN fell within the "normal" range with respect to magnitude (CI = 235) and was essentially symmetrical, findings which in no way correlated with the unilateral (left) and severe loss of hearing and canal function.

3) Normal hearing, normal canal function: The distribution of magnitude of counterrolling among the normal test population (Figure 5) provides further evidence that there is a great range of otolithic function even among individuals with normal hearing and canal function. In rare instances otolithic function as indicated by this response is severely reduced; in one case it appeared completely lost.

These findings indicate that the use of results of testing auditory and semicircular canal function for predicting the functional status of the otolith organs is unreliable as well as unnecessary. A valid and precise method of measuring otolith function, such as outlined in this report, can supplement the routine clinical tests of inner ear function.

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13. ABSTRACT

Measurements of ocular counterrolling by the photographic method provide specific and valid otolith function information. The precision of the test method has extended the usefulness of ocular counterrolling as an indicator of otolith function of individuals with severe macular destruction as well as normals subjected to conditions which act physiologically to deafferent these organs such as near weightlessness of aerospace flight.

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