THE CALORIC TEST – H. HAMERSMA

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ACADEMISCH PROEFSCHRIFT TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE GENEESKUNDE AAN DE UNIVERSITEIT VAN AMSTERDAM, OP GEZAG VAN DE RECTOR MAGNIFICUS Dr. M. W. WOERDEMAN, HOOGLERAAR IN DE FACULTEIT DER GENEESKUNDE, IN HET OPENBAAR TE VERDEDIGEN IN DE AULA DER UNIVERSITEIT OP DONDERDAG 19 SEPTEMBER 1957 DES NAMIDDAGS TE 4 UUR PRECIES

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PROMOTOR:

PROF. Dr. L. B. W. JONGKEES

DIT PROEFSCHRIFT WERD BEWERKT
IN DE KEEL-, NEUS- EN OORHEELKUNDIGE KLINIEK DER UNIVERSITEIT
VAN AMSTERDAM

*Aan my ouers*
*Aan my vrou*

*CONTENTS.*

## *VOORWOORD.*

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# INTRODUCTION.

The Caloric Test still remains one of the most important methods of investigation of the equilibrial sense organ as it allows the separate examination of each labyrinth. The nystagmus which results from this type of stimulation has proved to be more reliable for estimating the qualitative and quantitative magnitude of the response than the turning sensation or the "Pulsionsreflexen".

The observation of the nystagmus is usually done with or without the aid of Frenzel's glasses. However, certain properties of the nystagmus, especially the speed of the slow component, cannot be measured in this way. Added to this is the fact that the personal judgement of the observer has to be relied upon to a large extent. This makes the comparison of results obtained by various investigators unsatisfactory. The necessity for a reliable and clinically practical nystagmogram has always been felt.

Thanks to the research on Electronystagmography and to the advancement of Electronics in recent years, we now have reliable apparatus at our disposal by which nystagmus can be recorded. As was the case with Electrocardiography and Electro-encephalography, the Electronystagmography is now approaching the stage where it will be generally accepted as a basic method to record certain types of nystagmus. In recent publications, authors dealing with the vestibular system have used Electronystagmography as a method for investigating the properties of nystagmus, whether resulting from artificial stimulation or as a result of a pathological disturbance.

A nystagmogram of the caloric test presents us with new information about the responses of the labyrinths. These data have to be compared with what is known to be normal. This thesis attempts to add to our knowledge of the nystagmic response of normal individuals to a thermic stimulation of their labyrinths. This knowledge is necessary before declaring a patient's reaction as abnormal.

## CHAPTER I.

## REVIEW OF THE LITERATURE.

In 1860 Brown-Séquard and in 1889 Breuer described that cold water, when introduced into the external auditory canal, caused a vertigo, a nystagmus and a tendency to fall. Bárány (1906) described the caloric test of the labyrinth and forwarded a hypothesis to explain what occurs when a thermic stimulation is applied in the vicinity of the ear drum. A temperature gradient is caused and this is conducted to the semicircular canals via the temporal bone. The first canal reached is the horizontal canal at its most lateral part. The difference in temperature causes a change in the specific gravity of the endolymph. This again results in a movement of the endolymph provided that this canal is not in a horizontal position. The flow of the endolymph causes an inclination of the cupula terminalis. As the cupula is the end organ of the vestibular nerve, a vestibular reaction is elicited.

Since Bárány published his hypothesis, many other explanations were offered for the mechanism of the caloric reaction. However, Bárány's theory is now generally accepted as it explains the most important phenomena occurring, and also why the direction of the nystagmus is reversed when the horizontal canal is placed in such a position that the direction of flow of the endolymph is reversed.

Maier and Lion (1921) and Steinhausen (1931) demonstrated the cupula movement caused by thermic stimulation ad oculos, even when the temperature used as a stimulus differed only 0.5° C from body temperature. This proves that a thermic stimulation, when applied to the external auditory canal, reaches the labyrinth. This finding supported the theory of Bárány.

Investigations on the temperature conduction in the temporal bone were carried out by Meurman (1924) and Dohlman (1925) and by Schmaltz (1932). Cawthorne and Cobb (1954) investigated the temperature conduction in the living human being during operations. Their findings supported Bárány's theory. The latency as well as the duration of the resulting nystagmus conformed very well with the course of the temperature gradient in the temporal bone. No other theories offered could fit in so well with the occurring phenomena (Jongkees, 1948).



The suggestion by Borries that the reversal of the direction of the nystagmus when the head is placed in a reversed position is caused by the otoliths, was never supported or proved. De Kleyn and Lund found normal caloric reactions in guinea pigs of which the otoliths had previously been destroyed by means of centrifuging, although the thoroughness of this destruction can be critisized as the nerve endings still remained intact. Experiments in which the sacculi were destroyed (Jongkees; Versteegh) and where the utricular nerve was severed (Versteegh) showed that a normal caloric reaction was still possible.

The paradoxic reactions which sometimes occur, e.g. a positive caloric reaction in a destroyed labyrinth (first described by Urbantschitsch 1917) cannot be explained by Bárány's theory. However, Mygind demonstrated that in these cases the direction of the nystagmus could not be reversed by either syringing with hot water as well, or by reversing the position of the head. Therefore this nystagmus does not comply to the requirements for an active labyrinth (de Kleyn). He defines a functioning labyrinth as follows:

a. Both cold *and* hot water must elicit the expected reactions, or
b. the direction of the nystagmus resulting from either cold *or* hot water must be reversible when the position of the head is reversed.

### *Various Techniques for performing the Caloric Test*

The technique originally described by Bárány (1906, 1907) was to irrigate with a large volume of water at 30° C or 20° C until nystagmus appeared. He used either the sitting or the supine position with the horizontal canal in a vertical position.

Brünings (1911) used several positions of the horizontal canal in order to influence the vertical canals to a higher or lesser degree. He introduced the otocalorimeter by which the temperature of the water could be accurately controlled.

Kobrak (1918, 1922) claimed that these stimuli were too strong and introduced a method of minimal stimulation by means of a small volume of water 5-10 c.c.).

De Kleyn also used small volumes of water (5-10 c.c.) against the postero-superior quadrant of the ear drum, but required that both hot and cold water should be used.

Fischer and co-workers applied the minimal stimulation method in the sitting position with the head 30° antero-flexed so that the horizontal canal was horizontal. The irrigation lasted 10 seconds and after another minute the head was slowly moved backwards during 20 seconds until the horizontal canal was exactly vertical (the first optimum position of Brünings). At this moment, according to the calculations by Schmaltz, the temperature influence would be at its greatest. Veits (1928) and Veits & Kosel (1932) used the same technique but syringed 10 c.c. water in 10 seconds, waited for one minute and then moved the head to the optimum position in 2 seconds.

Fitzgerald and Hallpike (1942) introduced the method of syringing with large volumes of water at 30° C and 44° C for 40 seconds in the supine position with the head anteverted 30°. They used water from an elevated douche can, from which a rubber tube led to the patient.

Both Aschan and Henriksson used the same technique as Fitzgerald and Hallpike but syringed for 30 and 40 seconds respectively and recorded the nystagmus electrically.

Jongkees (1948, 1949) used the same method as Fitzgerald and Hallpike but used a smaller volume of water (50-100 c.c.) and observed the nystagmus with the aid of Frenzel's glasses.

These are the most important methods described in the literature. Many otologists, however, use their own variations of these described procedures, with the result that comparisons between the quantitative findings of different investigators are unsatisfactory. Many proposals for a standard method have already been put forward as it was felt that this was one of the greatest drawbacks in vestibular research (Cambrelin; Arslan).



*The Response to Thermic Stimulation.*

The stimulation causes a turning sensation, a sensation of change in the position of the body in relation to its surroundings, as well as reflex movements of the eyes, body and extremities, i.e. nystagmus, past pointing, and deviation in walking as well as in the Romberg test. The question arises which of these phenomena is best suited for the determination of the magnitude of the response. The sensations which occur during rotatory stimulation have been applied in cupulometry with much success (van Egmond, Groen and Jongkees). According to Fischer and Wodak (1922) the sensation due to thermic stimulation can be of more value than the nystagmus. In addition they found that the sensation of a change in the position of the body was sometimes stronger than the turning sensation. Their observations, obtained from experiments on themselves, have not been accepted. This is probably due to the fact that it has been evident that many normal persons are often not able to give an accurate account of their sensations during a caloric test.

The temperature gradient reaches the cochlea and causes a diplacusis, and therefore probably also reaches the otoliths (Voogd). The sensation of a change in the position of the body is probably due to an otolith stimulation (Jongkees). It often happens that the sensation resulting from a cold water stimulation differs from that resulting from a hot water stimulation. A sensation of a change in the position of the body is characteristic of an otolith stimulation (Jongkees and Groen). The otoliths are the organs for the observation of a linear acceleration and the direction of the force of gravity is the basis of our posture sensation (Mach).

*Observation of the Nystagmus.*

Nystagmus can either be observed and/or recorded. A difference in the duration was found by various investigators, which was evidently due to visual fixation by the test subjects.

Cawthorne, Dix, Hallpike and Hood (1956) allow the test subject to fix his gaze upon a distant object during the reaction. They claim that fixation facilitates the determination of the end point. However, they acknowledge that this shortens the duration of the nystagmus. This means that an extravestibular influence is deliberately allowed. With the cold stimulus of 30° the duration is usually about 2 minutes; with the hot stimulus rather shorter, 1 min. 40 secs. (Hallpike 1956). The duration is measured from the beginning of the irrigation which lasts for 40 seconds.

Convex glasses of D. Sph. + 20 (Bartel's or Frenzel's glasses) abolish fixation to a great extent and facilitate the observation of the smaller eye movements. Jongkees published the results obtained from a series of normal test subjects examined with Frenzel's glasses. The stimuli used were practically the same as that of the Fitzgerald and Hallpike technique. He found an average duration of 140 seconds for the cold and 112 seconds for the hot reaction. The duration was measured from the end of the irrigation which lasted for 30 seconds.

When the nystagmus is recorded in complete darkness and with the test subject's eyes open, a more reliable registration is obtained (Kirstein and Schöpfer). Henriksson used this method and applied carefully adjusted stimuli (250 c.c. at 30° C and 43.6° C). In a series of normal test subjects he found an average duration of 155 seconds for both the hot and cold irrigations.

Aschan, Bergstedt and Stahle record the nystagmus with the test subject's eyes closed. Stahle found an average duration of 177 seconds for both the cold (30° C) and the hot (44° C) irrigations.

It is evident that fixation influences the duration of the caloric nystagmus and that this can only be abolished completely by recording the nystagmus on a test subject with closed eyes (Rossberg, 1954; Aschan, 1955; Stahle, 1956).

*Nystagmography.*

Mechanical, photographical and other methods were used to obtain an objective registration of nystagmus (Berlin, 1891; Buys, 1909; Ohm, 1914; Struycken, 1918, 1920; Dohlman, 1925; Kuilman, 1931). However, none of these methods were satisfactory for clinical use, as all of them impeded or influenced the eye movements to a certain extent.

Du Bois-Reymond (1849) discovered that a potential difference exists between the cornea and the retina in man, the cornea being positive and the retina negative. Thus the eye functions as a rotating dipole. Using this principle, electrical recording of the eye movements was developed by many workers, namely Schott (1922), Meyers (1929), Mowrer, Ruch and Miller (1936), Fenn and Hursch (1937), Hoffman, Wellman and Carmichael (1939), Perlman and Case (1939), Miles (1939), Perlman and Case (1944), Glorig, Spring and Mauro (1950), Powsner and Lion (1950), Hertz and Riskaer (1953), Ruding (1953), Mittermaier, Ebel, Kübler & Boesel (1952), Van Egmond and Tolk (1954), Montandon and Monnier (1955), Aschan and Bergstedt (1955), Henriksson (1955, 1956), Aschan, Bergstedt and Stahle (1956), Mahoney, Harlan and Bickford (1957).

The requirements for the amplifier are that it should be able to reproduce every eye movement accurately, and preferably also the position of the eye. Therefore a direct current amplifier as used by Powsner and Lion would be ideal. In practice, however, an alternating current amplifier has technical and financial advantages. It does not reproduce the position of the eye accurately, but it can reproduce the movements with accuracy provided the amplifier has a sufficiently long time constant e.g. between 1.5 and 3 seconds (Aschan, Bergstedt and Stahle).

Today the main variations in Electronystagmography are either the use of an electro-encephalograph (Montandon and Monnier) or the use of a special amplifier connected to an electrocardiograph (Mittermaier; Aschan and Bergstedt; Henriksson).

A disadvantage is that it is only possible to record eye movements occurring in the plane of the electrodes. Aschan, Bergstedt and Stahle used a two-channel instrument for the simultaneous recording of both horizontal and vertical nystagmus. They claim that: "Purely rotatory nystagmus cannot be registered by this technique. Purely rotatory nystagmus is rarely met with in clinical practice, however, and the slightest horizontal or vertical component in the movement produces a deviation in the tracing. The term 'rotatory nystagmus' is often loosely applied to nystagmus in which the visual axis performs circular movements. In such cases the cornea-retina potentials are displaced, resulting in nystagmus being recorded."

According to the principles given by Powsner and Lion (1950), Henriksson (1955) developed an electronic derivation of the ordinary nystagmus curve by means of which the speed of the slow phase could be recorded directly and on a short, easily read recording. This was done by adding a clipping diode to the circuit. Unfortunately Henriksson did not publish details of his apparatus so that the only details of such a derivation unit so far available are those published by Aschan, Bergstedt and Stahle (1956) who developed their own derivation unit.

*The Nystagmus resulting from thermic stimulation.*

Next will be considered the properties of the caloric nystagmus and how it is influenced by various factors.

a) *Latency.*

Brunner, Brünings and many others, mostly neurologists, ascribe a definite value to the latency, as this can show small differences in the threshold value of the vestibular organ, or be of value in the diagnosis of centrally situated pathology (Wodak). Barbey; Cawthorne, Fitzgerald and Hallpike and other investigators attach no value to the latency as it is directly dependant on the structure of the temporal bone. A sclerotic temporal bone allows a far more rapid conduction of a temperature gradient and thus causes a shorter latent period than in the case of a normally pneumatized bone. Rossberg found that by cooling off a mastoid process from the outside, a normal caloric reaction occurred, although it had a very long latent period. Very short latent periods however, were found in patients with a radical mastoid cavity or fenestration cavity. An occlusion of the external auditory canal by ear wax or cotton wool lengthens the latent period up to 100%, but has little influence on the duration or strength of the reaction (Jongkees).



The Veits technique for performing the Caloric Test was designed in order to measure the true latent period of the cupula-endolymph system. The horizontal canal remains in a neutral position until the thermic effect is at its greatest, and only then the head is rotated to the optimum position. This method, although strongly supported by Arslan, is still only in use in a minority of clinics. The method according to Fitzgerald and Hallpike is now more commonly in use.

Jongkees (1953) is of the opinion that in view of the present knowledge about the latency, the value of the latent period must be viewed with reserve, especially as it is only possible to measure the latent period of the first quick stroke of the nystagmus (nystagmus always begins with a slow phase).

According to Stahle (1956), "more pronounced asymmetry in the latent periods is usually reflected also in other features of the nystagmus, however; but it seems to me without doubt that the latent periods constitute a complement to the examination undertaken to assess the irritability of the labyrinths."

b) *Duration.*

So far the property of the nystagmus most commonly used to determine the magnitude of the response due to thermic stimulation, is the duration.

The measurement can be started at different points. It would be ideal to detect the start of the first nystagmus stroke's slow phase, but this is practically impossible, as the appearance of the first quick phase is always the first sign of a nystagmus being present. Fitzgerald and Hallpike start the measurement at the beginning of a 40 seconds stimulation, Jongkees measures from the end of a 30 seconds stimulation, while in the Veits method it is calculated from the moment the rotation of the head is completed. An objection to the method where the measurement is started when the stimulation has already been applied, especially in the case of a stimulation lasting 30 seconds or more, is that it is possible that a very short nystagmus, which has stopped before the completion of the syringing, may have disappeared already (Schierbeek). This is only a theoretical possibility, however, as Jongkees claims that he has never encountered such a nystagmus.

It is therefore evident that the difficulty in the determination of the latency is the reason why the duration is usually measured from a predetermined moment. This allows a certain error if the latencies of the various reactions differ, but in practice it seems to be of little importance.

The nystagmus resulting from thermic stimulation usually lasts much longer than the postrotatory nystagmus, even when strong rotatory stimuli are applied. In the rotatory test the duration of the postrotatory nystagmus is due to the returning of the cupula to its original position owing to elastic forces within the cupula itself (Steinhausen). The analogy between the duration of the nystagmus in the caloric test and the course of the temperature gradient in the temporal bone was demonstrated by Schmaltz (1932) and his explanation is now universally accepted.

In determining the duration the end point is therefore the most important measurement. Arslan, who observes the nystagmus by means of Frenzel's glasses, advises to have an assistant ready with a stop-watch. The observer then calls out the beats when approaching the end point. If no nystagmus is seen for a period of say 15-20 seconds, the previous beat is taken as the end point. Cawthorne, Dix, Hallpike and Hood deliberately allow the patient to fix his gaze upon a distant object, as this facilitates the determination of the end point. They suggest that a better standardization of results is obtainable if it is appreciated that no true end point is observed, but rather, the time point at which the nystagmus ceases to be visible to the unaided eye at a distance of 10 inches (25 cm).

These methods are applicable only when the nystagmus is observed, but when nystagmography is used, the end point can be deducted from the recording. To facilitate the determination of the end point, Henriksson, using the derivation unit, records the speed of the eye movements in both directions, as this allows the feeble nystagmus strokes to be more easily detected. This is possible because the speed of the quick phase remains practically the same during the reaction (Dohlman, Henriksson and Andrén, 1956). The duration found when nystagmography is used is isually longer than that found by the other methods,



as fixation is abolished and small eye movements, which cannot be observed due to fixation of the test subject, can be recorded.

Jongkees assesses the error in the direct determination of the duration to be at least 10%, even in the case of practised observers. Added to this is the fact that a considerable difference exists between what the one observer would consider as still being nystagmus and what the other would not. This is one of the drawbacks in the vestibular research, and is one of the reasons why a clinically applicable nystagmogram will be appreciated.

Hallpike (1956) claims that in practice a large response usually has a long duration. The possibility of the duration being of less value in the case of a short reaction with a large amplitude, or a reaction with a small amplitude and a long duration, practically does not exist. Nystagmography proved that this statement is not tenable, as revealed by the findings of Mittermaier, Henriksson as well as by the work of Aschan, Bergstedt and Stahle (see pages 28).

The duration reveals a directional preponderance when it exists, but the maximum speed of the slow phase can reveal this as well, if not better (Henriksson). Aschan, Bergstedt & Stahle found the same, and in addition they found that the total number of beats can also reveal a directional preponderance. The same applies to detecting a difference between the sensitivity of the two ears.

The values found by other investigators will be discussed together with the results obtained from the author's own experiments. (See Chapter IV).

In the majority of cases, the duration of the nystagmus resulting from a cold irrigation lasts longer than that due to a hot irrigation (Hallpike, Jongkees, Schierbeek, Aschan). To investigate this phenomenon, Jongkees determined the influence of inhalation of amyl nitrite on the duration and found that the durations were then practically the same. The same results were obtained when he performed caloric tests on test subjects in the prone position. He concluded that the reason for these results was probably due to the increased blood supply of the temporal bone owing to vasodilatation and therefore a quicker restoration of the normal temperature. Aschan (1955) offered a theory which explained the shorter duration due to the irrigation as due to a viscosity factor of the endolymph.

c) *Total number of beats and Frequency.*

Many authors agree that the significance of the total number of beats as well as the derivation from this, the frequency, has a limited value. The frequency of the nystagmic beats is often not reproducable as it varies considerably in the same person (Fischer; Wodak). When the patient's attention is distracted, or manipulations on the head of the patient occur, a change in the frequency can occur (Grahe; Hennebert). Jongkees is of the opinion that the measurement of the frequency makes the observation of the nystagmus more laborious, while the information which can be derived from it is very limited. If it is desirable to determine the frequency, he recommonds the method described by Törok. The number of beats is observed during a fixed period of ten seconds, usually 60-70 seconds after the completion of the irrigation. Mittermaier reported a case in which, on successive irrigations, the total amplitude changed from 1400° to 700°, while the frequency changed from 0.70 to 0.88 beats/second. Therefore the frequency did not reveal the big difference between the two responses.

Hallpike and co-workers, who observe the nystagmus with the unaided eye, report that the number of beats follows a parallel course to the duration, so that it is not necessary to observe both. Aschan, Bergstedt and Stahle reported cases in which a directional preponderance or unilateral preponderance could be demonstrated by the duration, maximum speed of the slow phase, total amplitude as well by the total number of beats. Stahle reported that in a series of normal test subjects the number of beats seemed to be subject to greater variations than the duration.

Although many observers determine the number of beats (Arslan; Mittermaier; Aschan, Bergstedt and Stahle; Stahle), all of them regard the frequency with a certain amount of reserve.



d) *The Speed of the Slow Component.*

The relationship which exists between the speed of the slow component of vestibular nystagmus in rotatory experiments and the stimulus, was first demonstrated by Buys (1924). In 1925 Dohlman found that the speed of the slow phase of the nystagmus produced by thermic stimulation was a linear function of the difference between the temperature of the test subject and that of the water used for irrigation. Since then, many investigators agreed that the slow phase of vestibular nystagmus represents the vestibular action in the nystagmus. Whether the quick phase is of vestibular origin is not sure and is even improbable.

As the recording of the speed of the slow component calls for nystagmography of a high standard, publications dealing with a reliable registration of the speed of the slow component in caloric tests are limited.

Henriksson demonstrated that when irrigating an ear with water at various temperatures, the duration of the resulting nystagmus increased only slightly when irrigating with temperatures differing more and more from body temperature. (This confirmed the findings by direct observation of Jongkees). However, the speed of the slow component increased far more, thus showing the increased response more accurately. Henriksson could demonstrate this reliability of the speed of the slow component even better in a patient with one normal ear, the other ear having a radical mastoid cavity. The duration of the nystagmus resulting from irrigation of the normal ear and the abnormal ear differed only slightly, but the maximum speed of the slow phase reached in the operated ear was more than three times as high as that in the normal ear. This indicated that the operated ear had a considerably stronger response, because the temperature gradient which developed in the exposed horizontal canal of the operated ear must have been much steeper.

In the recording of the caloric tests on patients with early vestibular pathology, Henriksson could detect a unilateral preponderance by measuring the speed of the slow component, while the duration did not reveal this abnormality.

Aschan, Bergstedt and Stahle found the same importance of the maximum speed of the slow phase. They also demonstrated the importance of the speed of the slow component in patients with a spontaneous nystagmus. Hitherto it was practically impossible to obtain accurate values when performing a caloric test on such patients. However, if the speed of the slow component of the spontaneous nystagmus is subtracted from the speed of the induced nystagmus in the same direction, the sensitivity of the canal can be calculated. In the case of an induced nystagmus in the opposite direction than that of the spontaneous nystagmus, the two values are added. This is a considerable clinical advancement.

Aschan, Bergstedt and Stahle as well as Henriksson demonstrated that the values of the maximum speed of the slow component obtained in the caloric test, could reveal a diminished sensitivity or directional preponderance just as well as, or even better than the duration.

Mittermaier is of the opinion that although the maximum speed of the slow component represents the response to caloric stimulation, the total amplitude (i.e. the amplitudes of all the nystagmus beats added together) is probably a better standard by which to measure the magnitude of the response. His objection to the maximum speed of the slow phase is that the moment at which the slow phase reaches its maximum speed varies.

Aschan compared the maximum speed of the slow phase due to irrigations with hot water with that of the nystagmus resulting from irrigation with cold water. The water used was of a carefully controlled temperature and the body temperatures of the test subjects were determined also. The temperatures of the cold and hot water differed equally from body temperature. He found that although the nystagmus following the hot irrigations lasted shorter than in the case of the cold water, the maximum speeds of the slow phases were practically the same. This demonstrated that the duration could give an incorrect interpretation of the results, while the maximum speed of the slow phase gives the correct values.

e) *Total Amplitude.*

The sum of the amplitudes of all the nystagmic beats represents the total deviation of the eye if it had not been interrupted by the quick phase. This is called the total amplitude. This can only be determined when the nystagmus is recorded and the calibration of the eye movements is very accurate.



Jung and Tönnies, Mittermaier, Mittermaier and Christian regard the total amplitude as an important measure of the magnitude of the response. It is more sensitive to a change in the stimulus than the duration, as was demonstrated by Mittermaier and Christian who irrigated ears with water at various temperatures. The total amplitude also reveals a response decline long before it is shown by the duration (Mittermaier). Although a certain amount of error is present when the total amplitude is determined from the nystagmogram, Mittermaier is of the opinion that the error remains within reasonable limits if the calculations are always done by the same person. However, to measure and calculate the total amplitude from the conventional curve takes a considerable time (Henriksson).

Aschan, Bergstedt and Stahle confirmed the findings of Mittermaier. In addition they found that in certain cases with diminished sensitivity and in others with directional preponderance, the total amplitude corresponded closely with the speed of the slow phase, number of beats and duration, and therefore also revealed these two properties of the response. In a series of investigations on normal test subjects, they found that the values of the total amplitude showed considerable variations, although they still fall within reasonable limits.

f) *Amplitude × Frequency Product (AF).*

Ohm (1939) introduced the formula Total Amplitude × Frequency = Energy as measure of the magnitude of the response. Mittermaier and Christian (1954) suggested adding time to the formula by comparing certain 30 seconds periods of the reaction with one another, e.g.

$$\text{Wirkungszahl} = \left( \frac{\text{Number of beats} \times \text{Total Amplitude}}{30''} \right) 30''$$

Henriksson compared the speed of the slow component with the Energy according to the formula and concluded that the speed of the slow component is a better expression of the energy of the reaction than this arithmetical product.

g) *Mean amplitude per beat and average speed of the slow component.*

Mittermaier found that the mean amplitude per beat, calculated by dividing the total amplitude by the total number of beats, showed the difference in the magnitude of the response better than the frequency but was still of less diagnostic value than the total amplitude. The same applied to the average speed of the slow component, which can be calculated by dividing the total amplitude by the duration. He objected to the use of the average speed of the slow component as a measure of the response as the speed of the slow component varied during the reaction.

h) *Intensity.*

Stahle (1956) suggested to use the "intensity" instead of the speed of the slow phase as a measure of the response. The intensity is defined as the total deviation of the eye during a chosen period. To calculate this, the total amplitude is measured during a 10 second period in the same way as already suggested by Jung and Tönnies in 1948. The mean eye speed for that period can be calculated by dividing this total amplitude by the number of seconds. If the intensity is measured when the reaction is most intense, e.g. after 60-90 seconds in the method he used, the "maximum intensity" is arrived at. This "maximum intensity" can then be used as one quantitative measure of the whole vestibular reaction.

i) *The volume of the water used and the velocity of the irrigation.*

Jongkees (1953) is of the opinion that when a big volume of water is used, the effect of the stimulation will not necessarily be bigger than when smaller quantities are used (at least as far as the duration is concerned. If the temperatures used do not differ very much from body temperature, the amount of water used has little influence. However, when temperatures which differ very much from body temperature are used, a large volume of water will have a paralysing effect and thus give a shorter duration (Inhibition of Kobrak). This is due to the fact that the whole labyrinth is cooled and not only the lateral part. When the temperature used approaches that of body temperature, a stronger stimulation is possible with a larger volume of water.

Other influences are also found when very small quantities of water are used according to the minimal stimulation method of Kobrak. The eyes perform many irregular movements when the end point is approached and this, together with the fact that the "minimal" stimulation method causes a nystagmus with a small amplitude, makes the determination of the end point difficult (Jongkees; de Bournonville). Jongkees (1949) compared the nystagmus resulting from irrigations with 50 c.c. of water at 30° with that caused by irrigations with 5 c.c. water at the same temperature. He found that the duration of the nystagmus due to the 5 c.c. irrigation could not be reproduced satisfactorily. From this he concluded that a small volume of water is not desirable for use in the caloric test. Groen and Jongkees (1949) found no significant difference in the duration of nystagmus elicited by 500, 50 and 5 c.c. of water at 30° C and 44° C.

The velocity of the irrigation has little influence on the nystagmus, provided that the whole tympanic membrane is covered with water (Jongkees). Often a large volume of water leads to stronger subjective sensations (nausea, vertigo), without giving better measurable results. Therefore he advises the use of a moderate amount of water syringed at a moderate velocity, e.g. 50-100 c.c. in 25-30 seconds.

The technique of Fitzgerald and Hallpike is also designed to cause a moderate stimulation with little discomfort to the patient (Hallpike) and has proved to be so in practice. According to this method a volume of 250-500 c.c. is irrigated from a height of approximately 3 feet above the patient's head during 40 seconds, with temperatures of 30° and 44° C.

j) *Temperature of the water used.*

According to Jongkees, the temperature of the water has a stronger influence on the response than the volume of water. When the temperature of the water differs only a few degrees form body temperature, the duration increases as the temperature difference increases. As soon as the difference increases to more than approximately 5° C, the duration increases less than before. Therefore the difference in duration between irrigations with 30° C and 18° C is less than that between irrigations with 35° and 30° C.

Henriksson compared the speed of the slow phase with the duration when irrigating with water at various temperatures. He found that the speed of the slow phaze increased more rapidly than the duration when he decreased the temperature of the water. When the stimulus increased from 3°C to 8° C below body temperature, the speed of the slow phase reached four times its initial value, while the duration did not even reach its double value. Thus, in a caloric test, if the temperature is 30° instead of 31°, the speed of the slow phase will be influenced four times more than the duration.

Aschan confirmed this influence of the temperature on the speed of the slow phase.

Mittermaier reported than in a test subject who was irrigated with water at 27° C and later at 17° C, the duration found was 143 and 138 seconds respectively, while the number of beats increased with 13.7% and the total amplitude with 61.2%. The duration did not show the bigger response as well as the beats and the total amplitude did.

Jongkees and Groen demonstrated that the change from a heterolateral to a homolateral nystagmus did not always occur at exactly body temperature, but often 1-2° C above. This could not have been due to the cooling of the water in the external auditory canal as it was found that the water at the drum still had its original temperature. They could not explain this by Bárány's theory. Fischer & Wodak and Plum found that temperatures which differed only a tenth of a degree from body temperature could elicit a caloric reaction.

A maximal effect is obtained when water at 30° and 44° C



is used, which has the advantage of being equally far from body temperature and thus allowing a quantitative comparison between the hot and cold irrigations (Jongkees 1953). When temperatures which differ more than 7° C from body temperature are used, the sympathetic reactions (vertigo, nausea and pain) increase but the duration does not increase.

k) *The type of nystagmus and how it is influenced by the position of the head.*

When the minimal stimulation method of Kobrak is used, a purely horizontal nystagmus occurs (Veits). When stronger stimuli are used, however, a frontal (rotatory) component is added to it. This frontal component could be caused by stimulation of the vertical canals (Quix). When an ear is irrigated with the head 60° backwards in relation to the vertical and 45° sideways to the side of the other ear, the nystagmus is of a rotatory type (Brünings). In addition Brünings reported that the size of the stimulus necessary to elicit a caloric nystagmus varies for different positions of the head. However, the duration of the nystagmus elicited with the test subject's head in various positions does not confirm this fact (Jongkees), but the type of nystagmus can be influenced.

In the supine position cold water causes a heterolateral nystagmus and hot water a homolateral nystagmus, both being mostly of a pure horizontal type. In the prone position, the direction of both is the opposite and a rotatory component is usually added to the horizontal component. The change of direction of the nystagmus can be demonstrated when examining a test subject on the posture table. When rotating him around a binaural axis, two indifferent zones for a horizontal nystagmus elicited from the horizontal canals are found (Behrmann; de Kleyn and Storm van Leeuwen; Jongkees; Schierbeek). No horizontal nystagmus occurs in these indifferent zones; if any, only a frontal nystagmus. According to Jongkees, all investigators found, contrary to the opinion of Veits, that these two indifferent zones are not exactly 180° from each other. Actually, it was found that the so-called "upper zone" (in which cold water elicits a heterolateral nystagmus) comprises 200°, while the "lower zone" (in which cold water causes a homolateral nystagmus) comprises 140°. The remaining 20° is divided between the two indifferent zones. Thus the two indifferent points are not exactly 180° from one another, and often differ for right and left and for hot and cold.

Experiments on test subjects fastened to the posture table showed that when a person is moved during a caloric examination, the duration is influenced to a large extent (Jongkees). In addition, it could often be demonstrated that when a person is rotated to the prone position after the end point of a heterolateral nystagmus, induced in the supine position, had been reached, a homolateral nystagmus, often of long duration, occured. (Jongkees, Thornval, Wiskovsky, Boenninghaus). The duration of this "secondary" nystagmus was not always reproducable. Wiskovsky ascribed this "secondary" nystagmus to a central genesis but with a possible utricular component, as this phenomenon did not occur when the test subject's head had not been moved. Because of this phenomenon, one should regard the results of a caloric examination according to the methods of Fischer or Veits with reserve (Jongkees). Moving the patient's head backwards may even introduce unknown factors which could influence the reaction.

The supine position with the head anteverted 30° as used by Fitzgerald and Hallpike, is today used by many investigators (Jongkees; Aschan; Henriksson). The position of the head need not be exactly in 30° anteversion, provided that the patient does not move during the reaction, and the successive examinations are done with the head in the same position (Jongkees).

Movements during the caloric reaction cause interference when the nystagmus is recorded electrically, and therefore patient should remain in the same position when the nystagmus is recorded (Mittermaier).

1) *Response Decline (R. D.)*

How long one should wait between the successive irrigations is an important aspect in the technique of the caloric test in order to prevent a progressive diminution of the responses.



Many authors advise a long period, e.g. up to 30 minutes (Arslan; Crabbé; Lanos). They claim that the thermic stimulation causes a disturbance of the equilibruim in the vestibular nuclei and this can possibly influence the response to the successive irrigations. However, many investigators agree that this would make the duration of the caloric test extremely long (Brunner; Hallpike; Woletz). When using the minimal stimulation method of Kobrak, one can continue with the next irrigation after a few minutes (van Deinse). Lorente de Nó and Groen & Jongkees (1949) found that the reaction continues as long as the temperature influence on the skull lasts. Jongkees allowed an interval of 6 minutes between irrigations and found no detectable error in the duration, provided that the temperatures used did not differ more than 10° C from body temperature.

Experiments to determine the response decline due to repeated irrigations were reported by Mittermaier. He found that a response decline could be obtained if the time interval between irrigations was too short. This was especially revealed by the total amplitude of the reaction, and to a lesser extent by the number of beats, measured by means of nystagmography. The duration remained largely unchanged. He concluded that although the labyrinth showed a decreased activity, the functional condition of the centres was also concerned with the decline. The fatigue of the labyrinth itself might be responsible but not to such an extent as the possibility of the suppression of the following response. Mittermaier therefore advised to wait at least 30 minutes between irrigations.

Stahle (1956) investigated the possibility of a R.D. when the Hallpike technique is used but irrigation done for only 30 seconds. He allowed a time interval of at least 10 minutes between each successive syringing and recorded the nystagmus electrically. No hint of a R.D. was found in the duration and the number of beats. The total amplitude decreased successively with each syringing, but statistical analysis revealed the difference as insignificant. The intensity of nystagmus (Stahle) did not show any R.D. although the possibility could not be excluded entirely. He concluded that in clinical practice a response decline can be disregarded, provided a long enough pause is allowed between each syringing and that suitable stimuli are employed.

m) *The Secondary Phase Nystagmus.*

After the end point of a caloric reaction has been reached, a secondary phase nystagmus, usually in the opposite direction, sometimes occurs after an interval. The same phenomenon was observed more frequently after a rotatory stimulation.

The secondary phase nystagmus following a thermic stimulation mostly occured when the irrigation lasted for a considerable period (Kobrak; de Kleyn; Versteegh; Jongkees, Boenninghaus). It has already been mentioned previously that an irrigation of long duration causes a frontal component to be added to the horizontal componant. This may be due to the temperature wave penetrating deeper into the temporal bone and reaching the vertical canals. According to Jongkees, the latter possibility can be an aid in the explanation of the mechanism causing a secondary phase nystagmus when irrigating for a long time. The temperature wave, when penetrating the temporal bone, then also reaches the medial part of the horizontal canal. In the mean time however, the lateral part of the canal is already returning to its original temperature. This may cause a reversal of the flow of the endolymph by which a secondary phase nystagmus in the opposite direction in caused. The calculations by Schmaltz gives this hypothesis a sound basis.

Thornval (1932) found that a secondary phase nystagmus sometimes occurred, provided that a reasonably large stimulation was used to elicit the primary phase. He used water at 30° C and irrigated until the primary phase started. The secondary phase, if it occurred, usually started $^{1}/_{2}$—2 minutes after the end point of the primary phase, and lasted up to 5 minutes. A change in the position of the head did not influence the direction of the secondary phase nystagmus. This phenomenon could also be demonstrated when the primary phase was elicited in the prone position, as well as in the case of an irrigation with hot water (44° C). Thornval ascribed this phenomenon to a central genesis.

Boenninghaus (1953) could seldom elicit a secondary phase nystagmus when applying the normal stimuli used in caloric tests, but he succeeded in demonstrating the phenomenon when he used a variation of the Veits method. 50 c.c. of water at 17° C were irrigated in 10 seconds, and when the head was rotated to the optimum position after an interval of 20 seconds, another irrigation of 100 c.c. at 37° was carried out for 20 seconds. This type of stimulation was used in an effort to immitate the rotatory type of stimulation. In a series of 60 test subjects, 26 showed the secondary phase after an interval of $^{1}/_{2}$—2 minutes after the end point of the primary phase. The secondary phase could also be elicited from both right and left ears and was always in the opposite direction to the primary phase. He also ascribed this phenomenon to a central genesis.

Aschan (1955) reported that he did not find a secondary phase in a series of caloric tests on normal test subjects. He used the Fitzgerald-Hallpike technique but irrigated for 30 seconds only and recorded the nystagmus electrically behind closed eyes. In the case of simultaneous double irrigations with cold water in one ear and hot water in the other, which caused a nystagmus with a high speed of the slow phase, the phenomenon occurred in 14 out of 20 cases. Of these 11 had it in a direction contrary to that of the primary phase. The interval between the two phases varied from 20 to 30 seconds.

As already mentioned previously, a secondary phase nystagmus can also occur when the test subject is rotated after the primary phase has been reached (Thornval; Wiskovsky; Jongkees; Schierbeek; Boenninghaus). This nystagmus is usually in a direction contrary to that of the primary phase, and appears from 5-30 seconds after the rotation has been completed. Wiskovsky could demonstrate this phenomenon even when a small stimulation was used. The nystagmus was also present when the head was rotated anteriorly until it was in the indifferent zone, thus supporting a central genesis. He was of the opinion that although the genesis is apparently of central origin, it was quite possible that the utricle played an important part.

A secondary phase nystagmus, sometimes accompanied by a turning sensation, often occurs in rotatory tests (Buys; Dodge 1923; Fischer and Wodak 1922; Woletz 1832; Lange 1939; van

Egmond, Groen and Jongkees 1949, 1952; Boenninghaus 1953; Arslan 1955; Aschan 1955). Two different hypotheses exist for the explanation of the mechanism of this phenomenon. Groen and Jongkees are of the opinion that the cause might be after-effects in the cupula itself. Fischer and Wodak, Dodge, Lange, Aschan support the hypothesis that it is of central origin. The fact that changes in the position of the head influence the subjective turning sensation in the primary phase but not in the secondary phase, was quoted by Fischer and Wodak in support of this hypothesis.

Schmaltz (1932) is of the opinion that the interval between the two phases could perhaps be an indication of a central genesis. Boenninghaus pointed out that the interval in the case of the rotatory stimulation was usually much shorter than in the case of a thermic stimulation. In the former the interval is usually short, about 10 seconds, and in the latter it varies from 30-120 seconds. However in the case of a secondary phase resulting from a rotation of the head after the end point of a caloric reaction, the interval varies from about 0-30 seconds.

Aschan demonstrated a secondary phase nystagmus, which followed a primary phase optokinetic nystagmus and recorded it behind closed eyes. The interval between the two phases varied from 10 to 30 seconds. From this he concluded that as a secondary phase nystagmus can occur while every form of cupular stimulation is excluded, it is apparently due to a central origin.

The following types of secondary phase nystagmus have therefore been reported :

1. After rotatory stimulation. Occurs fairly often. Interval between the two phases is usually about 10 seconds. A secondary turning sensation can occur.
2. After optokinetic stimulation. Interval varies from 10-30 seconds.
3. After a moderate thermic stimulation. Occurs rarely, probably because the stimulation is not strong enough. Interval varies from 30-120 seconds.
4. After a thermic stimulation of long duration. Occurs fairly often. Interval from $^1/_2$—2 minutes.



5. After a large thermic stimulation, e.g. double irrigation. Occurred in 14 out of 20 cases in one series, of which 11 had a direction contrary to that of the primary phase. Interval from 20-30 seconds.
6. After a moderate thermic stimulation followed by an irrigation with water at body temperature and using the Veits method. Occured in 26 out of 60 cases, was always in the opposite direction to that of the primary phase, and could be elicited from both ears. Interval from 40-90 seconds.
7. After even a small thermic stimulation, followed by a rotation of the head when the end point of the primary phase has been reached. Occurs often. Interval from 0-30 seconds.

The secondary phase nystagmus due to a thermic stimulation is usually of a much longer duration than that due to a rotatory stimulation (Boenninghaus). The latter can last op to 5 minutes (Thornval).

n) *Directional Preponderance.*

Bauer and Leidler (1911) found that after the removal of the hemisphere of a rabbit, a postrotatory nystagmus to the side of the lesion was of longer duration than that to the other side. This was confirmed by Dusser de Barenne and de Kleyn (1923), who repeated these experiments. They also demonstrated that in the case of a caloric test with hot and cold water, the same phenomenon occured, e.g. in the case of a left hemispherectomy, cold irrigation of the right ear and hot irrigation of the left ear caused a nystagmus of longer duration than was the case when the opposite temperatures were used. They called this a "Nystagmusbereitschaft" to the left. This means that the nystagmus in the one direction lasts longer than the nystagmus in the other direction, provided that both hot and cold irrigations were performed.

Soon after these experiments, reports were published of this phenomenon being present in humans (de Kleyn and Versteegh 1924; Barré and Charbonnel 1935; Barbey and Morsier 1938; Brunner; Cawthorne, Fitzgerald and Hallpike 1942; Koch 1933).

Cawthorne, Fitzgerald and Hallpike (1942) introduced the name directional preponderance for this phenomenon, and found that it occurs in many brain pathologies, e.g. temporal tumours very often show a directional preponderance to the diseased side.

Most authors are of the opinion that the origin of directional preponderance is central (Koch; Mittermaier; Barbey and Morsier; Vogel), and may be due to a preponderance of activity of one half of the brain (Crabbé). Brunner believes the origin to be in the brain-stem, while van Deinse ascribes it to vascular disturbances. Unterberger and Wirth believe it to be of peripheral origin and Hallpike (1943) ascribes it to a possible utricular genesis. Carmichael, Dix and Hallpike (1954, 1956) found a directional preponderance in most cases with lesions in the posterior part of the temperol lobe.

The occurrence of this phenomenon in patients with Ménière's disease was described by the following investigators: de Kleyn and Versteegh (17%), Hallpike (21%), and van Deinse in 22% of patients.

A directional preponderance can also occur in normal persons (Borries; Grahe; Montandon; Terracol; Lundberg). In a series of 64 normal test subjects, Lundberg found a directional preponderance in 37 of them; 80% of these had a directional preponderance to the left. Jongkees (1948) demonstrated this phenomenon in 17% of a series of 60 normal test subjects, of whom 13% had the preponderance to the left and 3% to the right. He accepted a directional preponderance as being present when the nystagmus in one direction surpassed that in the other by at least 20%. Of the 2 cases with a preponderance to the right, one was left handed and Jongkees drew the attention to the possibility that left - or right - handedness might be a factor in the mechanism of this phenomenon.

Schierbeek (1951) found that in his series of 24 normal test subjects, 3 had a directional preponderance (12%), all of them to the left. He also required a 20% difference as Jongkees did. Peterman (1953) found this phenomenon in 1% of his series Hallpike, Harrison and Slater (1951) found no directional preponderance in 93 selected, high-level normal individuals.

Henriksson (1955), who used nystagmography, demonstrated that the maximum speed of the slow phase of the nystagmus could also reveal a directional preponderance.



Aschan, Bergstedt and Stahle (1956) confirmed the fact that the maximum speed of the slow phase can reveal the phenomenon, and also showed that the number of beats as well as the total amplitude can be used to demonstrate a preponderance.

Jongkees (1953) is of the opinion that directional preponderance is essentially a spontaneous nystagmus which remains latent. This he bases upon the fact that in patients with a pathological process, a directional preponderance may become a spontaneous nystagmus and vice versa.

Boenninghaus (1953) found that a difference in tone (directional preponderance) could be demonstrated by both the primary and secondary phase nystagmus. This occured in rotatory as well as caloric tests. It was most evident in the case of patients with a direction-fixed positional nystagmus (Nylen Type II) [1]) which could be provoked into a spontaneous nystagmus as well as in cases with an already existing spontaneous nystagmus. It was also evident in patients without a spontaneous nystagmus. They revealed a secondary phase either in one direction alone or, if in both directions, the nystagmus in the one direction was of a much longer duration. He found that the ordinary caloric test procedures did not suffice in eliciting a secondary phase nystagmus and therefore used a special way by which to elicit this phenomenon as has already been described previously. When using this method, he claimed that the occurrence of a secondary phase nystagmus can be of help in distinguishing between a directional preponderance and a diminished sensitivity of one labyrinth if one or both of these phenomena occur in the same patient. Boenninghaus concluded that a secondary phase nystagmus could reveal a difference in tone (which is central) even better than the primary phase nystagmus, as the latter is dependant on the condition of the peripheral labyrinth.

To conclude, it is interesting to note the view of Frenzel

1) Classification done by author.

(1955) [2]: "Directional preponderance may also be due to a damage of the peripheral labyrinth, but for its creation it is of course dependant upon the brain, as is the case with a spontaneous nystagmus. Both the spontaneous nystagmus and the nystagmus with a predilection for one direction are signs of a vestibular tone difference, i.e. either in the case of a disturbance of the centres due to a damage of the peripheral labyrinth, in the case of a damage of the centres or pathways without any peripheral cause.

It is my experience that a directional preponderance is usually accompanied by a spontaneous or a provocable nystagmus. The quantitative contribution of a spontaneous nystagmus to the production of the phenomenon of directional preponderance can defintely not always be excluded simply by arithmetical calculations. It is worth while to consider the possibility whether a pathological directional preponderance does exist when a spontaneous or provocable nystagmus has been excluded carefully, because this much discussed phenomenon also exists in normal individuals!

One should in any case bear in mind the possibility that a pathological directional preponderance without a simultaneous spontaneous or provocation nystagmus does not exist at all.

All the time consuming and difficult tests may be replaced by a relatively simple and systematic examination for spontaneous or provocation nystagmus. I am of the opinion that nothing essential can be overlooked if instead of all the special stimulation methods, one accentuates the thorough and systematic search for a spontaneous and provocation nystagmus This would exclude the danger of examining a pathological phenomenon in detail, while this phenomenon does not exist at all".

2) Author's own translation.



CHAPTER II.

## *THE AIM OF THE INVESTIGATION.*

Although the caloric test was introduced half a century ago, the values of the properties of the nystagmus which occurs in normal persons are still not standardized. This is probably one of the greatest drawbacks in vestibular research (Cambrelin; Arslan). This is due firstly, to the various techniques employed to perform the caloric test, and secondly to the fact that some investigators observe the nystagmus with, and others without the aid of Frenzel's glasses, while still another group records the nystagmus electrically.

When the nystagmus is observed, the personal factor is of paramount importance in determining the duration. The values obtained by an experienced observer can be relied upon but it is only possible for him to compare his own results. To compare his results with those obtained by other investigators, however, a definition of the end point is necessary. Arslan employs a definition which differs from that of Hallpike and the former observes the nystagmus with the aid of Frenzel's glasses, while the latter allows visual fixation by the test subject. In addition the techniques used by these authors differ. Which is true for Arslan and Hallpike holds true for many other investigators too.

Nystagmography is now applied in many clinics. The nystagmogram is a valuable aid for determining the duration and supplies information on the eye speed, total amplitude, etc. as well. It is therefore necessary to be acquainted with all these properties of the nystagmus when nystagmography is employed.

The aim of our investigation is twofold. Firstly, to investigate the responses of the normal person to thermic stimulation of his labyrinth, and secondly, to compare various techniques of performing the caloric test. This is carried out in the following way :

a. A series of normal test persons is subjected to a caloric test according to the technique of Fitzgerald and Hallpike (1942).
b. Ten of these subjects are examined again, but according to the techniques of Veits (1928) as well as Kobrak (1918). This allows a comparison between the responses to a large volume of water and to a small volume of water.
c. Normal ears are irrigated with water at various temperatures in order to investigate the influence of the temperature on the magnitude of the response.
d. The influence of an obstruction of the external auditory canal (ear wax) on the caloric reaction is determined.

Electronystagmography is employed in all cases.

The test series consists of both right- and left-handed persons in order to investigate the suggestion of Jongkees (see p. 36) that this might affect the directional preponderance in normal individuals.

The results obtained are analysed statistically and an attempt is made to arrive at normal values for the various properties of the nystagmus. The results are also compared with those obtained by other investigators who used comparable methods.



## CHAPTER III.

### *THE RECORDING OF THE NYSTAGMUS.*

#### *The Amplifying System.*

The system consists of a two-channel alternating current amplifier from which the signal is fed to a direct-writing two-channel electrocardiograph (Elema's Mingograf 24, Stockholm). It is therefore a similar arrangement as that used by Aschan, Bergstedt & Stahle (1956) and by Henriksson (1955). For details, reference is made to the publication of de Boer, who designed the amplifier and the derivation unit.

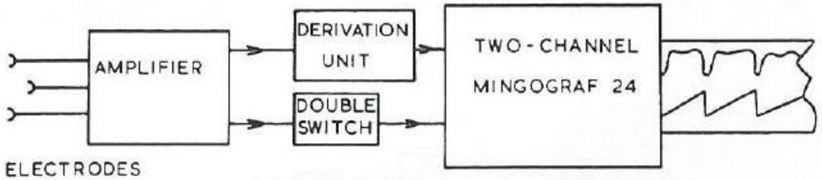


Fig. 1. Block diagram of the electrical arrangements.

The A.C. amplifier consists of two channels with a time constant of 10 and 7 seconds resp., which allows the recording of two different signals at the same time, e.g. horizontal as well as vertical eye movements. In the experiments described in this thesis the channel with a time constant of 10 seconds was always used.

The amplifier has a special response characteristic which allows an accurate reproduction of the nystagmus (see Fig. 6). The amplifier is fed with a stabilized power supply. The details are shown in the circuit diagrams (see Figs. 2-5). A double switch is used to reset the amplifier quickly when overloading occurs. This expedient was found to be very useful in practice.

The eye movements are recorded on the conventional curve. The speed of the eye movements is recorded on the "derived"

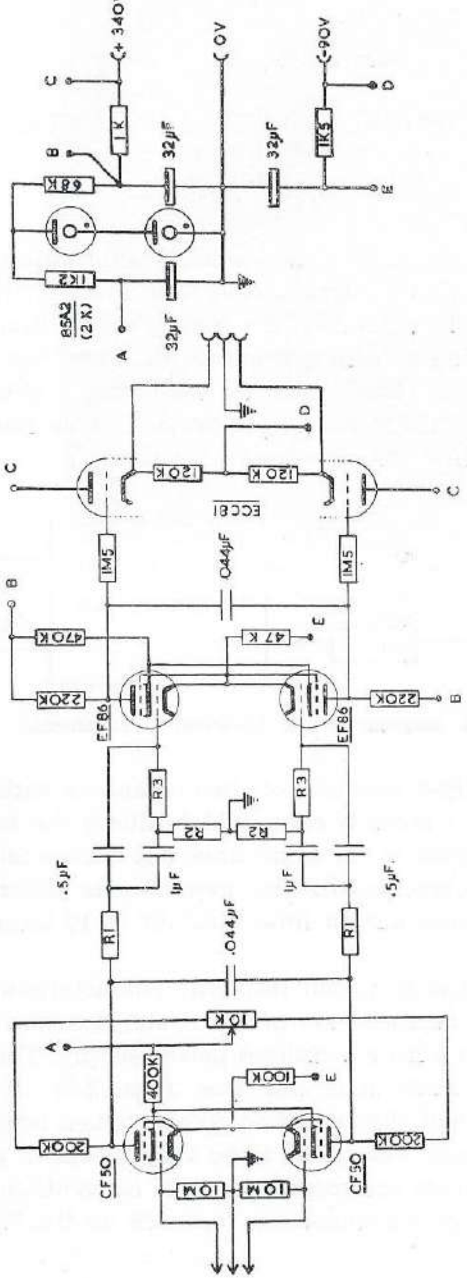


Fig. 2. Circuit diagram of the A. C. amplifier.



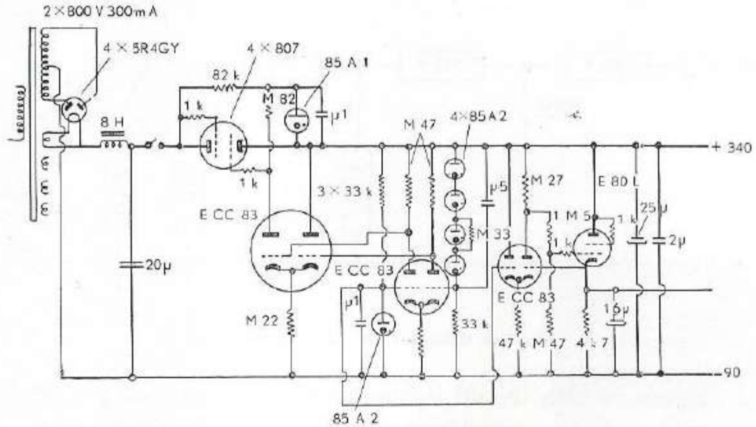


Fig. 3. Circuit diagram of the stabilizing unit.

curve as described by Henriksson. For this an R. C. circuit with a short time constant is used. One channel of the amplifier (time constant 10 seconds) supplies the signal for both the conventional recording and the derivation unit. The input of the derivation unit can be switched to either of the two phases of the amplifier so that the quick phase produces a negative peak at the input of the valve. In this way the flow of

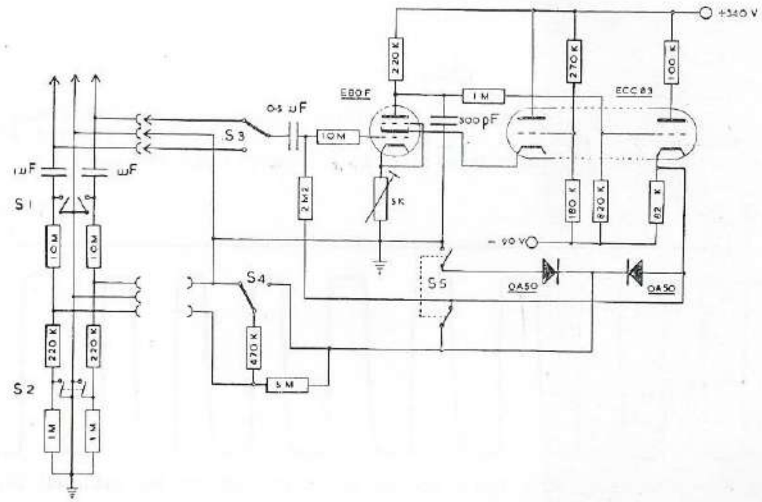


Fig. 4. Circuit diagram of the derivation unit.

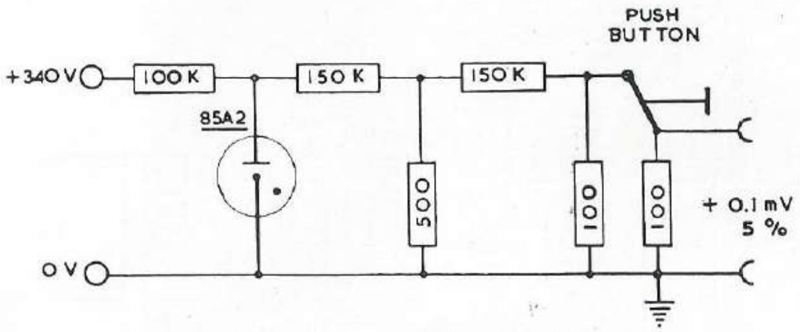


Fig. 5. Circuit diagram of the calibration unit.

grid current, which would influence the zero line, is prevented. The whole circuit constitutes a D.C. amplifier so that no change of zero level caused by discharge of capacitors can occur. Even after conditions of severe overload, the working point remains stable. For convenience the quick phase can be suppressed by the crystal diodes shown in the circuit diagram. This permits a rapid evaluation of the course of the speed of the slow phase in nystagmus. Near the end of a reaction, the

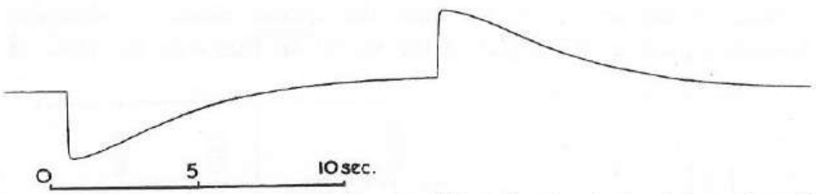


Fig. 6a. Step response of the amplifier. The input signal is a step of 0.1 millivolt, followed by a step in the revers direction. The channel with a time constant of 10 seconds is used. Paper speed 1 cm. per second.

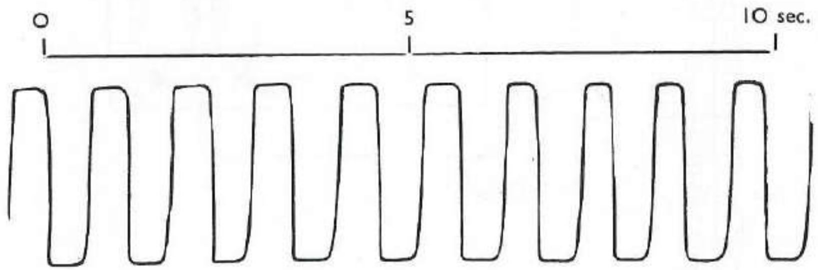


Fig. 6b. Recording of a block voltage by means of the 0.1 millivolt unit. Paper speed 1 cm. per second.



diodes are switched off so that the events can be studied both from the conventional nystagmus curve and its time derivative, thereby facilitating the determination of the end point of the reaction (see Fig. 8).

A faradic cage was not found necessary for nystagmography according to this method since interference from the surroundings did not occur.

Calibration of the amplifier is done by means of a voltage of 0.1 millivolt. This is derived by attenuation from the + 340 volt supply of the stabilizing unit. A push button permits recording of a block voltage at any desired low frequency (see Fig. 6b). It was found that the amplifier always remained stable after a heating period of 15 minutes.

*Recording of the nystagmus.*

Three stainless steel discs, 8 mm. in diameter, 2 mm. thick and with concave surfaces are used as electrodes. The concavity is filled with ordinary electrode paste as is used in electrocardiography. When horizontal nystagmus is recorded, two electrodes are fastened with adhesive tape to the skin of the temples, approximately 2 cm. from the outer angles of the eyes. The third electrode, which serves as a ground electrode, is placed medially on the forehead. The leads are arranged so that an eye movement to the left is always recorded as a downward deviation on the recording, and vice versa. The nystagmus is always recorded in a semi-darkened room and on a test subject with closed eyes.

*Calibration.*

The eye movements, expressed in degrees of rotation of the eye, are calibrated by asking the test subject to fix his gaze alternately upon two spots on a black board 3 metres away from him and arranged in such a way as to cause a rotation of the eyes through an angle of exactly 20°. Thus the degrees rotation of the eye are translated into millimetres deviation in the recording. The electrode voltage for a 20° rota-

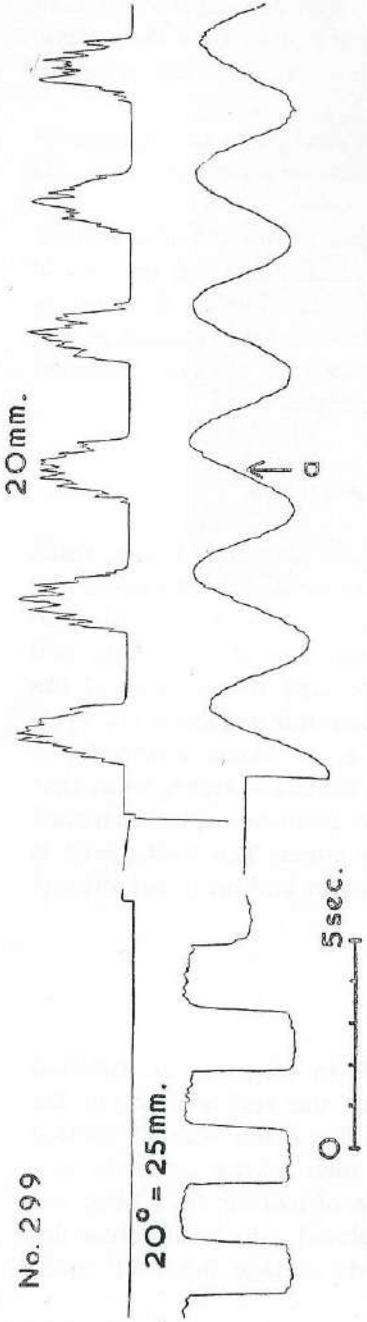


Fig. 7a. Calibration of the conventional (bottom) curve is done first. After that, the eye follows the pendulum and at a the amplitude is 25 mm., i.e. 20°. The deviation in the derived (top) curve is then 20 mm. Hence an eye speed of 20°/sec. is equivalent to a 20 mm. deviation in the derived curve. See text also.

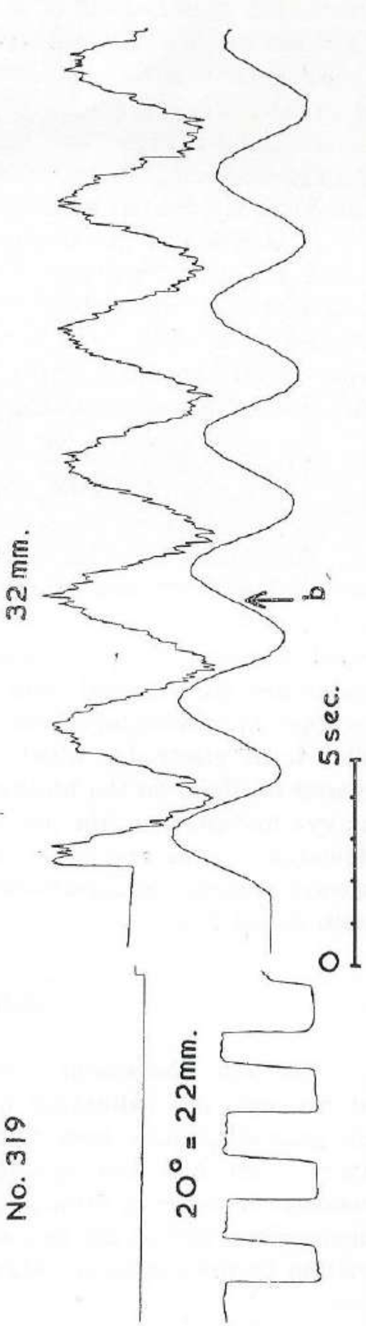


Fig. 7b. The same as in Fig. 7a, except that in the derived curve both polarities of the speed are recorded. When the amplitude is 22 mm. (20°) at b, and the total deviation in the derived curve is 32 mm., it follows that a deviation of 16 mm. from the base line (not shown here) will be equivalent to an eye speed of 20°/sec. See text also.



tion of the eye usually varied from 0.25 to 0.6 millivolt, measured by means of the 0.1 millivolt calibration unit.

The calibration of the eye speed (which is recorded in the derived curve) is done by asking the test subject to fix his gaze upon a moving object. A very convenient object is a pendulum, as its maximum velocity is always proportional to the amplitude. This method was introduced by Henriksson. In order

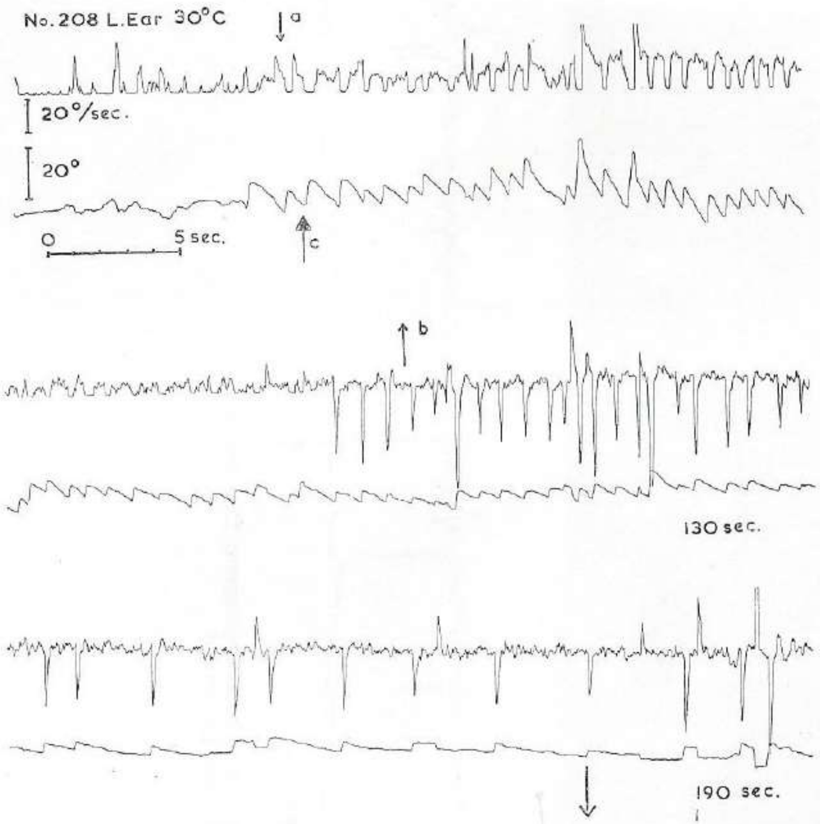


Fig. 8. Recording of a caloric nystagmus. The bottom curve is the conventional curve. At c the irrigation, which lasted 30 seconds, has stopped. At a the turning sensation starts and stops at b. At first the derived curve measures the speed of the slow phase only, but later on the speed of the quick phase is also measured. It is then evident that there is a preponderance of peaks below the base line, but after the end point has been reached (indicated by an arrow) at 186 seconds, peaks occur to the same extent on both sides of the base line. Paper speed 1 cm. per second.


Fig. 9. The end point of a caloric nystagmus. The derived curve measures the speed of the eye movements in both directions. Paper speed 1 cm. per second.

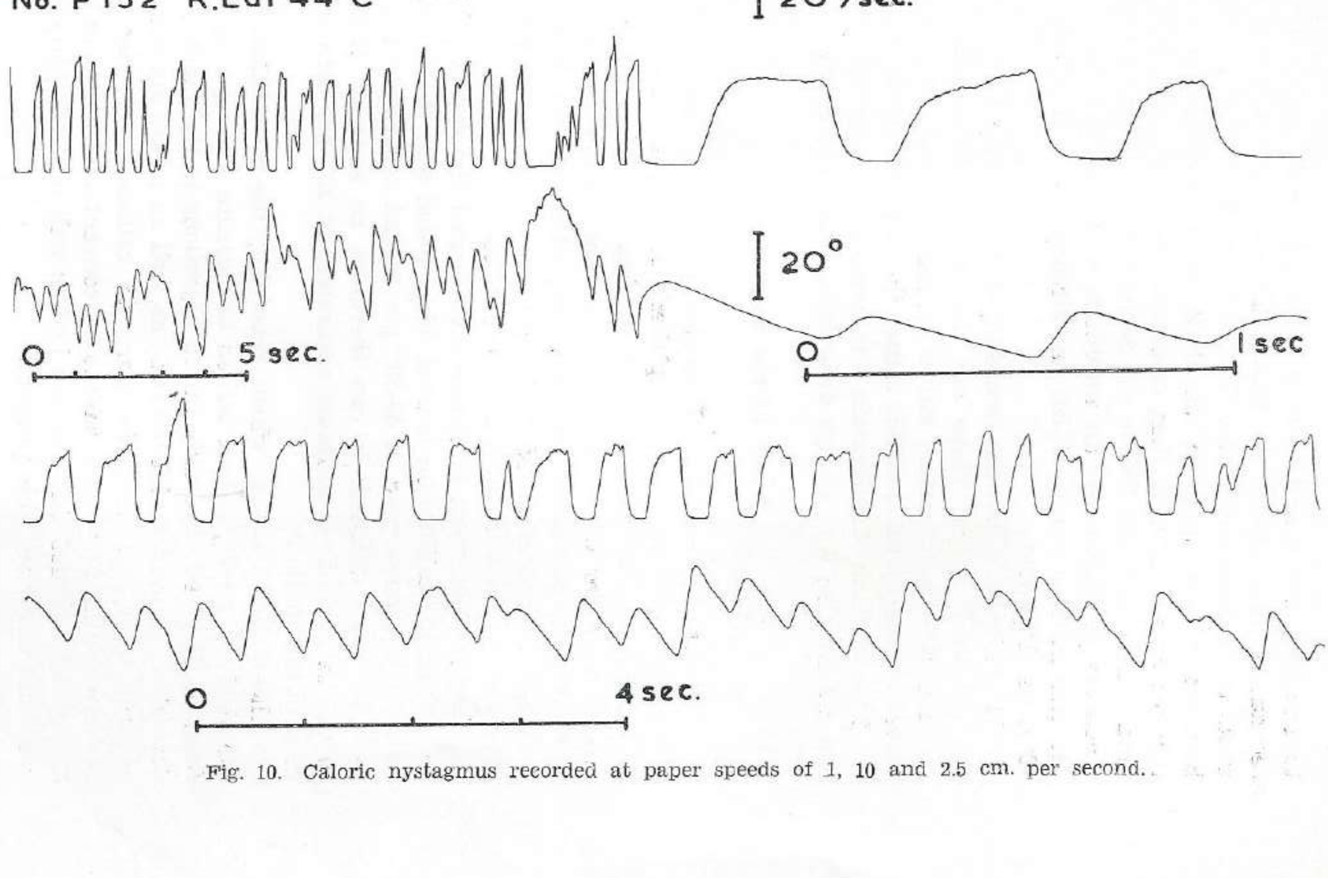


Fig. 10. Caloric nystagmus recorded at paper speeds of 1, 10 and 2.5 cm. per second.

to simplify the calculations a pendulum with a period of $\pi$ seconds is used. Hence the maximum velocity is numerically equal to the total amplitude. The pendulum is allowed to swing between the two spots on the black board. The calibration of the eye speed curve is then calculated by measuring the deviation from the zero line in the derived curve at that moment when the pendulum has an amplitude of 20° (arrived at from the conventional curve, which has already been calibrated for 20°). See Fig. 7.

It can be seen that the recording of the velocity is impaired by numerous peaks. These are due to limited accuracy of fixation. The conventional curve reveals that the eye always moves in small jerks and this causes the peaked velocity curve.

This method of calibration was found to be easy and practical. Calibration was always done before each recording.

*Errors of the method.*

Accurate reproduction of the slow phase of nystagmus was always possible due to the amplifier's long time constant (10 seconds), provided the speed was not less than 5° per second. A D.C. amplifier will of course be a more suitable instrument to reproduce eye movements with such a low velocity, but this A.C. amplifier was found to be satisfactory as it was rarely necessary to measure such slow eye speeds.

Aschan, Bergstedt & Stahle investigated the errors when an optokinetic calibration is used. They found that the eye can follow a constant speed of 40-50° per second accurately but it soon becomes fatigued. It can therefore be assumed that it should be possible to calibrate accurately at 20° per second as used in this method.

The question arises, which recording, the conventional or the derived curve, is best suited to measure the eye speed. Aschan, Bergstedt & Stahle raised objections to the method of derivation as used by Henriksson, as well as to his method of calibration. It is indeed necessary to calibrate this derived curve from the previously calibrated conventional curve and it can then be argued that one can just as well use only the conventional curve for this purpose.



In our experiments we seldom found much difference between the calculations of the eye speed from the two curves. To investigate this further, optokinetic nystagmus was recorded with various paper speeds (see Fig. 11). A continuous tape was made to move at a practically constant speed (between 19°

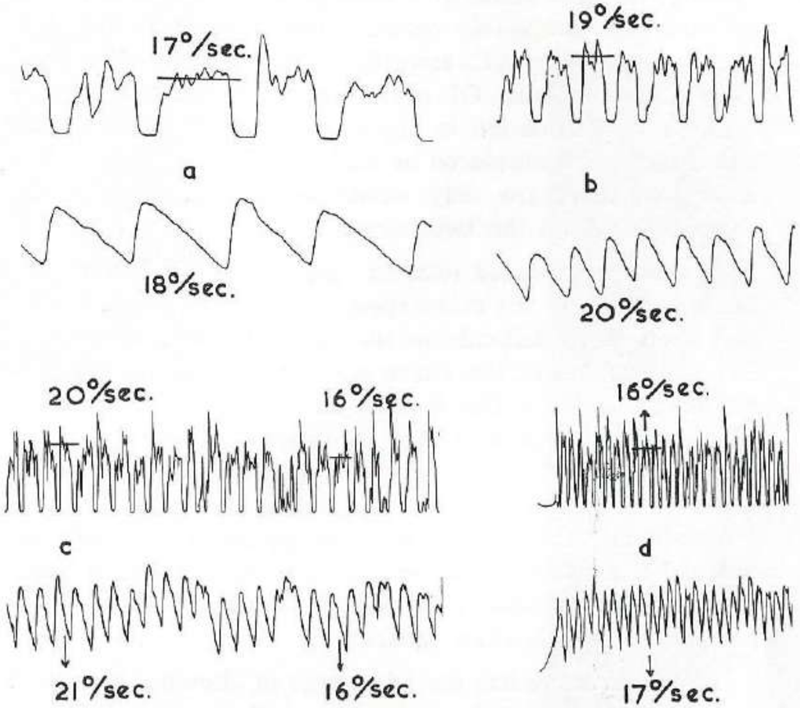


Fig. 11. Optokinetic nystagmus recorded at various paper speeds : (a) 2.5 cm. per second, (b) 1 cm. per second, (c) 0.5 cm. per second and (d) 0.25 cm. per second. As is shown in these recordings, the speeds measured from the derived curve (above) and conventional curve (bottom) correspond well, provided the **mean** eye speed is measured, as shown in (a). The slow phase of one nystagmus beat seldom has a constant speed and therefore the mean speed has to be calculated. Note how difficult it is to measure the eye speed at a slow paper speed (d).

and 20° per second in respect to the position of the test subject). On the tape white spots were painted at regular intervals and test subjects were asked to follow the spots with their eyes. From the recordings the following deductions can be made :

a. The speed of the slow phase of the optokinetic nystagmus varied between 15° and 20° per second, therefore the eye did not always follow the tape accurately. This is in contrast to the findings of Aschan, Bergstedt and Stahle (see page 50). Fatigue of the eye became evident when the test lasted longer than approximately one minute.

b. During the slow phase of a nystagmus beat, the eye speed is often not completely constant (see Fig. 11a). This cannot be due to the A.C. amplifier since the amplifier has a long time constant. Of course the derived curve also reveals this fluctuation in the eye speed. Hence the *mean* speed has to be measured as shown in Fig. 11. The results show that there are only small differences between the calculations from the two curves.

c. At a slow paper speed (0.25 cm. per second) it is very difficult to measure the mean speed in the conventional curve and even more difficult in the derived curve because of the compression of the curve and blotting of the ink. The numerous peaks in the derived curve may cause an error and it is quite possible that the maximum eye speed occurring during a caloric reaction can be judged too high. On the other hand, the error of judging the speed from the conventional curve is also large as an angle of nearly 90° has to be measured. This is especially the case in a vestibular nystagmus with a frequency of more than one beat per second, which often occurs.

d. The derived curve has the advantage of allowing the speed to be calculated much easier, as well as revealing the point of maximum eye speed better than the conventional curve. In addition, when the speed of the quick phase is recorded at the same time, the determination of the end point is facilitated. Therefore it was found that it is ideal to have both curves, as the conventional curve is essential for studying the type of eye movements. This was also the case when examinations were done for spontaneous nystagmus on patients of the clinic.

e. When the test subjects closed their eyes after an optokinetic nystagmus of a few minutes, a secondary phase nystagmus to the opposite direction was often found. This confirmed the findings of Aschan (1955).



In practice a paper speed of 1 cm. per second was found to be ideal. This speed allows easy measurement of the mean height in the derived curve. It is then not necessary to calculate the speed from the conventional curve while the eye movements themselves are well reproduced (far better than at a speed of 0.25 cm. per second as used by Henriksson). A recording of the caloric response then produces a piece of paper which is still convenient to handle.

*Influence of illumination upon the cornea-retina potential.*

As the nystagmus is recorded on a test subject with closed eyes, a change in the cornea-retina potential due to decreased illumination is possible. Miles (1940) found a decrease of about 10 per cent after a dark adaptation of 5 minutes. Henriksson as well as Aschan, Bergstedt & Stahle found the decrease insignificant. Ten Doesschate & ten Doesschate (1956) found that "during dark adaptation the steady potential decreases slowly and passes through a minimum value and reaches an end valua which is about 90% of the previous light-adaptation level. The intensity and the time relations of the effect depend on the intensity of the previous light-adaptation. If the eye is light-adapted again, the potential rise passes through a maximum before it attains the original level again. The fact that the amplitude of the E.N.G. is dependent on the state of adaptation of the eye has some practical consequences for electronystagmography and should not be neglected in experiments in which the state of adaptation of the eye changes during their performance". Lansberg (1956) stressed the importance of calibration at regular intervals during a prolonged registration as well as keeping the conditions during the registration constant.

In our experiments we nearly always found a decrease in the potential at the end of each recording, although an adaptation time of 30 minutes was allowed in the semi-darkened room. This was therefore investigated on a series of normal test subjects (see Fig. 12). For the conditions under which our caloric tests were done a decrease in the potentials is evident.

It has already been established that the cornea-retina potential decreases in the dark and becomes stable after 20-60 minutes in full darkness (Granit). When illumination is resumed, the potential increases and reaches a constant value provided that the room is evenly illuminated with a constant intensity.

In our experiments a period of 30 minutes was always allowed between successive irrigations to prevent a response decline. In addition a dark adaptation time of 30 minutes was always allowed before the first examination. The calibrations, which were repeated before each irrigation, varied only slightly in the same test subject unless the electrodes were replaced. It can therefore be assumed that 30 minutes are sufficient to allow potentials to return to their previous levels. The decrease in the potentials during each recording necessary for a caloric test will then be practically the same in the same test subject, provided that the illumination of the room remains constant (Horsten). For a comparison of the four recordings of a test subject this error can therefore be disregarded. However, to determine the true values of the eye speed and the total amplitude, the values should be corrected.

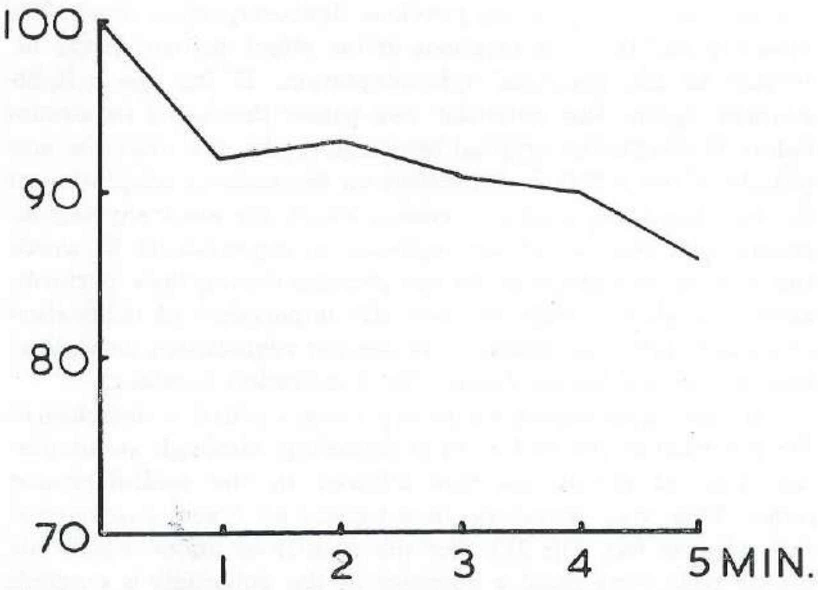


Fig. 12. Mean percentage decrease in the cornea-retina potentials of 10 normal test subjects due to closing their eyes for various intervals in a semi-darkened room.



# CHAPTER IV.

## *OWN EXPERIMENTS.*

In order to investigate the reactions of the normal person to a caloric test and to compare the responses found when the technique of performing the test is varied, normal persons were subjected to the caloric test according to the techniques described by (a) Fitzgerald and Hallpike (1942),
(b) Veits (1928)
and (c) Kobrak (1918).

As the stimuli used in the various techniques differ, we had to make them as similar as possible in order to be able to compare the results. In Chapter I the influence of the temperature of the water on the slow phase of nystagmus was described. It was therefore decided to use uniform temperatures in all these tests, thereby allowing only the amount of water used and some other factors to vary. The temperatures used were 7° C below and 7° C above body temperature and accurate to 0.1° C. In the Fitzgerald-Hallpike method and the Veits method the same amount of water was used (250 c.c. irrigated in 30 seconds). In the Kobrak method 10 c.c. of water was syringed in 10 seconds.

Due to practical reasons, the tests were not always performed at the same time of day. Most tests were done in the morning or in the afternoon and a small number in the evening. In a few cases the cold and the hot irrigations were done on separate days. This was usually the case in persons who showed a tendency to nausea. In order to exclude the possibility of a response decline, a 30 minutes interval was always allowed between succesive irrigations.

The nystagmus was recorded with the eyes of the test subject closed (see Chapter III). The following properties of the nystagmus were measured: duration, total amplitude, total number of beats, maximum speed of the slow phase and the latency.

In addition, the duration of the turning sensation was measured when possible and the test subjects were asked to note the type and the direction of the turning sensation. The recordings were always continued for a few minutes after the end point of the nystagmus had been reached, in order to register a secondary phase nystagmus when it occurred.

Before the first irrigation was applied, a period of 30 minutes was always allowed for the adaptation of the cornea-retina potentials to the semi-darkened condition of the room used for the experiments. During this period the electrodes were applied, the body temperature was measured orally and the amplifying system allowed to warm up. The calibration was then done and this was repeated immediately before each following irrigation.

The room was kept as quiet as possible as it was found that disturbances, for instance the ringing of a telephone, the opening of a door or a loud conversation in the vicinity influenced the nystagmus, which often stopped or decreased in intensity for a few seconds. The test subjects were also requested not to talk, laugh or move during the test and to swallow or cough as little as possible. Swallowing seldom caused interference in the recording and when it occurred could readily be distinguished from nystagmus, but coughing and laughing often caused gross disturbances.

The series of test subjects comprised students, nurses and doctors of both sexes and various ages between 16 and 48 years. None of them had ever suffered from otological or intracranial diseases.

The four irrigations were not performed in a uniform sequence. The cold irrigations were usually started with and in a few cases, as already mentioned, the cold and hot irrigations were done on seperate days.

*Application of the thermic stimulus.*

The water is drawn from a water bath of which the temperature is controlled by a thermostat with an accuracy of 0.1°C. The water flows to the ear through a double rubber tube. This arrangement corresponds to the one used by Henriksson. An electric motor * pumps the water through the central tube and

*) Hans Heidolph, Germany. Type P 50.



the excess water returns to the water bath through the outer tube (see Fig. 13). In this way the loss of heat is minimized. The water is introduced into the external auditory canal by means of a nozzle very similar to that used by Hallpike (1956). The amount of water used for irrigation is controlled with a cock in the main tube distally to the end of the inner tube. With water of 44.0° C in the water bath, a loss of 0.3° C occurs when the room temperature is 18° C. When using water of 30.0° C the loss due to cooling in the tube is 0.15° C.

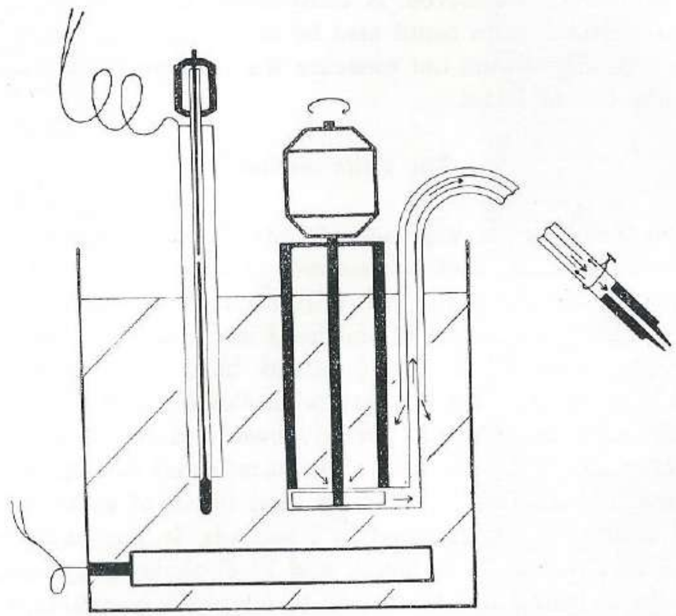

Fig. 13. Water bath with pump, double rubber tube and nozzle, thermostat and heater.

*The Fitzgerald-Hallpike method.*

Forty-seven test subjects were examined by this method. In order to investigate the occurence of a directional preponderance in left- and right-handed individuals, the series consisted of 24 right-handed and 23 left-handed test subjects.

The test subjects were examined in the supine position with the head and shoulders 30° anteverted. Two hundred and fifty c.c. of water at exactly 7° C below and 7° C above body temperature were irrigated into the external auditory canal during a period of thirty seconds. The duration of the nystagmus was measured from the beginning of the irrigation. We irrigated for only 30 seconds in contrast to the 40 seconds of the original Fitzgerald-Hallpike technique, so as to compare our results with those obtained by Aschan, Bergstedt & Stahle (1956) and Stahle (1956). They used the same technique of nystagmography and also applied water of which the temperatures were accurately measured. A comparison with the results obtained by Henriksson could also be made although he irrigated for 40 seconds and did not measure the total amplitude and the total number of beats.

*The Veits method.*

Ten test persons, who had already been subjected to the Fitzgerald-Hallpike method, served as test subjects. The test person is examined in the sitting position. A goniometer is used to determine the position of the head in the sagittal plane. The goniometer consists of the forehead band of a headlight to which a protractor with a vertical indicator is attached. This contraption is fitted to the person's head and calibrated for the vertical position. The head is then anteflected 30 degrees.

As a stimulus Veits originally used 10 c.c. of water at 20° C or 27° C and 47° C, irrigated in 7 seconds. In our experiments 250 c.c. of water at 7° C below and 7° C above body temperature was irrigated in 30 seconds to enable a comparison with the Fitzgerald-Hallpike method.

The irrigation is done with the horizontal canal in the horizontal position (indifferent zone). Fourty seconds after the completion of the irrigation, i.e. seventy seconds after the beginning of stimulation, the head is rotated backwards through ninety degrees to the optimal position. The rotation takes three seconds. The chair in which the test person is seated is fitted with a head rest so that the head can remain stable and comfortable in this position.

The purpose of the 30° anteflexion is to place the horizontal canal exactly in the indifferent zone. While the canal is in this position, the temperature gradient develops and the specific gravity of the endolymph changes. However, the flow of endolymph is impossible due to the indifferent position of the canal. According to the calculations of Schmaltz, the temperature gradient in the region of the horizontal canal reaches its maximum at approximately 70 seconds after the beginning of thermic stimulation. When the canal is rotated to the optimum position at this moment, the flow of endolymph becomes possible. Hence, cupular deflection can occur, resulting in nystagmus. The period between the end point of rotation and the first nystagmus stroke is then supposed to be the "true labyrinthine latency", as it does not include the time necessary for the development of the temperature gradient in the temporal bone and the time necessary for the change in specific gravity of the endolymph.

It has been established that it is difficult to reach the exact indifferent zone in a test subject as the position of the right and left horizontal canal often differs in the same person (see p. 30). The position of the horizontal canal also varies amongst individuals. This was also the case in our test subjects. At first this was a considerable problem and an effort was made to determine the indifferent zone first before performing the actual test. This was even more difficult, however, as the slightest movement of the head caused interference in the recording and the nystagmus, when it occurred, could seldom be stopped by varying the position of the head. This was probably due to the fact that the nystagmus was recorded with the eyes closed and therefore even a very small nystagmus could be recorded. It is quite possible that when nystagmography is not used, undetected nystagmus may be present in the so-called indifferent zone in many patients examined by the Veits method. When the test subject's head was manually supported, interference in the recording immediately occurred.

This problem was solved in the following way: the test subject steadies his head on his arms while grasping the edge of an immovable object (couch). When this was done, nystagmus in the indifferent zone occurred in only 9 out of the 40 recordings. Therefore it was possible to measure the latency in

31 recordings. In some cases where a nystagmus occurred in the "indifferent" zone, the tests were repeated. In these repeated tests, where no nystagmus occurred in the indifferent zone, the maximum speeds of the slow phases were practically the same as in the first tests. This can be explained, because the moment the nystagmus is supposed to begin (70 seconds after the beginning of the irrigation), the intensity of the nystagmus is dependent on the extent of the temperature gradient in the temporal bone at that moment. Therefore a nystagmus which occurs in the "indifferent" zone is of no importance whatsoever to the nystagmus which is revealed in another position at a later stage. This corresponds to the calculations of Schmaltz.

During the rotation of the head towards the optimum position, a strong interference in the recording often occurred. However, the double switch, by which an overload of the amplifier can be reset, proved to be of immense practical value to prevent loss of time.

*The Kobrak method.*

In 1918 Kobrak introduced the "minimal stimulation" method ("Schwachreizmethode"). In contrast to the large volumes of water introduced by Bárány in 1906, small quantities of water (5-10 c.c.) at 20° C or 27° C and 47° C are used.

Ten test persons, who had already been subjected to the Fitzgerald-Hallpike method, were examined by this method. The test was performed in the same way as the Fitzgerald-Hallpike method (see p. 57), the only difference being the quantity of water used. By means of an ordinary injection syringe with a blunt needle, 10 c.c. of water at 7° C below and 7° C above body temperature were syringed onto the postero-superior quadrant of the tympanic membrane under direct otoscopic control through an ear speculum.

§ 1. *Results of the Caloric Test according to the technique of Fitzgerald and Hallpike.*

Nystagmography was found to be very satisfactory for determining the various properies of nystagmus. In tables 2 and



3 (at p. 64) the values obtained in the series of 47 normal test subjects are given. When a secondary phase nystagmus occurred, it is indicated.

The various properties of the response to thermic stimulation will next be discussed.

*Latency.*

The latency could always be measured with an error of a few seconds only. As it was impossible to detect the beginning of the slow phase of the very first nystagmic beat, the first quick phase was taken as the beginning of the reaction. This is the normal procedure, but it involves a principal, unavoidable error. An additional error was due to the fact that some test subjects did not remain passive during the irrigation and movements often caused interference in the recording.

As the latency has not yet proved to be of any importance in the diagnosis of vestibular pathology, the values found were not analysed statistically. However, the mean value for all irrigations (25.5 seconds) is exactly the same as that found by Stahle.

Stahle repeatedly noted a considerable asymmetry in the latency of abnormal cases, especially when directional preponderance was present; the preponderance was then reflected by a shorter time-lag. In one of our normal test subjects with directional preponderance (test subject no. 24, table 2) we noted the same phenomenon. However, other test subjects with directional preponderance did not show this time-lag.

The latency will again be discussed when the results obtained with the Veits method are reviewed (see p. 88).

*Sensation.*

Thirty-six of the test subjects were asked to observe the subjective sensations.

A small number of test persons experienced a slight sensation of change in the position of the body, which always preceded the actual turning sensation. The information concerning this change in position was very vague, however, except in one case. With each irrigation this particular person had a distinct sensation of rocking to and fro for a few seconds before the turning sensation started. This could be an otolith stimulation (see Chapter I, p. 15). Another person repeatedly experienced the illusion of a flash of light just before the turning sensation started.

All test subjects experienced a turning sensation. However, it did occur that one or two irrigations in the caloric test caused no turning sensation at all, this being usually in the case of the hot water irrigation. According to the test subjects, it was possible to determine the beginning of the turning sensation fairly accurately, but it was more difficult to determine the end point. However, the mean values given in table 1 show a reasonable constancy. The limit values for the latency of the turning sensation were 12-65 seconds and for the duration of the turning sensation 26-150 seconds.

Table 1. Mean values in seconds of the turning sensation experienced by test persons when subjected to a caloric test according to the technique of Fitzgerald & Hallpike. The figures in brackets indicate the number of test subjects.

| | Latency | | Duration | |
|---|---|---|---|---|
| Left ear 30° | 30.8 | (29) | 80.3 | (28) |
| Right ear 30° | 34.2 | (30) | 75.1 | (28) |
| Left ear 44° | 33.6 | (30) | 74.0 | (28) |
| Right ear 44° | 31.8 | (30) | 72.7 | (29) |

Total means : Latency — 32.6 seconds.
Duration — 75.5 seconds.

With very few exceptions, the turning sensation started after the nystagmus had already commenced (mean value for latency of nystagmus 25.5 seconds).

No vomiting occurred, but a few test subjects had a slight nausea at the end of the test. Many persons complained of an unsteady feeling for the rest of the day. All test subjects judged the intensity of the turning sensation according to the speed of the turning sensation. When the latter was low, the person invariably had a low maximum speed of the slow phase of the nystagmus (hereafter also called max. eye speed). When the max. eye speed exceeded 40°/sec., the speed of the turning sensation was always very high and the test subjects often became pale or had a tendency to nausea. It is our impression that although these observations, are based upon the test subjects' own subjective observations, one may possibly relate the max. eye speed to the speed of the turning sensation.

The type of turning sensation varied. Half of the test persons had a turning sensation in a horizontal plane (i.e. in the supine position they turned around a vertical axis which passed through the umbilicus) and the rest turned around their body axes. In two cases both types occurred in the same person, e.g. one irrigation caused a turning sensation around the body axis, while another irrigation caused a turning in the horizontal plane. In three test subjects the turning sensation started with a turning around the body axis for a few seconds and this changed into a turning in the horizontal plane. Two subjects had a sensation of turning in both planes at the same time. Turning in a diagonal plane occured only in one test subject.

The direction of the turning sensation was usually in the direction of the quick phase of the nystagmus, but a few test persons claimed that they turned in the direction of the slow phase.

Four test subjects experienced a secondary phase turning sensation in a direction contrary to the primary phase. This secondary phase occurred a few seconds after the end point of the first phase, lasted from 10 to 20 seconds, but always stopped before the end point of the primary phase nystagmus. Two of these test subjects had a directional preponderance, of which one had a secondary phase nystagmus as well.

*Conclusion :* It is quite interesting to obtain data on the subjective sensations experienced during a caloric test, but one should be very careful before drawing definite conclusions. However, our impression is that inexperienced test subjects can often observe the subjective sensations fairly well. It may therefore be worth while to ask patients to observe the sensations, as one may discover something of interest.

It can be stated with certainty that in most normal persons the threshold of the turning sensation is higher than that of the nystagmus. This agrees with the findings of Jongkees (1949). The reverse occurs in the case of the turning test with small regulable stimuli, i.e. cupulometry (van Egmond, Groen and Jongkees).

Although the turning sensation could often be observed with surprising accuracy, we do not find this phenomenon reliable enough for judging the labyrinthine response. Sometimes it may even be absent.

*Duration, total amplitude, beats and maximum eye speed.*

The values found for these properties of the nystagmus are given in tables 2 and 3. The duration was measured from the beginning of the irrigation. The total amplitude was calculated by adding together the amplitudes of all the nystagmus beats. It represents the total deviation of the eye if it had not been interrupted by the quick phases. The maximum speed of the slow phase, also called maximum eye speed, was determined from the derived curve as described in the previous chapter.

These values will be discussed with the statistical analysis.

*Statistical Analysis.*

The values found for duration, total amplitude, total number of beats and maximum speed of the slow phase were analysed by means of the test for symmetry of Wilcoxon and Wilcoxon's two sample test. The analysis was done under guidance of Constance van Eeden of the Statistical Department*), Mathematical Centre, Amsterdam. The methods used are described in the appendix (see page 117).

A difference was accepted when the tail probability *(k)* was 0.05 or less.

The above-mentioned properties of the nystagmus will be discussed together. For convenience the irrigations are num-

*) Head of the Department : Prof. Dr. D. van Dantzig.

Table 2. Values obtained from the caloric test according to the technique of Fitzgerald and Hallpike carried out on 24 right-handed normal test subjects.

| Test subj. no. | 30° C | | | | | | | | | | | | 44° C | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Ear | | | | | | Right Ear | | | | | | Left Ear | | | | | | Right Ear | | | | | |
| | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh |
| 1. | 174 | 670 | 113 | 22 | 21 | L | 298 | 928 | 177 | 19 | 18 | — | 266 | 1086 | 170 | 29 | 21 | — | 176 | 929 | 134 | 25 | 20 | L |
| 2. | 214 | 833 | 155 | 20 | 21 | — | 218 | 720 | 131 | 15 | 15 | — | 322 | 837 | 184 | 11 | 27 | — | 203 | 706 | 165 | 15 | 24 | — |
| 3. | 208 | 1727 | 278 | 27 | 10 | — | 180 | 940 | 169 | 17 | 21 | — | 163 | 832 | 232 | 27 | 20 | R | 170 | 1259 | 215 | 31 | 9 | — |
| 4. | 145 | 562 | 167 | 20 | 23 | L | 165 | 728 | 145 | 23 | 28 | — | 134 | 495 | 154 | 24 | 28 | — | 124 | 506 | 133 | 24 | 16 | — |
| 5. | 162 | 975 | 160 | 20 | 25 | — | 220 | 808 | 167 | 19 | 20 | — | 168 | 1383 | 196 | 27 | 26 | — | 162 | 700 | 130 | 19 | 26 | — |
| 6. | 187 | 691 | 206 | 16 | 18 | — | 193 | 786 | 135 | 20 | 30 | — | 177 | 751 | 209 | 22 | 19 | — | 169 | 495 | 178 | 12 | 17 | — |
| 7. | 156 | 656 | 172 | 16 | 21 | — | 203 | 878 | 191 | 19 | 20 | — | 164 | 574 | 184 | 23 | 21 | — | 156 | 682 | 177 | 19 | 23 | — |
| 8. | 180 | 920 | 171 | 25 | 16 | — | 184 | 1053 | 170 | 29 | 20 | R | 192 | 1188 | 198 | 40 | 25 | R | 171 | 1396 | 203 | 42 | 13 | L |
| 9. | 156 | 814 | 231 | 16 | 16 | L | 247 | 902 | 259 | 24 | 11 | — | 244 | 1011 | 278 | 28 | 18 | — | 147 | 980 | 263 | 33 | 10 | L |
| 10. | 232 | 995 | 189 | 21 | 19 | — | 219 | 1056 | 226 | 21 | 22 | R | 221 | 953 | 248 | 20 | 19 | — | 282 | 720 | 167 | 17 | 18 | — |
| 11. | 212 | 791 | 197 | 16 | 24 | — | 163 | 994 | 136 | 19 | 32 | R | 141 | 764 | 174 | 21 | 22 | — | 209 | 1051 | 209 | 17 | 24 | — |
| 12. | 201 | 766 | 210 | 24 | 43 | — | 244 | 497 | 229 | 16 | 41 | — | 204 | 1048 | 277 | 23 | 33 | — | 178 | 844 | 161 | 24 | 44 | — |
| 13. | 205 | 284 | 102 | 12 | 50 | — | 172 | 437 | 119 | 14 | 48 | — | 191 | 156 | 71 | 11 | 70 | — | 188 | 369 | 117 | 14 | 43 | — |
| 14. | 190 | 1235 | 211 | 23 | 23 | — | 203 | 785 | 166 | 19 | 24 | — | 237 | 1383 | 199 | 25 | 17 | — | 253 | 1738 | 244 | 26 | 19 | — |
| 15. | 412 | 1171 | 235 | 20 | 18 | — | 216 | 1043 | 186 | 24 | 21 | R | 184 | 1387 | 209 | 28 | 20 | R | 288 | 1058 | 243 | 22 | 20 | — |
| 16. | 186 | 873 | 182 | 18 | 28 | — | 194 | 1230 | 192 | 21 | 23 | — | 194 | 1005 | 243 | 19 | 20 | — | 126 | 691 | 138 | 25 | 15 | L |
| 17. | 197 | 662 | 170 | 18 | 34 | — | 433 | 1173 | 318 | 22 | 19 | — | 275 | 896 | 252 | 20 | 32 | — | 187 | 620 | 171 | 19 | 23 | L |
| 18. | 265 | 1083 | 148 | 17 | 36 | — | 236 | 642 | 132 | 15 | 43 | — | 220 | 615 | 106 | 13 | 38 | — | 297 | 987 | 170 | 15 | 37 | — |
| 19. | 212 | 1028 | 136 | 34 | 15 | — | 190 | 1408 | 142 | 35 | 14 | — | 213 | 1612 | 160 | 44 | 14 | — | 217 | 1777 | 215 | 40 | 14 | — |
| 20. | 165 | 662 | 150 | 12 | 34 | — | 193 | 518 | 132 | 16 | 37 | — | 220 | 1050 | 242 | 16 | 20 | — | 134 | 376 | 101 | 11 | 30 | — |
| 21. | 179 | 449 | 199 | 21 | 27 | — | 153 | 543 | 176 | 19 | 26 | — | 167 | 889 | 223 | 31 | 23 | — | 161 | 910 | 232 | 37 | 15 | — |
| 22. | 171 | 827 | 143 | 19 | 28 | — | 308 | 2093 | 353 | 33 | 23 | — | 266 | 2495 | 369 | 50 | 28 | — | 176 | 1044 | 199 | 31 | 23 | — |
| 23. | 152 | 1208 | 195 | 31 | 25 | — | 182 | 1144 | 186 | 26 | 36 | — | 178 | 950 | 168 | 28 | 25 | — | 207 | 999 | 172 | 23 | 35 | — |
| 24. | 176 | 824 | 225 | 17 | 28 | L | 307 | 1401 | 427 | 25 | 16 | — | 243 | 890 | 300 | 26 | 15 | — | 145 | 848 | 221 | 30 | 28 | L |
| Mean Values | 197.3 | 862.8 | 181.8 | 20.2 | 25.1 | | 221.8 | 946.1 | 194.3 | 21.3 | 25.3 | | 207.7 | 1010.4 | 210.3 | 22.1 | 25.0 | | 188.6 | 903.5 | 177.5 | 23.8 | 22.8 | |

D = Duration in seconds, measured from the beginning of the irrigation.
TA = Total amplitude (degrees).
B = Total number of beats.
ES = Maximum speed of the slow phase (degrees per second).
Lt = Latency (seconds).
SPh = Secondary phase nystagmus.
L = Left-beating nystagmus.
R = Right-beating nystagmus.

bered as follows: 1) Left 30° C, 2) Right 30° C, 3) Left 44° C, and 4) Right 44° C. This does not mean that the irrigations were performed in this sequence.

The following analyses were done :

a. Left-handed test subjects compared with right-handed test subjects.
b. Mean values and Standard Deviation *(s)* determined.
c. The possibility of a response decline (R.D.) investigated.
d. The values of the four irrigations compared with one another, e.g. all values of 1) compared with those of 2), with 3) etc.
e. The values of the two ears compared, i.e. (1+3) with (2+4).
f. The values of the left-beating nystagmus (2+3) compared with those of the right-beating nystagmus (1+4).

a) *Comparison of right-handed with left-handed test subjects.*

The values of each of the four types of irrigations obtained from the right-handed group were compared with those of the corresponding irrigations of the left-handed group by means of Wilcoxon's two sample test, e.g. (1) with (1), (2) with (2), etc.. No difference of statistical significance was found in any of the four properties under consideration.

Comparison of the left-beating nystagmus values (2+3) and of the right-beating nystagmus values (1+4) revealed no difference between the two groups either. The suggestion by Jongkees (1948) that a difference may exist between the direction of a directional preponderance in right-handed and left-handed normal test subjects is therefore not confirmed by our experiments.

For the rest of the statistical analysis the two groups were therefore combined into a series of 47 normal test subjects.

b) *Mean values and Standard Deviation (s).*

The mean values and Standard Deviation of the various properties of the nystagmus as obtained by each irrigation are given in table 6 (p. 82). The Standard Deviation $(s)$ was calculated by means of the formula

$$s^2 = \frac{1}{46} \sum_{i=1}^{47} (x_i - m)^2$$

where $m$ = mean value, obtained by

$$m = \frac{1}{47} \sum_{i=1}^{47} x_i$$

and $x_i$ = observations = $x_1, \ldots, x_{47}$.

The normal limits may be set at twice the standard deviation from the mean value. The probability of a value falling outside this limit will be approximately five percent, provided the distribution is normal, e.g. in the case of the left ear and an irrigation with water of 30° C, ninety-five percent of the duration values of a normal series will be between 66 and 353 seconds (mean value 212, $s$ = 73 seconds).

c) *Response Decline (R.D.).*

The possibility of a response decline was investigated for each of the four irrigations separately. For each irrigation the test persons were arranged in four groups, I, II, III and IV, in such a way that group I consisted of all test persons for which the irrigation under consideration was the first irrigation performed, group II of all the test persons for which it was the second irrigation performed, etc. The number of test persons in each group for each irrigation is given in table 4.

Table 4.

| Irrigation | Number of test persons in group I | II | III | IV |
|---|---|---|---|---|
| No. 1 (L. 30) | 8 | 34 | 2 | 3 |
| No. 2 (R. 30) | 35 | 8 | 2 | 2 |
| No. 3 (L. 44) | 3 | 10 | 7 | 27 |
| No. 4 (R. 44) | 10 | 3 | 28 | 6 |

Table 3. Values obtained from the caloric test according to the technique of Fitzgerald and Hallpike carried out on 23 left-handed normal test subjects.

| Test subj. no. | 30° C | | | | | | | | | | | | 44° C | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Ear | | | | | | Right Ear | | | | | | Left Ear | | | | | | Right Ear | | | | | |
| | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh |
| 25. | 283 | 1238 | 238 | 19 | 18 | — | 246 | 903 | 179 | 17 | 33 | — | 212 | 571 | 91 | 8 | 46 | — | 250 | 709 | 152 | 11 | 41 | — |
| 26. | 134 | 174 | 91 | 11 | 28 | — | 177 | 418 | 172 | 13 | 21 | — | 209 | 842 | 196 | 16 | 30 | — | 168 | 394 | 122 | 16 | 23 | — |
| 27. | 306 | 978 | 148 | 22 | 33 | — | 257 | 740 | 145 | 22 | 35 | — | 205 | 826 | 140 | 22 | 32 | — | 312 | 927 | 155 | 24 | 32 | — |
| 28. | 276 | 886 | 222 | 19 | 20 | — | 188 | 489 | 159 | 19 | 22 | — | 197 | 536 | 166 | 21 | 24 | — | 246 | 709 | 211 | 19 | 16 | — |
| 29. | 204 | 506 | 119 | 19 | 27 | — | 206 | 934 | 234 | 19 | 28 | — | 108 | 154 | 61 | 13 | 26 | — | 112 | 144 | 44 | 21 | 45 | — |
| 30. | 145 | 429 | 104 | 20 | 28 | — | 206 | 519 | 117 | 20 | 35 | — | 203 | 457 | 129 | 16 | 21 | — | 174 | 558 | 149 | 16 | 19 | — |
| 31. | 147 | 1553 | 298 | 27 | 21 | — | 196 | 1899 | 321 | 34 | 18 | — | 149 | 1460 | 338 | 32 | 18 | — | 145 | 1326 | 275 | 33 | 20 | — |
| 32. | 198 | 1009 | 146 | 24 | 53 | — | 201 | 835 | 179 | 26 | 35 | — | 205 | 1136 | 201 | 24 | 37 | — | 204 | 1157 | 256 | 22 | 28 | — |
| 33. | 314 | 1924 | 201 | 46 | 9 | — | 205 | 1988 | 240 | 38 | 15 | R | 183 | 744 | 132 | 42 | 16 | R | 193 | 1489 | 180 | 42 | 12 | L |
| 34. | 467 | 1763 | 319 | 21 | 32 | — | 332 | 1202 | 179 | 19 | 37 | R | 248 | 1199 | 187 | 21 | 32 | R | 364 | 1232 | 254 | 18 | 25 | — |
| 35. | 193 | 623 | 250 | 13 | 37 | L | 429 | 514 | 257 | 9 | 44 | — | 305 | 474 | 232 | 9 | 42 | — | 192 | 317 | 148 | 8 | 40 | — |
| 36. | 415 | 1306 | 241 | 25 | 26 | — | 137 | 588 | 120 | 18 | 29 | R | 134 | 610 | 132 | 24 | 23 | — | 245 | 934 | 180 | 27 | 26 | — |
| 37. | 178 | 513 | 131 | 13 | 28 | L | 177 | 622 | 160 | 12 | 24 | — | 207 | 1006 | 194 | 21 | 21 | — | 182 | 600 | 107 | 11 | 30 | L |
| 38. | 206 | 1123 | 189 | 27 | 19 | — | 226 | 1708 | 231 | 32 | 21 | — | 215 | 1781 | 252 | 35 | 17 | R | 186 | 1386 | 202 | 34 | 18 | — |
| 39. | 230 | 1623 | 224 | 33 | 14 | L | 388 | 1205 | 300 | 21 | 19 | — | 300 | 2502 | 336 | 51 | 18 | — | 192 | 1754 | 235 | 47 | 18 | L |
| 40. | 159 | 882 | 122 | 24 | 34 | L | 218 | 1355 | 161 | 30 | 27 | — | 206 | 1090 | 126 | 25 | 28 | — | 152 | 914 | 117 | 22 | 34 | — |
| 41. | 172 | 599 | 187 | 11 | 27 | L | 215 | 648 | 189 | 12 | 25 | — | 218 | 578 | 188 | 13 | 23 | — | 176 | 639 | 178 | 19 | 24 | L |
| 42. | 320 | 914 | 241 | 18 | 22 | — | 194 | 800 | 187 | 23 | 32 | — | 210 | 663 | 178 | 17 | 32 | — | 274 | 920 | 234 | 19 | 20 | — |
| 43. | 162 | 441 | 123 | 26 | 28 | L | 499 | 1451 | 341 | 25 | 14 | — | 365 | 731 | 184 | 25 | 15 | — | 189 | 452 | 110 | 27 | 24 | — |
| 44. | 173 | 629 | 168 | 22 | 24 | L | 242 | 939 | 231 | 24 | 22 | — | 174 | 657 | 145 | 21 | 22 | — | 177 | 853 | 164 | 18 | 18 | L |
| 45. | 202 | 465 | 165 | 21 | 32 | — | 216 | 910 | 200 | 21 | 25 | — | 148 | 522 | 103 | 18 | 35 | — | 198 | 685 | 147 | 18 | 40 | — |
| 46. | 196 | 1365 | 160 | 25 | 33 | L | 214 | 1103 | 160 | 17 | 29 | — | 258 | 1182 | 162 | 16 | 26 | — | 190 | 767 | 113 | 17 | 38 | L |
| 47. | 161 | 1038 | 166 | 38 | 22 | — | 168 | 756 | 172 | 26 | 30 | — | 198 | 1403 | 152 | 42 | 14 | — | 180 | 1806 | 180 | 36 | 16 | L |
| Mean Values | 227.9 | 955.7 | 184.9 | 22.8 | 26.7 | | 240.7 | 979.3 | 201.5 | 21.6 | 27.0 | | 211.2 | 917.6 | 175.0 | 23.1 | 26.0 | | 204.4 | 898.8 | 170.1 | 22.8 | 26.4 | |

D = Duration in seconds, measured from the beginning of the irrigation.
TA = Total amplitude in degrees.
B = Total number of beats.
ES = Maximum speed of the slow phase in degrees per second.
Lt = Latency in seconds.
Sph = Secondary phase nystagmus.
L = Left-beating.
R = Right-beating.

In order to investigate a response decline we applied Wilcoxon's two sample test, where the first sample consisted of the values in groups I and II and the second sample of the values in groups III and IV. We applied the one-sided test only, as a *decline* was investigated.

No response decline could be detected in the cold water irrigations. However, the total amplitude as well as the maximum eye speed of both hot water irrigations revealed that the irrigations performed first and second gave higher values than those performed third and fourth ($k$ values varying from 0.004 to 0.02). The fact that the cold water irrigations did not reveal a response decline may possibly be attributed to the smaller number of observations in the case of the cold water irrigations in groups III and IV.

*Conclusion :* Although most investigators claim that a response decline (Hallpike and Hood, 1953) in caloric tests rarely occurs (p. 31), our series of test subjects revealed a decline in the responses to the hot water irrigations despite an interval of 30 minutes between successive irrigations. The total amplitude and the maximum eye speed were found to be the most sensitive properties of the nystagmus with respect to a response decline. The mean values revealed that this decline was not of a great magnitude, but nevertheless it should be stressed that a response decline is not a negligible factor when performing a caloric test. Unfortunately we did not consult a statistician before we undertook our experiments. This resulted in an unfavourable distribution of the sequence in which the cold irrigations were performed. For a detailed investigation of a response decline it is essential to consult a statistician beforehand, so that the sequence of irrigations can be planned accordingly.

d) *Comparison between the various irrigations.*

The 47 values of each irrigation were compared with those of each of the other three irrigations, e.g. (1) with (2), (1) with (3), etc. in the following way : in the case of (1) with (2), the differences between the values of (1) and (2) were determined for each test subject separately and the test for symmetry of

Wilcoxon was then applied to these differences. The following results were obtained :

*Duration :* Four differences were detected :

*i.* The values of right 30° were higher than that of left 30° ($k = 0.04$).

*ii.* The values of right 30° were higher than that of left 44° ($k = 0.006$).

*iii.* The values of right 30° were higher than that of right 44° ($k = 0.02$).

*iv.* The values of left 30° were higher than that of right 44 ($k = 0.02$).

or, schematically

right 30° > left 30° > right 44°

and right 30° > left 44°

However, the comparisons between left 30° and left 44° as well as left 44° and right 44° did not reveal significant differences. The mean values correspond to this scheme, although the differences are not large, i.e.
right 30°—231 sec., left 30°—212 sec., right 44°—196 sec., left 44°—210 sec.

Analysis of the *total amplitude* and the *total number of beats* did not reveal any difference between the irrigations.

*Maximum eye speed :* Two differences of significance were found : *i.* Left 44° > right ($k = 0.0046$).
*ii.* Left 44° > left 30° ($k = 0.04$).

These differences could not have been due to a response decline as Left 44° was the irrigation performed last in a large number of tests.

*Conclusions :*

*i.* The duration of the responses to cold water was found to be longer than those due to hot water. This corresponds to hot water. This corresponds to the findings of other investigators (see p. 16). However, in our series of tests a response decline occured in the responses to hot irrigations, so that this difference could have been due to a response decline.



*ii.* The values for the total amplitude and the total number of beats revealed no difference between the four irrigations.

*iii.* The maximum speed of the slow phase revealed high values for Left 44°, which cannot be ascribed to a decline in the responses of the other three irrigations.

e) *Comparison between the responses of the left (1+3) and the right ear (2+4).*

The test for symmetry by Wilcoxon was applied to the differences of the responses between the two ears in the same way as in the case of (d). No difference was found between the responses elicited from the two ears. It can therefore be assumed that in normal test persons the responses from the two ears have no significant differences in the four properties of the nystagmus which were investigated.

f) *Left-beating nystagmus (2+3) compared with right-beating nystagmus (1+4).*

The test for symmetry by Wilcoxon was again applied as in (d). No difference was found between the magnitude of the left-beating nystagmus (2+3) and the right-beating nystagmus (1+4). This implies that in our series of 47 normal test subjects directional preponderances to the left occurred to the same extent as directional preponderances to the right.

*Directional Preponderance.*

The definition of directional preponderance, as quoted by various authors, does not include a quantitative basis as to when this phenomenon is present. Jongkees (1948) accepted this phenomenon as present when the value of the nystagmus beating in one direction surpassed that beating in the other direction by 20% or more. Hence, when the left-beating nystagmus value (2+3) is 400 seconds and the right-beating nystagmus value (1+4) is 480 seconds, the person has $\frac{80}{100} \times 100\% = 20\%$ directional preponderance to the right.

When this formula is applied to to the values obtained from our test subjects, the following results, as regards directional preponderance, are obtained :

| | |
|---|---|
| *Duration :* | 26 out of 47 test subjects (17 to the left, 9 to the right). |
| *Total Amplitude :* | 26 out of 47 test subjects (16 to the left, 10 to the right). |
| *Beats :* | 27 out of 47 test subjects (17 to the left, 10 to the right). |
| *Max. Eye speed :* | 16 out of 47 test subjects (10 to the left, 6 to the right). |

Approximately 55% of our test subjects then have a directional preponderance. This is considerably more than that found by Jongkees (17%) and Schierbeek (12%), who applied the same formula but measured the duration by direct observation. Aschan, Bergstedt & Stahle, who used nystagmography and the same technique of performing the caloric test as we did, found no apparent directional preponderance in their normal test persons (they did not apply the percentage formula). Hallpike, Harrison & Slater (1951) found no directional preponderance in their series of normal persons, while Peterman found a directional preponderance in 1% of his series.

We applied this percentage formula to the values published by Henriksson (Acta Oto-laryng., suppl. 125, p. 12) in order to compare his results with ours. In the cases where the caloric tests were repeated by Henriksson, only the values of the tests performed first were used. The reason for this is that there should be the same number of observations per test person, otherwise the reactions of some individuals will be regarded as more important than the reactions of others. The following results as, regards directional preponderance, were obtained :

| | |
|---|---|
| *Duration :* | 2 out of 25 test subjects (1 to the left, 1 to the right). |
| *Max. Eye Speed :* | 9 out of 25 test subjects (4 to the left, 5 to the right). |



When comparing the results obtained from our (given above) with these results calculated from Henriksson's table, the following are evident :

*i.* We found more persons with a directional preponderance as revealed by the duration, than Henriksson.

*ii.* The max. eye speed values showed approximately the same incidence of directional preponderance.

*iii.* In our test series the max. eye speed revealed a directional preponderance in fewer persons than the duration, total amplitude and the total number of beats.

In our series more persons have a directional preponderance to the left than to the right when the percentage formula is applied. This agrees with the findings of Jongkees, Schierbeek and Lundberg (the latter did not use the percentage formula), who did not apply nystagmography.

Although the percentage formula revealed that in our series more persons had a directional preponderance to the left than to the right, the test for symmetry by Wilcoxon did not reveal any significant difference between the left-beating and right-beating nystagmus values (p. 69). This appears to be a controversy. However, *the percentage formula is not a test for symmetry* and therefore the results obtained by Wilcoxon's test for symmetry have to be accepted, i.e. that the apparent surplus of a directional preponderance to the left is not significant. The percentage formula is a method by which the magnitude of the directional preponderance can be calculated and an arbitrary amount is used to set the normal limit. The 20% limit was proposed by Jongkees but a 25% of 30% limit can also be used. In contrast to this, the statistical method of determining the standard deviation is generally accepted as a reliable method to determine the variations which occur in normal persons. This is therefore the preferable method.

The standard deviation is used by Aschan, Bergstedt and Stahle as well as Stahle. The standard deviation in our series of test subjects will be discussed later.

*Conclusions :*

1. A directional preponderance occurred very often in our series of test subjects.

2. The directional preponderances to the left were symmetrical with those to the right.
3. Right-handed and left-handed individuals do not differ with respect to a directional preponderance.
4. A directional preponderance can be revealed by the duration, total amplitude, total number of beats as well as the maximum speed of the slow phase of nystagmus.

*Secondary phase nystagmus.*

In contrast to the findings of other investigators, this phenomenon was recorded frequently in our test subjects (24 out of 47 persons). The period between the end point of the primary phase and the beginning of the secondary phase nystagmus varied from 20 to 80 seconds. The duration varied considerably (from 30 to 300 seconds). The secondary phase nystagmus always had a very slow eye speed (less than 5° per second) as seen in Figs. 14 and 15.

Only two of the test subjects had a secondary phase nystagmus in both directions (nos. 8 and 33, Tables 2 and 3). The other test subjects, in whom a secondary phase occurred, revealed this in one direction only, i.e. when it occurred in a test subject, it was always in the same direction. Most of these test subjects had a directional preponderance in the same direction as that of the secondary phase nystagmus e.g. test persons no. 24, 34, 46, etc.. Most of them had the secondary phase after the two smaller responses. A few persons had the secondary phase nystagmus after only one of the four responses.

As this was a remarkable finding, the values of the reactions were analysed to investigate the relationship between the directional preponderance and the secondary phase nystagmus. The two test subjects who had a secondary phase nystagmus in both directions, were excluded from this analysis.

In the test subjects in whom a secondary phase nystagmus occurred, the relationship between the direction of the secondary phase nystagmus and the direction of the directional preponderance in the same test subject was investigated. This was done by means of the 2 x 2 - table, one-sided (see appendix). The directional preponderance in the duration and the total



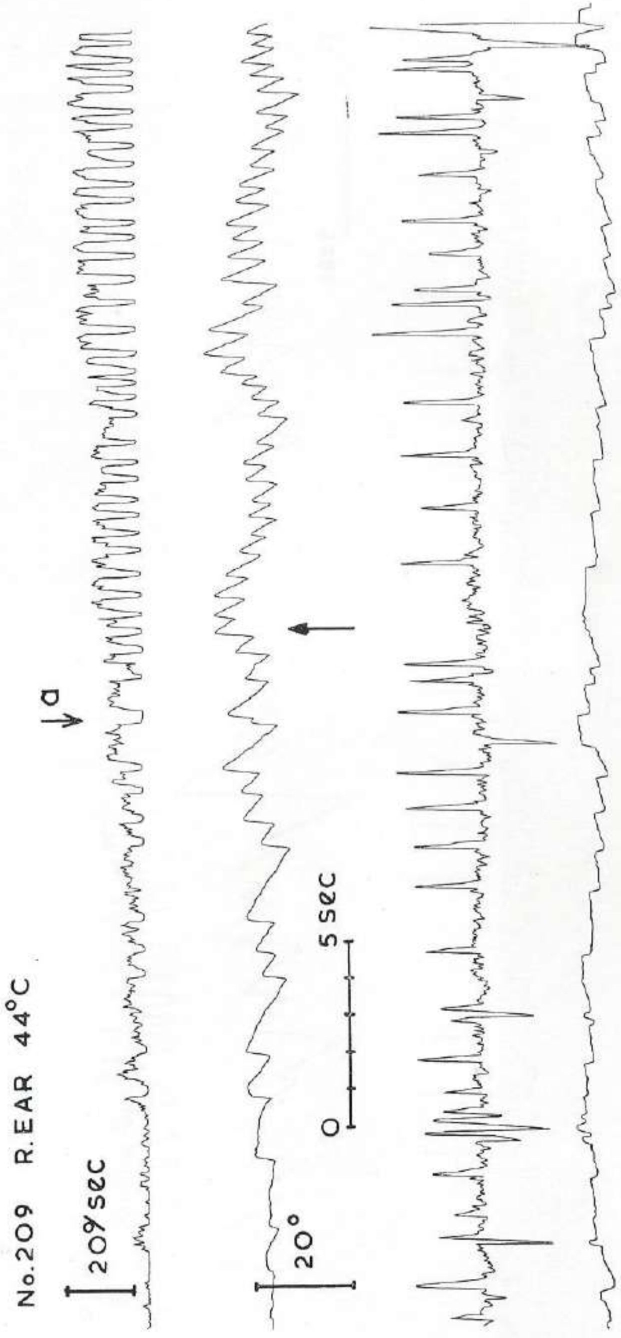


Fig. 14. Primary phase caloric nystagmus to the right (above) and secondary phase nystagmus to the left (below). The Fitzgerald-Hallpike technique is used. An eye movement to the left causes a downward deviation in the conventional curve. Note that the nystagmus has begun before the turning sensation starts at a. The arrow indicates the end of the irrigation. The eye speed of the secondary phase nystagmus is very low. Paper speed 1 cm. per second.

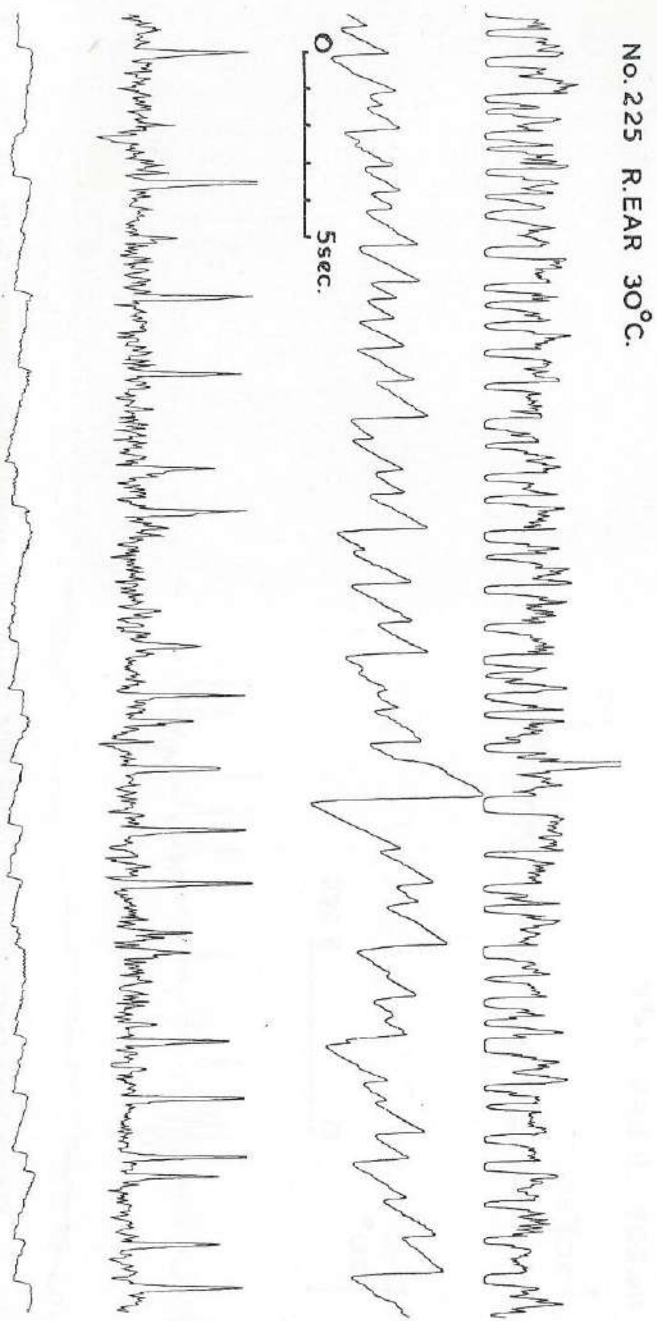


Fig. 15. The same as in Fig. 14, but here the primary phase nystagmus is to the left and the secondary phase nystagmus is to the right. An eye movement to the left causes a downward deviation in the conventional curve. Paper speed 1 cm. per second.



number of beats both showed the same direction as the secondary phase nystagmus ($k = 0.00009$ and $k = 0.01$ resp.). A comparison was then made between the absolute values of the differences between the left-beating and right-beating nystagmus of the test subjects with, and those without a secondary phase nystagmus. For this the Wilcoxon two sample test was used. The duration revealed higher values for these differences (directional preponderance) in the persons with a secondary phase ($k = 0.01$). This implies the following:

a. When a secondary phase nystagmus occurred, it was in the same direction as that of the directional preponderance, as duration.

b. The directional preponderance values (in the duration only) of persons with a secondary phase nystagmus are higher than those of persons without a secondary phase nystagmus.

*Discussion:* Although many investigators have already reported on the occurrence of this phenomenon in a caloric test (p. 32), none of them observed it as often as we did. This may be due to the fact that we applied nystagmography, but even Aschan (1955), who employed the same type of nystagmography as we did, did not find this phenomenon in a series of caloric tests on normal persons.

As already mentioned, the secondary phase nystagmus started long after the end point of the primary phase had been reached (20-80 seconds), and it may be that the other investigators did not wait long enough for its appearance.

The secondary phase nystagmus and its relationship with a directional preponderance (p. 72) supply us with more information on the mechanism of a directional preponderance. Jongkees (1953) already pointed out that a directional preponderance is essentially a spontaneous nystagmus which remains latent. That this may indeed be the case, was demonstrated by a test subject who was not included in our series. This person was examined on two occasions and had no previous history of ear disease or intracranial disease, but his non-indentical twin brother suffered from otosclerosis. He was therefore not included in our series as we accepted only persons with no family history of otoclerosis or Ménière's disease. On the first examination he had no spontaneous nystagmus before the test started. During the test he revealed a secondary phase nystagmus to the left. The latter followed the cold water irrigation of the left ear and the hot water irrigation of the right ear and lasted 15 and 3 minutes respectively. The nystagmus due to hot water irrigation of the left ear stopped only after 10 minutes. The maximum eye speed revealed no difference between the sensitivity of the two eers. On the second examination the secondary phase nystagmus started after the cold water irrigation of the left ear and was still present after 45 minutes. The test was therefore discontinued.

This test subject revealed a secondary phase nystagmus which resembles a provoked nystagmus. In addition he had a high degree of directional preponderance. The relationship between a secondary phase nystagmus and a directional preponderance allows one to relate the provoked nystagmus, found in this test person, with a directional preponderance.

Stahle (1956) reported that in abnormal cases, especially when a directional preponderance was present, the following was found : "After preliminary calorization, I have in some cases noted spontaneous nystagmus beating towards the side of the preponderance. This can perhaps be explained by the fact that D.P. and spontaneous nystagmus are probably expressions of the same phenomenon, though to unequal extents. The cases just described are probably cases of a mobilization of a D.P. ('latent spontaneous nystagmus') analogous to the 'provocation nystagmus' described by Frenzel (1955) after other types of stimulus (head-shaking, changes in position of the head, etc.) and confirmed by nystagmography in several cases by Aschan and Stahle (1956)."

Frenzel (1955) is of the opinion that it is worth while to consider the possibility whether a pathological directional preponderance does exist when a spontaneous or provocable nystagmus has been excluded carefully, because this much discussed phenomenon also exists in normal individuals.

The relationship between a secondary phase nystagmus and a directional preponderance, as demonstrated in our test subjects, confirm the views expressed by Frenzel and Stahle to a certain extent. A secondary phase nystagmus might therefore be regarded as a provokod nystagmus, usually found in persons with a directional preponderance, the latter being a spontaneous nystagmus which remains latent.

The findings of Boenninghaus (p. 32) that a secondary phase nystagmus can reveal a difference in tone even better than the primary phase nystagmus, correspond to a certain extent to our findings. However, Boenninghaus found that the ordinary caloric test did not suffice in eliciting a secondary phase nystagmus and used a special method to demonstrate this phenomenon.

*Conclusion :* The occurrence of a secondary phase nystagmus is a common feature in caloric tests where the nystagmus is recorded by our method of nystagmography. With the exception of two test subjects who showed a secondary phase nystagmus to the right as well as to the left, all other test subjects had a secondary phase nystagmus in one direction only and this usually followed the smaller responses in the case of a directional preponderance.

When a secondary phase nystagmus occurs, it will be in the same direction as that of a directional preponderance revealed by the total number of beats and the duration. In addition, the directional preponderance, as revealed by the duration, proved to be more pronounced in the test subjects who had a secondary phase nystagmus as well.

The view of Jongkees that a directional preponderance is essentially a spontaneous nystagmus which remains latent, is supported by our findings. In addition, it may be concluded from our experiments that a secondary phase nystagmus elicited in caloric tests, is this latent spontaneous nystagmus which is provoked to appearance by the unphysiological stimuli applied in the caloric test.

### *Reproduction of the results.*

In order to investigate whether the results could be repro-

Table 5. Values obtained from repeated caloric tests on normal test subjects according to the technique of Fitzgerald & Hallpike.

| Test subj. no. | 30° C | | | | | | | | | | | | 44° C | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Ear | | | | | | Right Ear | | | | | | Left Ear | | | | | | Right Ear | | | | | |
| | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh |
| 1. | 174 | 670 | 133 | 22 | 21 | L | 298 | 928 | 177 | 19 | 18 | — | 266 | 1086 | 170 | 29 | 21 | — | 176 | 929 | 134 | 25 | 20 | L |
| | 162 | 889 | 112 | 15 | 19 | L | 290 | 1045 | 173 | 20 | 19 | — | 233 | 735 | 139 | 18 | 22 | — | 202 | 721 | 123 | 16 | 23 | L |
| 11. | 212 | 791 | 197 | 16 | 24 | — | 163 | 994 | 136 | 19 | 32 | R | 141 | 764 | 174 | 21 | 22 | — | 209 | 1051 | 209 | 17 | 24 | — |
| | 155 | 738 | 121 | 19 | 31 | — | 146 | 728 | 115 | 21 | 22 | — | 179 | 860 | 115 | 19 | 26 | R | 254 | 1129 | 175 | 22 | 31 | — |
| 15. | 412 | 1171 | 253 | 20 | 18 | — | 216 | 1043 | 186 | 24 | 21 | R | 184 | 1387 | 209 | 28 | 20 | R | 288 | 1058 | 243 | 22 | 20 | — |
| | 211 | 899 | 199 | 20 | 33 | — | 146 | 676 | 165 | 18 | 28 | R | 146 | 588 | 185 | 22 | 23 | R | 138 | 918 | 228 | 25 | 22 | — |
| 42. | 320 | 914 | 241 | 16 | 22 | — | 194 | 800 | 187 | 23 | 32 | — | 210 | 663 | 178 | 17 | 32 | — | 274 | 920 | 234 | 19 | 20 | — |
| | 221 | 1038 | 250 | 24 | 15 | — | 154 | 664 | 167 | 19 | 27 | — | 193 | 607 | 178 | 14 | 31 | — | 235 | 1365 | 326 | 22 | 14 | — |

D = Duration in seconds, measured from the beginning of the irrigation.
TA = Total amplitude in degrees.
B = Total number of beats.
ES = Maximum speed of the slow phase in degrees per second.
Lt = Latency in seconds.
Sph = Secondary phase nystagmus.
L = Left-beating.
R = Right-beating.



duced, the caloric tests were repeated on four test subjects and the sequence of the irrigations varied. The values given in Table 5 show that the method employed gave fairly constant values when the tests were repeated under similar conditions.

*Eye movements other than nystagmus.*

Many publications dealing with the observation of nystagmus mention the importance of distinguishing between a nystagmus and to and fro movements of the eyes ("Augenunruhe") which do not comply with the definition of vestibular nystagmus (slow and quick phase). Eye movements which had to be distinguished from nystagmus occurred in all our recordings. In a small number of our test subjects we found that when the end point was approached, or just after the end point had been reached, certain to and fro movements of the eyes occurred. They usually occurred in groups of 10-20 beats, which had the same amplitude in both directions (see Fig. 16). Sometimes a secondary phase nystagmus occurred in between these movements. This observation was of interest and when it occurred repeatedly it was named the "Table Mountain Phenomenon".

After the end point of a nystagmus had been reached, we often observed curves which suggested a sinus (Fig. 17). This is due to slow and fairly regular pendulumlike movements of

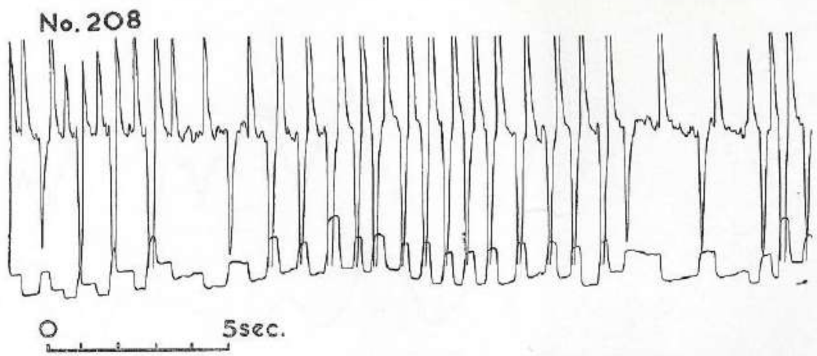


Fig. 16 (a). The "Table Mountain Phenomenon". The eyes perform rhythmic movements to both sides and produce rectangular figures in the conventional curve (below). Paper speed 1 cm. per second. See text also.

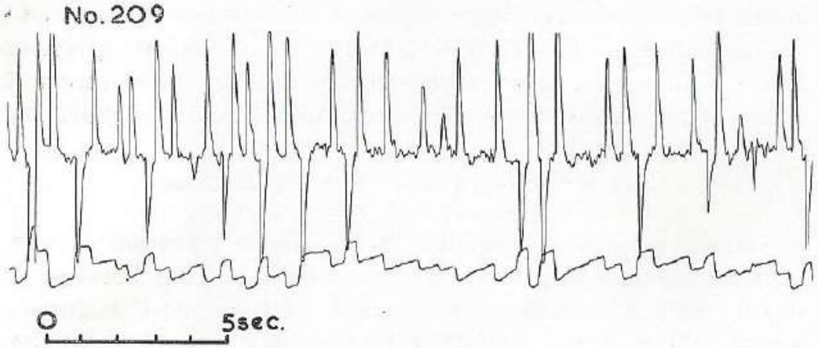


Fig. 16 (b). The same as in Fig. 16 (a), except that a secondary phase nystagmus to the left (downward deviation in the conventional curve) is also present. The derived curve aids in deciding whether a nystagmus is present or not, as the number of upward deviations in the derived curve exceeds the downward deviations by far. Paper speed 1 cm. per second.

the eyes. When information was obtained about the sensations experienced at that moment, most of the test subjects reported that they had been drowsy and might have dozed for a short while. Dozing was possible as the test persons lay on a comfortable couch with their eyes closed and a recording lasted anything up to 10 minutes. Quite often the test persons did not hear a noise which occurred in the vicinity. This confirmed that they were relaxed and dozing. It is our impression that these sinus curves might be due to the relaxed condition of the test subject. In the Veits method, where the test subjects

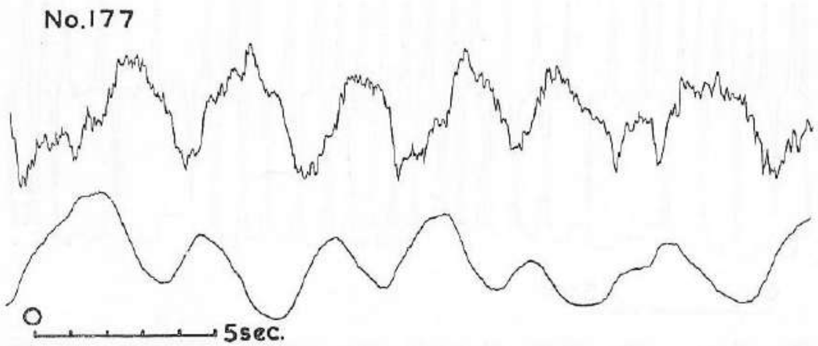


Fig. 17. "Sinus" curve produced after the end point of a caloric nystagmus. The test subject was relaxed and dozing. Paper speed 1 cm. per second.



were in an uncomfortable position, these eye movements seldom occurred.

*Dysrhythmia* in the course of the nystagmus (Aschan, Bergstedt and Stahle: "alternating periods of high and low intensity, the nystagmus being sometimes completely interrupted") was often observed in our test subjects. This dysrhythmia usually became more evident when a person was examined for a second or third time, despite a few months' interval between the tests. This phenomenon occurred so often that we view it with reserve and are inclined to ascribe little value to it.

### *Normal Values.*

As stated in Chapter II, the aim of this investigation is, amongst others, to try to establish the normal limits of the responses in a caloric test and to compare our results with those of other investigators who used comparable methods. The standard deviation can be used as a guide for establishing such limits. However, this method is not perfect as it only holds true for a normal distribution of the values. We determined the standard deviation $s$ by using the formula on page 66. The normal limits may then be set at twice the standard deviation from the mean value. The probability of a value falling outside this limit will be approximately 5%, provided the distribution is normal. When this method was applied to our results, we found that considerable variations are permissable (Table 6). Other investigators (Henriksson ; Aschan, Bergstedt & Stahle; Stahle) found smaller values for the standard deviation, but none of them supplied the formulas which they used to determine the standard deviation. This makes a comparison between our values for the standard deviation and theirs impossible, as they may have used either $s$ or $\frac{s}{\sqrt{n}}$

Henriksson published a table of the values found when 25 normal test persons were subjected to the caloric test according to the technique of Fitzgerald and Hallpike (Henriksson : Acta Oto-laryng., suppl. 125, page 12). We applied the formulas which we used for determining the standard deviation and the

Table 6. Results calculated from the values obtained by subjecting 47 normal test persons to a caloric test according to the technique of Fitzgerald & Hallpike. The limit values are calculated by adding 2 $s$ to and subtracting 2 $s$ from the mean values. Negative values indicate a preponderance of the responses elicited from the right ear or a preponderance of the right-beating nystagmus. Note that in the case of Left 44° the values for the max. eye speed had such a skew distribution that the method of 2 $s$ should not be applied in that case.

| | Duration (sec.) | | | Total Amplitude (degrees) | | | Max. Eye Speed (degrees p. sec.) | | | Beats | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $s$ | Mean | Limit values | $s$ | Mean | Limit values | $s$ | Mean | Limit values | $s$ | Mean | Limit values |
| Left 30° | 73 | 212 | 66<br>358 | 363 | 908 | 182<br>1634 | 52 | 183 | 79<br>287 | 7 | 22 | 8<br>36 |
| Right 30° | 68 | 231 | 95<br>367 | 402 | 962 | 158<br>1766 | 68 | 198 | 62<br>334 | 6 | 21 | 9<br>33 |
| Left 44° | 49 | 210 | 112<br>308 | 431 | 965 | 103<br>1827 | 66 | 193 | 61<br>325 | 13 | 23 | 0<br>49 |
| Right 44° | 68 | 196 | 60<br>332 | 401 | 901 | 99<br>1703 | 75 | 174 | 24<br>324 | 9 | 23 | 5<br>41 |
| (R 30 + L 44)<br>— (L 30 + R 44) | 162 | 32 | —292<br>356 | 665 | 117 | —1213<br>1447 | 120 | 32 | —208<br>272 | 8 | 0.8 | —15<br>17 |
| (L 30 + L 44)<br>— (R 30 + R 44) | 62 | —6 | —130<br>118 | 423 | 10 | —836<br>856 | 64 | —16 | —144<br>112 | 7 | 0.8 | —13<br>15 |

$s$: Standard Deviation



mean value (p. 66) to these values in order to compare his results with ours. In the cases where Henriksson repeated the caloric tests, only the values of the tests performed first were used. The reason for this is that there should be the same number observations per test person, otherwise some individuals will be regarded as more important than others. The values found for the standard deviation and the mean values are given in Table 7.

Table 7. Mean values and standard deviations ($s$) calculated from the results of Henriksson (Henr.) and those found by us (Ours) when subjecting normal persons to the Fitzgerald-Hallpike method. D = duration in seconds ; MES = maximum speed of the slow phase in degrees per second.

| | | Left 30° | | Right 30° | | Left 44° | | Right 44° | |
|---|---|---|---|---|---|---|---|---|---|
| | | D | MES | D | MES | D | MES | D | MES |
| Mean value | Henr. | 160 | 30 | 162 | 29 | 151 | 29 | 160 | 30 |
| | Ours. | 212 | 21 | 231 | 21 | 210 | 23 | 196 | 23 |
| $s$ | Henr. | 36 | 8.5 | 21 | 10.0 | 26 | 14.7 | 30 | 14.2 |
| | Ours. | 73 | 6.9 | 68 | 6.3 | 49 | 13.3 | 68 | 9.2 |

In the case of the *maximum eye speed,* our values for the standard deviation are smaller, but those of the *durdtion* are much higher than the values found by Henriksson. The method used by Henriksson differs from ours in that he irrigated for 40 seconds and we only for 30 seconds. It is possible that his higher values of the maximum eye speed may be due to this factor, but we found a longer duration, which cannot be explained in this way. Henriksson's higher values for the eye speed may also be due to his method of calculating the eye speed (Aschan, Bergstedt & Stahle). We used the same method, however, although we did not use the slow paper speed which may lead to a more difficult calculation of the eye speed (see page 52). Our mean values for the maximum eye speed are slightly higher than those found by Aschan, Bergstedt & Stahle (16° per second), but lower than those found by Henriksson.

We found consistently higher mean values for the *duration* (approximately 212 seconds) than Aschan, Bergstedt & Stahle (approximately 175 seconds), Stahle (approximately 177 seconds) and Henriksson (approximately 160 seconds).

The mean value for the *total amplitude* found by Stahle (approximately 1250°) is higher than in our series (approximately 934°) although the same method was employed.

The mean value for the *total number of beats* found by Stahle (approximately 187) corresponds well with our findings.

For clinical use, the difference between the responses elicited from the two ears, i.e. (1+3)—(2+4), as well as the difference between the left-beating and the right-beating nystagmus values, i.e. (2+3)—(1+4) are important. Tables 8 and 9 show the values found by various authors.

Table 8. Mean values and standard deviation values (s) found by various authors for the difference between the responses from the two ears, i.e. (1+3) — (2+4), when subjecting normal persons to the Fitzgerald-Hallpike method, compared with the values found by us (Ours). The negative values indicate a preponderance of the reaction elicited from the right ear. See text also.

| | Duration (seconds) | | Tot. Ampl. (degrees) | | Beats | | Maximum Eye speed (degr. p.sec.) | |
|---|---|---|---|---|---|---|---|---|
| | Means | s | Means | s | Means | s | Means | s |
| Henriksson | —0.2 | 24 | — | — | — | — | 0.8 | 11 |
| Asch., Berg. & Stahle | 1.2 | — | —5 | — | — | — | —0.6 | — |
| Stahle | 4 | — | —82 | — | 14 | — | — | — |
| Ours | —6 | 62 | 10 | 423 | —16 | 64 | 0.8 | 7 |

*Left/right sensitivity (Table 8):* The difference between the responses elicited from the two ears will be zero in the case of a perfect symmetry. The mean values for the differences between the ears of a series of test persons found by various authors reveal quite a reasonable distribution around zero. However, when calculating twice the standard deviation from



the mean value, it is evident that a considerable asymmetry is still within normal limits. Our series shows a higher value for the standard deviation in the duration than Henriksson's series. The values for the maximum eye speed of the nystagmus found in our series, correspond well to those found by other investigators.

Table 9. Mean values and standard deviation values (s) found by various authors for the difference between the left-beating and right-beating nystagmus, i.e. (2+3) — (1+4), when subjecting normal persons to the Fitzgerald-Hallpike method, compared with the values found by us (Ours). The negative values indicate a preponderance of the right-beating nystagmus. See text also.

| | Duration (seconds) | | Tot. Ampl. (degrees) | | Beats. | | Max. Eye Speed. (degr. p. sec.) | |
|---|---|---|---|---|---|---|---|---|
| | Means | s | Means | s | Means | s | Means | s |
| Henriksson | —1 | 39 | — | — | — | — | —3 | 11 |
| Aschan, Bergstedt & Stahle | 4 | — | —60 | — | — | — | —0.8 | — |
| Stahle | 7 | — | —38 | — | 27 | — | — | — |
| Ours | 32 | 162 | 117 | 665 | 32 | 120 | 0.8 | 8 |

*Left-beating/right-beating nystagmus (Table 9):* The difference between the left-beating and right-beating nystagmus values will be zero in the case of a perfect symmetry. A directional preponderance to the left will produce a positive value of this difference while a negative value will indicate a directional preponderance to the right. The mean values for the differences between the left-beating and right-beating nystagmus of a series of test persons found by various investigators reveal a reasonable distribution around zero in the duration and the max. eye speed, while the total amplitude and the beats show deviations of the mean values from zero.

We frequently found a directional preponderance in our test subjects. This is also revealed by the high standard deviation value for the duration, which is higher than that found by

Henriksson. Therefore our series of test persons show that a considerable deviation from zero is still within normal limits, i.e. when calculating twice the standard deviation from the mean value. Our standard deviation value for the max. eye speed corresponds to that found by Henriksson.

*Conclusion:* The use of nystagmography allowed a comparison of the results obtained by various authors. This is an important progress in the examination of the vestibular organ.

The comparison between our results and those obtained by other investigatotors revealed that our values correspond with theirs to a great extent. The *maximum eye epeed* values showed the best correlation with those found by other investigators, especially in the left/right sensitivity and the left-beating/right-beating nystagmus. We found higher mean values as well as higher standard deviation values for the duration. The mean values for the *total amplitude* and the *total number of beats* revealed no great differences as far as a comparison was possible.

Considerable variations in the magnitude of the responses in a caloric test occur in normal individuals. We suggest the following maximum permissable differences between the responses elicited from the two ears, i.e. (1+3)—(2+4), when the Fitzgerald-Hallpike technique is used and our method of nystagmography is applied:

Duration: 125 seconds.

Total amplitude: 850°.

Total number of beats: 130.

Maximum speed of the slow phase: 13°/second.

The probability of a normal person showing values outside these limits will be approximately 5%.

## § 2. *Comparison between the Veits and the Fitzgerald-Hallpike methods.*

*Sensation.*

All our test subjects found the Veits method more unpleasant than the Fitzgerald-Hallpike method. The turning sensation was more unpleasant since it commenced as soon as



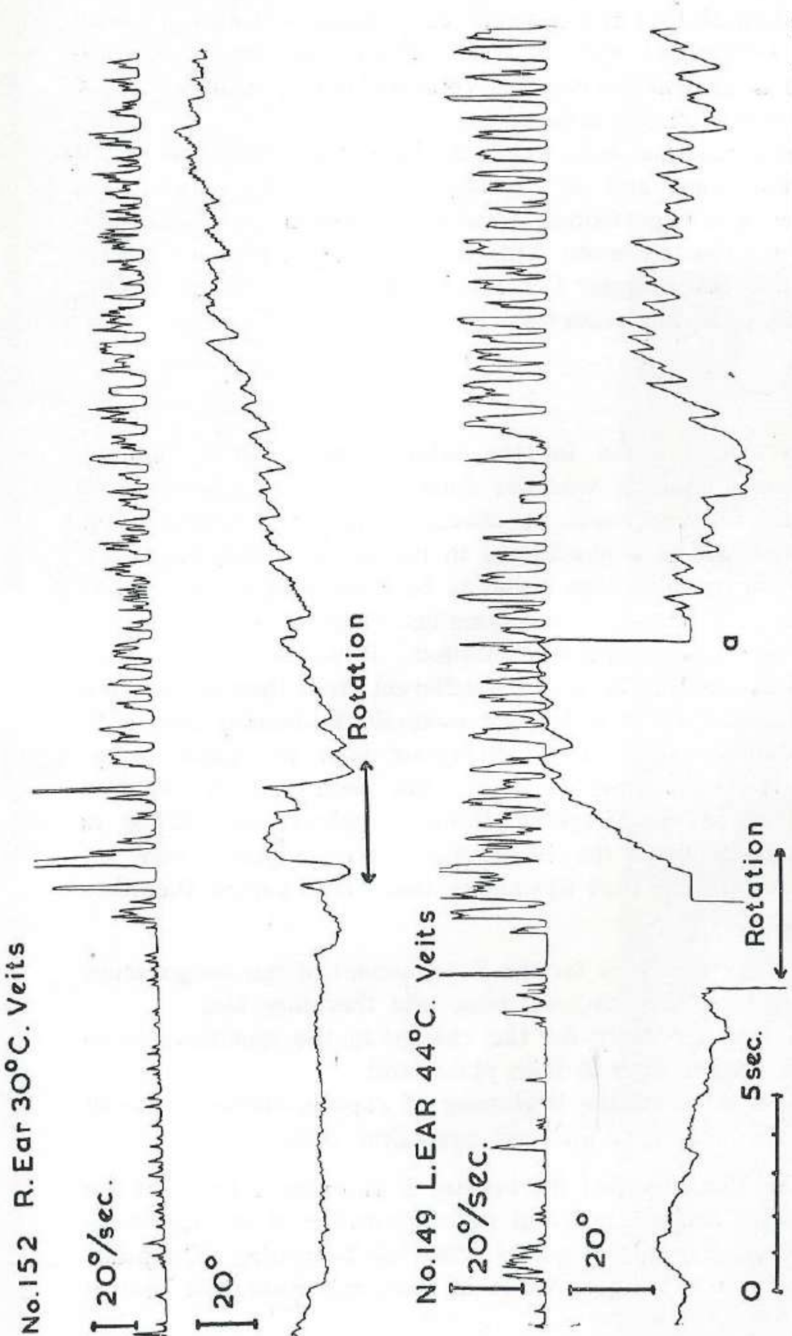


Fig. 18. Two recordings of a caloric nystagmus induced by the Veits technique. No nystagmus is present in the indifferent zone. The rotation causes disturbances in both recordings. At a the conventional curve is reset by means of the double switch. After the rotation the speed of the slow phase reaches its maximum within 10 to 20 seconds. Paper speed 1 cm. per second.

the rotation started and reached its maximum intensity within a few seconds. However, if small volumes of water had been used (as is used in the original Veits technique), this complaint might have been less severe.

During the period in which the horizontal canal was in the indifferent zone and no nystagmus occurred, no turning sensation was experienced. However, a tendency to fall sideways was often observed. This was probably due to an otolith stimulation (see Chapter I, p. 15). Further details of the turning sensation were not observed.

*Latency.*

The values found for the latency are given in table 10. A statistical analysis was not done. As already described on p. 59, the latency could be measured in only 31 of the 40 recordings, due to a nystagmus in the indifferent zone.

The mean value was found to be 3 seconds, in contrast to a latency of 22 seconds in the same test subjects when examined by the Fitzgerald-Hallpike method. However, the latency in the Veits method is entirely different from that in the Fitzgerald-Hallpike method. In both methods the latency ends with the appearance of the first nystagmic beat i.e. quick phase, because it is impossible to detect the beginning of the first slow phase. In the *Fitzgerald-Hallpike method* the latency is the period between the beginning of the irrigation and the appearance of the first nystagmic beat. This period therefore includes :

a) The time necessary for the development of the temperature gradient in the temporal bone and therefore also
b) the time necessary for the change in the specific gravity of the endolymph to take place, and
c) the period from the beginning of cupular deflection until the appearance of the first nystagmic beat.

In the *Veits method* the latency is the period between the end point of the rotation and the appearance of the first nystagmic beat. Hence, the period from the beginning of cupular deflection until the appearance of the first nystagmic beat is

Table 10. Values obtained from caloric tests on ten normal test subjects according to the techniques of Fitzgerald & Hallpike and Veits.

| Test subj. no. | Method | 30° C | | | | | | | | | | | | 44° C | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Left Ear | | | | | | Right Ear | | | | | | Left Ear | | | | | | Right Ear | | | | | |
| | | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh |
| 1. | F & H | 174 | 670 | 113 | 22 | 21 | L | 298 | 928 | 177 | 19 | 18 | — | 266 | 1086 | 170 | 29 | 21 | — | 176 | 929 | 134 | 25 | 20 | L |
| | Veits | 166 | 1252 | 116 | 22 | 3 | — | 224 | 1136 | 163 | 22 | 4 | — | 280 | 1625 | 210 | 22 | 5 | — | 165 | 1035 | 107 | 17 | 3 | — |
| 2. | F & H | 214 | 833 | 155 | 20 | 21 | — | 218 | 720 | 131 | 15 | 15 | — | 322 | 837 | 184 | 11 | 27 | — | 203 | 706 | 165 | 15 | 24 | — |
| | Veits | 155 | 698 | 162 | 16 | 4 | — | 160 | 254 | 71 | 12 | 6 | — | 228 | 1310 | 170 | 22 | 5 | — | 214 | 961 | 166 | 17 | 5 | — |
| 3. | F & H | 208 | 1727 | 278 | 27 | 10 | — | 180 | 940 | 169 | 17 | 21 | — | 163 | 832 | 232 | 27 | 20 | R | 170 | 1259 | 215 | 31 | 9 | — |
| | Veits | 165 | 1302 | 236 | 25 | — | — | 154 | 873 | 169 | 21 | 0 | — | 167 | 1060 | 255 | 21 | 0 | — | 168 | 1482 | 274 | 28 | — | — |
| 5. | F & H | 162 | 975 | 160 | 20 | 25 | — | 220 | 808 | 167 | 19 | 20 | — | 168 | 1383 | 196 | 27 | 26 | — | 162 | 700 | 130 | 19 | 26 | — |
| | Veits | 67 | 299 | 68 | 21 | 2 | — | 88 | 373 | 88 | 19 | 1 | — | 255 | 1128 | 224 | 25 | 2 | — | 86 | 342 | 86 | 19 | 2 | — |
| 15. | F & H | 412 | 1171 | 253 | 20 | 18 | — | 216 | 1043 | 186 | 24 | 21 | R | 184 | 1387 | 209 | 28 | 20 | R | 288 | 1058 | 243 | 22 | 20 | — |
| | Veits | 245 | 918 | 185 | 19 | — | — | 118 | 361 | 89 | 18 | — | R | 96 | 508 | 118 | 19 | — | R | 257 | 756 | 202 | 15 | — | — |
| 20. | F & H | 165 | 662 | 150 | 12 | 34 | — | 193 | 518 | 132 | 16 | 37 | — | 220 | 1050 | 242 | 16 | 20 | — | 134 | 376 | 101 | 11 | 30 | — |
| | Veits | 118 | 364 | 85 | 14 | 2 | — | 136 | 505 | 135 | 14 | 2 | — | 155 | 808 | 161 | 22 | 1 | — | 115 | 295 | 78 | 14 | 3 | — |
| 18. | F & H | 265 | 1083 | 148 | 17 | 36 | — | 236 | 642 | 132 | 15 | 43 | — | 220 | 615 | 106 | 13 | 38 | — | 297 | 987 | 170 | 15 | 37 | — |
| | Veits | 157 | 806 | 101 | 20 | 3 | — | 117 | 184 | 36 | 11 | 3 | — | 120 | 273 | 56 | 13 | 2 | — | 170 | 1029 | 139 | 18 | 3 | — |
| 19. | F & H | 212 | 1028 | 136 | 34 | 15 | — | 190 | 1408 | 142 | 35 | 14 | — | 213 | 1612 | 160 | 44 | 14 | — | 217 | 1777 | 215 | 40 | 14 | — |
| | Veits | 203 | 1897 | 202 | 47 | — | — | 134 | 1559 | 193 | 45 | 1 | — | 157 | 1658 | 242 | 45 | — | — | 224 | 2355 | 280 | 54 | — | — |
| 42. | F & H | 320 | 914 | 241 | 18 | 22 | — | 194 | 800 | 187 | 23 | 32 | — | 210 | 663 | 178 | 17 | 32 | — | 274 | 920 | 234 | 19 | 20 | — |
| | Veits | 135 | 759 | 215 | 20 | — | — | 115 | 306 | 120 | 20 | 3 | — | 181 | 914 | 234 | 20 | 0 | — | 215 | 722 | 140 | 17 | 2 | — |
| 43. | F & H | 162 | 441 | 123 | 26 | 28 | L | 499 | 1451 | 341 | 25 | 14 | — | 365 | 731 | 184 | 25 | 15 | — | 189 | 452 | 110 | 27 | 24 | — |
| | Veits | 131 | 423 | 122 | 18 | 4 | — | 99 | 267 | 63 | 21 | 5 | — | 242 | 503 | 161 | 21 | 4 | — | 153 | 418 | 113 | 25 | 5 | — |
| Mean Values | F & H | 221.6 | 950.6 | 185.7 | 21.6 | 22.0 | | 244.4 | 885.8 | 134.3 | 20.8 | 24.1 | | 233.1 | 944.4 | 186.1 | 23.7 | 23.7 | | 211.0 | 885.1 | 171.7 | 22.4 | 22.4 | |
| | Veits | 154.4 | 771.8 | 149.2 | 22.2 | 3.0 | | 134.5 | 601.8 | 112.7 | 20.3 | 2.6 | | 145.2 | 724.9 | 183.1 | 23.0 | 2.4 | | 176.7 | 939.5 | 158.5 | 22.4 | 3.4 | |

D = Duration in seconds, measured from the beginning of the irrigation.
TA = Total amplitude in degrees.
B = Total number of beats.
ES = Maximum speed of the slow phase in degrees per second.
Lt = Latency in seconds.
Sph = Secondary phase nystagmus.
L = Left-beating.
R = Right-beating.
F & H = Method according to Fitzgerald and Hallpike.

measured. This is supposed to be the "true labyrinthine" latency, because the temperature gradient develops and the specific gravity of the endolymph changes while the canal is in the indifferent position.

### *Statistical Analysis.*

The values found for the *duration, total amplitude, total number of beats* and *maximum speed of the slow phase* of nystagmus with the Veits method were compared with those found when the same test subject was examined by the Fitzgerald-Hallpike method. For example in the case of Left 30°, the difference between the values obtained by the two methods was determined for each test subject separately and the test for symmetry applied to these differences. The analysis was done under guidance of Constance van Eeden (see appendix). The following analyses were made :

a. The values of each type of irrigation in the Veits method were compared with those of the corresponding type of irrigation in the Fitzgerald-Hallpike method, e.g. Left 30° Veits with Left 30° Fitzgerald-Hallpike.
b. The values of directional preponderance, i.e. $(1+4)-(2+3)$, found by each method were compared with one another.

*Results :* All *duration* values found by the Fitzgerald-Hallpike method exceeded those obtained by the Veits method ($k$ values less than 0.05). However, in the Veits method the measurement of the duration was started 70 seconds later than in the Fitzgerald-Hallpike method.

Although the mean values given in Table 11 reveal a difference in the total amplitude and the total number of beats, no difference of statistical significance between the two methods was found in the values for *total amplitude, total number of beats* and *maximum eye speed* ($k$ values being more than 0.05).

Table 11.

| Method. | Duration. | Total. Ampl. | Beats. | Max. Eye Speed |
|---|---|---|---|---|
| Veits | 175 sec. | 832° | 157 | 22°/sec. |
| Fitz.-Hall. | 223 sec. | 955° | 174 | 22°/sec. |

Comparison of the values for *directional preponderance* between the two methods revealed no difference in the four above-mentioned properties of the nystagmus.

*Secondary phase nystagmus:* In this series of 10 test subjects this phenomenon occurred in four of the test subjects when subjected to the Fitzgerald-Hallpike method (see Table 10). However, only test subject no. 15 revealed a secondary phase nystagmus when tested with the Veits method.

*Discussion:* In the Veits method, the "true labyrinthine" latency is supposed to be measured. However, the latency has not yet proved to be of any clinical use (see Chapter I, p. 18). In addition it is not always possible to measure this latency, as nystagmus can be present before the rotation is commenced. Therefore the argument that the Veits method should be used as a routine clinical test, because it measures a more reliable latency, carries no weight.

The shorter duration of the nystagmus in the Veits method is due to the fact that the nystagmus is allowed to begin only when the temperature gradient in the temperal bone has already developed. This temperature gradient lasts equally long in both methods as the same stimuli are used, but the nystagmus in the Veits method lasts for a shorter time (difference in mean values: 48 seconds). This shows that the duration of nystagmus in the caloric test is dependent on the *duration of the temperature gradient* in the temporal bone and as such is not a measure of the labyrinthine activity alone, but to a great extent of the heat conduction in the temporal bone.

The total amplitude and the total number of beats showed no significant differences between the two tests. The maximum eye speed of the slow phase was the same in both methods (mean values 22°/sec.). This proves that the temperature gradient in the temporal bone reaches its maximum only after a period of at least 70 seconds from the beginning of the irrigation.



The Veits method does not reveal a secondary phase nystagmus as well as the Fitzgerald-Hallpike method does. It is our impression that this is due to the discomfort of the test subject when examined by the Veits method, because nystagmus can be influenced by disturbances in the surroundings (see p. 56) and possibly also by the uncomfortable position of the test subject. As the secondary phase nystagmus has a low eye speed, it might easily be influenced or suppressed. The relationship between a secondary phase nystagmus and a directional preponderance has been established (see p. 75). Although this series of test subjects is small, there is reason to believe that a directional preponderance, which interests otologists so much, is revealed more clearly by the Fitzgerald-Hallpike method.

The Veits method is definitely unsuitable for nystagmography, as the rotation of the head and the discomfort of the patient attributes to disturbances in the recording.

*Conclusion:* The Veits method revealed no advantages above the Fitzgerald-Hallpike method, but, in contrast, it was found to have certain disadvantages, especially in the recording of the nystagmus.

### § 3. *Comparison between the Kobrak and the Fitzgerald-Hallpike methods.*

The *turning sensation* caused by the "minimal stimulation" method of Kobrak was found to be far less than in the case of the Fitzgerald-Hallpike method, and also less unpleasant. Quantitative values of the sensation were not determined, however.

The recordings obtained by the Kobrak method were satisfactory, but the bigger stimuli used in the Fitzgerald-Hallpike method produced better recordings which could be more easily analysed and with less possibility of error.

The values found for the *latency* (see Tables 12 and 13) were practically the same in both methods and the mean values were exactly the same (23 seconds).

*Statistical Analysis.*

The values found for the *duration, total amplitude, total number of beats* and *the maximum speed of the slow phase* in the two methods were compared in the same way as in the case of the Veits method (see p. 89).

The Fitzgerald-Hallpike method produced higher values of these four properties of the nystagmus ($k$ values less than 0.05 in all cases). The mean values of all the irrigations combined correspond with this finding (Table 12).

Table 12

| Method | Latency | Duration | Tot. Ampl. | Beats. | Max. Eye Speed |
|---|---|---|---|---|---|
| Fitz.-Hall. | 23.1 sec. | 216.6 sec. | 863.6° | 193.2 | 20.8°/sec. |
| Kobrak | 23.2 ,, | 47.8 ,, | 375.8° | 105.5 | 12.6°/sec. |

Comparison of the values for *directional preponderance*, i.e. (1+4)—(2+3), showed that the duration and the maximum eye speed revealed no significant difference in the magnitude of the directional preponderance between the two methods. However, the total amplitude and the total number of beats had higher values of the directional preponderances in the case of the Fitzgerald-Hallpike method ($k$ values 0.004 and 0.0002 resp.).

A detailed analysis for a *response decline* could not be made as the sequence of the irrigations was unsuitable and the series too small for reliable results. However, our impression is that a response decline did not occur in the Kobrak method.

The Fitzgerald-Hallpike technique elicited a *secondary phase* nystagmus in four of the test subjects included in this series, but the Kobrak method revealed this phenomenon in only two test subjects.

Table 13. Values obtained from caloric tests on ten normal test subjects according to the techniques of Fitzgerald & Hallpike and Kobrak.

| Test subj. no. | Method | 30° C | | | | | | | | | | | | 44° C | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Left Ear | | | | | | Right Ear | | | | | | Left Ear | | | | | | Right Ear | | | | | |
| | | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh | D | TA | B | ES | Lt | SPh |
| 1. | F & H | 174 | 670 | 113 | 22 | 21 | L | 298 | 928 | 177 | 19 | 18 | — | 266 | 1086 | 170 | 29 | 21 | — | 176 | 929 | 134 | 25 | 20 | L |
| | Kobrak | 144 | 523 | 81 | 11 | 25 | L | 170 | 809 | 110 | 17 | 26 | — | 201 | 618 | 121 | 12 | 22 | — | 148 | 477 | 84 | 10 | 19 | L |
| 2. | F & H | 214 | 833 | 155 | 20 | 21 | — | 218 | 720 | 131 | 15 | 15 | — | 322 | 837 | 184 | 11 | 27 | — | 203 | 706 | 165 | 15 | 24 | — |
| | Kobrak | 119 | 525 | 77 | 15 | 20 | — | 184 | 248 | 71 | 5 | 26 | — | 262 | 260 | 97 | 5 | 31 | — | 175 | 373 | 107 | 8 | 28 | — |
| 15. | F & H | 412 | 1171 | 253 | 20 | 18 | — | 216 | 1043 | 186 | 24 | 21 | R | 184 | 1387 | 209 | 28 | 20 | R | 288 | 1058 | 243 | 22 | 20 | — |
| | Kobrak | 162 | 566 | 159 | 16 | 21 | — | 137 | 330 | 76 | 15 | 21 | — | 126 | 274 | 74 | 9 | 20 | R | 172 | 432 | 147 | 10 | 18 | — |
| 20. | F & H | 165 | 662 | 150 | 12 | 34 | — | 193 | 518 | 132 | 16 | 37 | — | 220 | 1050 | 242 | 16 | 20 | — | 134 | 376 | 101 | 11 | 30 | — |
| | Kobrak | 112 | 291 | 79 | 11 | 19 | — | 112 | 393 | 108 | 11 | 18 | — | 116 | 236 | 86 | 9 | 24 | — | 120 | 159 | 49 | 12 | 25 | — |
| 21. | F & H | 179 | 449 | 199 | 21 | 27 | — | 153 | 543 | 176 | 19 | 26 | — | 167 | 889 | 223 | 31 | 23 | — | 161 | 910 | 232 | 37 | 15 | — |
| | Kobrak | 84 | 121 | 46 | 10 | 22 | — | 118 | 198 | 65 | 14 | 27 | — | 118 | 141 | 55 | 10 | 21 | — | 142 | 338 | 99 | 20 | 18 | — |
| 26. | F & H | 134 | 174 | 91 | 11 | 28 | — | 177 | 418 | 172 | 13 | 21 | — | 209 | 842 | 196 | 16 | 30 | — | 168 | 394 | 122 | 16 | 23 | — |
| | Kobrak | 109 | 124 | 50 | 9 | 23 | — | 128 | 229 | 95 | 8 | 22 | — | 123 | 261 | 89 | 9 | 26 | — | 95 | 176 | 53 | 10 | 25 | — |
| 31. | F & H | 147 | 1553 | 298 | 27 | 21 | — | 196 | 1899 | 321 | 34 | 18 | — | 149 | 1460 | 338 | 32 | 18 | — | 145 | 1326 | 275 | 33 | 20 | — |
| | Kobrak | 121 | 682 | 208 | 27 | 25 | — | 147 | 826 | 212 | 29 | 16 | — | 117 | 218 | 111 | 14 | 17 | — | 125 | 218 | 93 | 15 | 19 | — |
| 41. | F & H | 172 | 599 | 187 | 11 | 27 | L | 215 | 648 | 189 | 12 | 25 | — | 218 | 578 | 188 | 13 | 23 | — | 176 | 639 | 178 | 19 | 24 | L |
| | Kobrak | 133 | 513 | 116 | 10 | 25 | — | 140 | 283 | 105 | 7 | 25 | — | 151 | 353 | 92 | 9 | 25 | — | 142 | 204 | 70 | 6 | 27 | — |
| 42. | F & H | 320 | 914 | 241 | 18 | 22 | — | 194 | 800 | 187 | 23 | 32 | — | 210 | 663 | 178 | 17 | 32 | — | 274 | 920 | 234 | 19 | 20 | — |
| | Kobrak | 239 | 877 | 260 | 12 | 19 | — | 168 | 540 | 166 | 14 | 21 | — | 204 | 361 | 116 | 10 | 22 | — | 222 | 541 | 161 | 12 | 20 | — |
| 43. | F & H | 162 | 441 | 123 | 26 | 28 | L | 499 | 1451 | 341 | 25 | 14 | — | 365 | 731 | 184 | 25 | 15 | — | 189 | 452 | 110 | 27 | 24 | — |
| | Kobrak | 149 | 264 | 76 | 15 | 37 | — | 206 | 933 | 187 | 27 | 22 | — | 158 | 321 | 91 | 19 | 29 | — | 113 | 274 | 84 | 12 | 24 | — |
| Mean Values | F & H | 207.9 | 834.3 | 181.0 | 18.8 | 24.7 | | 235.9 | 896.8 | 201.2 | 20.0 | 22.7 | | 231.0 | 952.3 | 211.2 | 21.8 | 22.9 | | 191.4 | 771.0 | 179.4 | 22.4 | 22.0 | |
| | Kobrak | 137.2 | 400.7 | 114.7 | 13.6 | 23.6 | | 151.0 | 478.9 | 119.5 | 14.7 | 22.4 | | 157.6 | 304.3 | 93.2 | 10.6 | 24.3 | | 145.4 | 319.2 | 94.7 | 11.5 | 22.3 | |

D = Duration in seconds, measured from the beginning of the irrigation.
TA = Total amplitude in degrees.
B = Total number of beats.
ES = Maximum speed of the slow phase in degrees per second.
Lt = Latency in seconds.
Sph = Secondary phase nystagmus.
L = Left-beating.
R = Right-beating.
F & H = Method according to Fitzgerald and Hallpike.

*Discussion.*

Neither the smaller volume of water used in the Kobrak method, nor the shorter period of syringing (10 seconds in contrast to 30 seconds) influenced the latency to any extent. The temperature of the water was the same in both methods. It is therefore possible that the latency is dependent on the temperature of the water used. This will be discussed later (p. 96).

The small volume of water syringed in 10 seconds proved to be a smaller stimulus than the large volume of water at the same temperature and irrigated in 30 seconds. This difference was revealed by the duration, total amplitude, total number of beats, as well as the maximum speed of the slow phase of nystagmus. Green & Jongkees (1949) who did not apply nystagmography, found no significant difference in the duration of nystagmus elicited by 500 c.c., 50 c.c. and 5 c.c. of water at 30° C and 44° C, i.e. the same temperatures as were applied by us. However, nystagmography revealed that the small volume of water (10 c.c.) is a smaller stimulus than the irrigation with 250 c.c. This was evident in the duration as well as in the other properties of the nystagmus.

The magnitude of the directional preponderance as revealed by the total amplitude and the total number of beats was smaller in the case of the Kobrak method. The duration and the maximum speed of the slow phase did not reveal this difference, however. Therefore the Kobrak method is less suited for eliciting a secondary phase nystagmus, which is related to a directional preponderance.

*Conclusion :* In the Kobrak method smaller responses are obtained than in the Fitzgerald-Hallpike method. These small responses are less unpleassant than large responses and a response decline probably does not occur when the Kobrak method is used and the interval between the irrigations is thirty minutes. However, certain disadvantages of the Kobrak method are evident, e.g. smaller directional preponderance values, recordings which are more difficult to interpret and a secondary phase nystagmus not elicited to such an extant as in the case of the Fitzgerald-Hallpike method. Furthermore, Jongkees

(1948) found that the values obtained by the Kobrak method could not be reproduced satisfactorily (see p. 27). Therefore the Kobrak method is less suitable as a routine clinical method.

§ 4. *The temperature of the water and its influence on the caloric reaction.*

In Chapter I the influence of the temperature of the water on the caloric reaction was reviewed (page 28). In order to investigate the temperature influence, 5 normal ears were irrigated with water at various temperatures. The results are given in Table 14.

Table 14. Values obtained by irrigating 5 normal ears with water at various temperatures.

| Test subj. no. | Volume water (c.c.) | Temp. (°C) | Duration (seconds) | Tot. Ampl. (degrees) | Beats | Maximum Eye speed (degrees p. s.) | Latency (sec.) |
|---|---|---|---|---|---|---|---|
| 1. | 250 | 34 | 161 | 565 | 90 | 12 | 26 |
| | | 32 | 181 | 959 | 146 | 19 | 23 |
| | | 30 | 146 | 1421 | 181 | 33 | 18 |
| | | 28 | 203 | 1869 | 239 | 39 | 20 |
| 2. | 250 | 34 | 156 | 674 | 125 | 17 | 34 |
| | | 32 | 172 | 813 | 171 | 21 | 25 |
| | | 30 | 160 | 992 | 228 | 24 | 25 |
| | | 28 | 182 | 1122 | 283 | 27 | 23 |
| 3. | 10 | 30 | 239 | 877 | 260 | 12 | 19 |
| | | 20 | 309 | 1490 | 411 | 30 | 20 |
| | | 0 | 286 | 2329 | 458 | 44 | 8 |
| 4. | 10 | 30 | 144 | 523 | 81 | 11 | 25 |
| | | 12 | 162 | 1321 | 143 | 31 | 16 |
| 5. | 10 | 30 | 170 | 809 | 110 | 17 | 26 |
| | | 8 | 218 | 1254 | 150 | 35 | 14 |

From these results the following deductions can be made: As the temperature of the water used for the irrigation is lowered, the maximum eye speed, total amplitude and the total number of beats show a definite increase in the nystagmic



response. The duration, however, reveals this increase in the response to a limited extent only. These findings agree with that found by Aschan, Henriksson and Mittermaier, who also employed nystagmography. Jongkees, who observed the nystagmus with the aid of Frenzel's glasses, found that the duration of the nystagmus increased steadily when the temperature of the water was lowered from 37° C to 30° C, but when the temperature was decreased still further, the duration revealed only a slight increase. This is also revealed in our results. In addition, by decreasing the temperature from 30° C to 20° C, the response increase is relatively bigger than when the temperature is decreased from 20° C to 0° C, especially as revealed by the duration.

It is therefore evident that the response to a thermic stimulation is dependent on the temperature of the water used. The total amplitude, total number of beats and the maximum speed of the slow phase reveal an increase in the magnitude of the response while the duration shows this increase only to a certain extent, or not at all. But why does the duration not increase when the other properties of the nystagmus increase in magnitude? This can be explained in the following way:

The duration of the reaction to a thermic stimulation depends on the speed with which the flow of blood through the temporal bone can restore the temperature of the temporal bone to that of body temperature. Our experiments with water at various temperatures revealed that the durations of the reactions, i.e. the time required to eliminate the thermic disturbances in the temporal bone, did not vary to a great extent. However, the total amplitude, total number of beats and the maximum speed of the slow phase did show that the responses varied in magnitude. Therefore Hallpike's statement that (a) in practice a large response usually has a long duration, and (b) that the possibility of the duration being of less value in the case of a short reaction with a large amplitude, or a reaction with a small amplitude and a long duration, practically does not exist, is therefore not tenable. This demonstrates the importance of information which can be obtained when nystagmography is employed.

It has been found that the volume of water used has little influence on the latency (p. 93). However, from the results in Table 14 it is evident that the latent period is shortened when the temperature of the water is lowered.

*Conclusions :*

*i.* The response to a thermic stimulation is determined by the extent of difference between the body temperature and the temperature of the water.

*ii.* The duration is revealed as an unreliable property of the nystagmus for judging the increase of the response.

*iii.* The maximum eye speed, total amplitude and total number of beats appear to be good indicators of the strength of the stimulation.

*iv.* The length of the latent period is dependant on the temperature of the water.

A further discussion will be given on page 97.

### § 5. *The influence of an obstruction in the external auditory canal on the caloric reaction.*

An occlusion of the external auditory canal by ear wax or cotton wool lengthens the latent period up to 100%, but has little influence on the duration of the reaction (Jongkees). In his experiments the nystagmus was observed with the aid of Frenzel's glasses.

We investigated this on two normal ears and recorded the nystagmus electrically (see Table 15).

Table 15. Values obtained when irrigating two normal ears with 250 c.c. of water at 30° C before and after removal of a piece of ear wax which obstructed the external auditory canal.

| | Duration (seconds) | Total Ampl. (degrees) | Beats | Max. Eye Speed (degr. p. sec.) | Latency (seconds) |
|---|---|---|---|---|---|
| With cerumen | 316 | 390 | 91 | 11 | 41 |
| After removal | 290 | 1045 | 173 | 20 | 19 |
| With cerumen | 159 | 573 | 84 | 13 | 42 |
| After removal | 162 | 889 | 112 | 18 | 19 |



From the results given in Table 15 the following is evident:

i. Occlusion of the external auditory canal by ear wax does not influence the duration of the response, but the latency is doubled.

ii. The total amplitude, total number of beats and the maximum speed of the slow phase reveal the damping effect of ear wax while the duration does not.

*Discussion :* The irrigation results in the development of a temperature gradient in the temporal bone, which lasts for a certain period. Its duration is dependent on the speed with which the flow of blood through the temporal bone can restore the temperature of the temporal bone to that of body temperature. When ear wax occludes the external auditory canal, a longer latent period in necessary before the temperature gradient affects the labyrinth. Once this has been established, the labyrinth responds to the stimulation, but less vigorously than when no ear wax is present. This is because the labyrinth is cooled to a greater extent when ear wax is absent. However, the duration of the response is the same in both cases, which implies that the flow of blood through the temporal bone requires the same length of time to equalize the temperatures (see also discussion on p. 95).

The extent of the temperature difference determines the magnitude of the response, the latter being revealed by the speed of the slow phase, total amplitude and total number of beats, but inadequately by the duration. From the experiments it is apparent that the time which the body requires to restore the temperature in the temporal bone, varies only slightly when, a) lower temperatures are applied, especially lower than 30° C (see p. 95), or b) when the establishing of the temperature difference is impaired by ear wax.

### § 6. *The influence of the quantity of water used on the caloric reaction.*

In the Fitzgerald-Hallpike method 250 c.c. of water at 30° C and 44° C were used and in the Kobrak method 10 c.c. at the same temperatures. Full details on the differences between the responses which occurred in the two methods are given on page 92. The conclusions arrived at are briefly as follows :

a. The latent period of the nystagmus was found to be the same.
b. The duration, total amplitude, total number of beats and the maximum speed of the slow phase of the nystagmus revealed that in the case of the 10 c.c. irrigations the responses were approximately half of that due to the 250 c.c. irrigations.

These experiments demonstrated that the magnitude of the responses elicited are not directly proportional to the amount of water used, but the responses can be increased by using larger volumes of water (N.B. at 30° C and 44° C).



## CHAPTER V.

## *CONCLUSIONS.*

### *Nystagmography.*

Nystagmography proved to be a satisfactory method by which the nystagmic response resulting from a thermic stimulation of the labyrinth can be determined. It has considerable advantages over methods which rely on visual observation alone. It eliminates to a large extent the possibility of various observers having various interpretations. The nystagmograms are available for analysis by other persons as well. When no nystagmography is employed, only the duration can be measured with fair accuracy, the duration being to a great extent an unreliable property of the nystagmus. Nystagmography provides us with data on the speed of the slow phase, the total amplitude and the total number of beats, which are more reliable properties of the nystagmus. However, in detecting pathology, spontaneous nystagmus is extremely important and in this case nystagmopraphy is a valuable aid, because the eye movements can be studied while the patient's eyes are closed. A very feeble nystagmus can then also be recorded as the visual fixation is abolished completely. This is probably the most important advance in the investigation of the vestibular organ.

The disadvantages of nystagmography are numerous. The equipment is expensive. The eye movements can only be recorded in the plane of the electrodes. Interferences due to move-ded in the plane of the electrodes. Interferences due to movement of the test subject, laughing, speaking, coughing and swallowing often occur. The temperature of the water has to be very accurate as the speed of the slow phase, the total amplitude and the total number of beats are very sensitive to changes in the temperature of the water. A response decline, although of small magnitude, can occur even when the interval between successive irrigations is 30 minutes. Therefore a caloric test according to our method is time-consuming ($2$—$^1/_2$ hours). The time factor makes electronystagmography more suited for use in clinics than in a busy consultant practice. An error in the calculation of the eye speed and the total amplitude is always present due to the change in the cornea-retina potentials when the eyes are closed. The test person's eyes must become adapted to the illumination of the room used for the investigation for at least 20-30 minutes before the test is commenced and calibration must be repeated immediately before each irrigation.

Taking all these factors into consideration, we still find nystagmography the most efficient method for investigating nystagmus. Nystagmography enables the investigator to compare his own results with those found by other investigators. The technique of performing nystagmography has improved during recent years and we can rely on additional improvements in the future. Spontaneous nystagmus can be investigated thoroughly and it is now possible to perform a caloric test on a patient who already has spontaneous nystagmus and still arrive at quantitative conclusions as to the function of the patient's labyrinths (Aschan, Bergstedt & Stahle).

We found the recording of the speed of the eye movements (introduced by Henriksson) and the simultaneous recording of the eye movements on two separate recordings extremely practical as it facilitates the interpretation of the nystagmogram. This method is recommended for routine clinical use.

### *The caloric test*

The method according to *Fitzgerald & Hallpike* proved to be the most suitable method for investigating the vestibular organ, especially when recording the nystagmus. However, an irrigation which lasts for 30 seconds only, is quite adequate as a stimulation.

The *Veits* method is not suited for use with nystagmography, as the movement of the head causes interference in the recording, while the uncomfortable position of the test subject (sitting position with the head retroflexed) suppresses a directional preponderance and a secondary phase nystagmus to a certain extent.

The *Kobrak* method is also suited for use with nystagmography, but the small stimulus, although less unpleasant, does



not elicit a secondary phase nystagmus or a directional preponderance as well as the stronger stimuli used in the Fitzgerald-Hallpike method. An advantage of the Kobrak method is that persons who react very strongly to a big stimulus, give quite good responses with a smaller stimulus. On the other hand, some test persons who react only mildly to the strong stimulation of the Fitzgerald-Hallpike method, react still less when subjected to the small stimuli applied in the Kobrak method. A response decline probably does not occur when the Kobrak method is used and the interval between the irrigations is 30 minutes. It would indeed be ideal to know beforehand whether a person reacts strongly to a thermic stimulation of his labyrinth, so that a suitable stimulus can be applied. However, so many techniques of performing the caloric test exist already, that it is advisable to use one test constantly in order to become accustomed to it and standardize the results. The Fitzgerald-Hallpike method is widely in use already and many investigators employ this method together with nystagmography. In the Fitzgerald-Hallpike method the temperature and the quantity of water used as a stimulus, as well as the position of the patient, are very satisfactory (Jongkees). A proper caloric reaction is elicited without harrassing the patient too much. This method is therefore recommended for routine use.

### *The response to thermic stimulation.*

It is important to know how the caloric reaction should be judged.

The *turning sensation,* although sometimes percieved with fairly great accuracy, is too unreliable for this purpose. More reliable information is obtained from the nystagmus.

The *latency* of the nystagmus has never proved to be of any importance in the diagnosis of vestibular pathology. In addition, the latency is solely a guide to the conduction of the temperature gradient through the temporal bone, as proved by experiments with ear wax in the external auditory canal, by irrigating with water at various temperatures as well as Henriksson's experiments in which he irrigated radical mastoid cavities. The experiments also revealed that the latency is determined by the temperature of the water and not by the volume of water used as a stimulus.

The *duration,* although it represents the labyrinthine activity to a certain extent, is more representative of the time needed for the flow of blood through the temporal bone to equalize the thermic changes produced by an irrigation with water at a temperature which differs from body temperature. This was demonstrated by experiments in which ears were irrigated with water at various temperatures, the effect of an occlusion of the external auditory canal by ear wax, and Henriksson's experiments in which he irrigated radical mastoid cavities. The duration did not reveal the variations in magnitude of the caloric reaction as well as the other properties of the nystagmus did. Therefore the duration is an unreliable property of the nystagmus to a large extent. However, it does reveal a directional preponderance adequately.

When nystagmography is employed, the labyrinthine activity can be measured more accurately by properties other than the duration, but when judging nystagmus by direct observation, one has to rely on the duration alone (although the total number of beats can be determined with a certain amount of accuracy).

The *maximum speed of the slow phase* of nystagmus, the *total amplitude* and the *total number of beats* represent the labyrinthine activity due to thermic stimulation more accurately than the duration. Variations in the magnitude of the stimulus are reproduced accurately. These three properties of the nystagmus react very much in the same way and it seems adequate to determine only the maximum speed of the slow phase when determining the labyrinthine response. The maximum speed of the slow phase is easily determined, and has the advantage that it can be calculated even when the patient has a spontaneous nystagmus (introduced by Aschan, Bergstedt & Stahle). These three properties of the nystagmus reveal a directional preponderance satisfactorily.

A *secondary phase nystagmus* occurs very often in normal persons (approximately half of our test subjects), but it varies considerably. It invariably has a slow eye speed (less than 5°/sec.), begins 20-80 seconds after the end point of the primary



phase nystagmus has been reached and lasts from 30-300 seconds or even longer. It is always in the opposite direction to that of the primary phase, although it is practically impossible to rule out the possibility that it can occur in the same direction (due to an undetectable transition of the primary into the secondary phase). The secondary phase nystagmus is related to a directional preponderance. Persons who have a secondary phase nystagmus have higher directional preponderance values than persons who do not show a secondary phase nystagmus. The secondary phase nystagmus usually follows the small responses in the case of a directional preponderance, i.e. in the case of a directional preponderance to the left, a secondary phase nystagmus to the left follows the cold water irrigation of the left ear and the hot water irrigation of the right ear. A secondary phase nystagmus in both directions in one caloric test rarely occurs. The fact that a secondary phase nystagmus is probably a type of provoked nystagmus was demonstrated by one of our test subjects (p. 75). The view of Jongkees that a directional preponderance is essentially a spontaneous nystagmus which remains latent, is supported by our findings. In addition, it may be concluded from our experiments that a secondary phase nystagmus elicited in caloric tests, is this latent spontaneous nystagmus which is provoked to appearance by the unphysiological stimuli. See also the discussion of directional preponderance which follows.

A *directional preponderance of caloric nystagmus* is commonly found in normal persons. It occurs to the same extent in both directions, both in left-handed and right-handed persons. A definite relationship exists between the occurrence of a secondary phase nystagmus and a directional preponderance (see above).

A directional preponderance is essentially a spontaneous nystagmus which remains latent (Jongkees, 1953). From the results of our experiments, we can define directional preponderance as this latent spontaneous nystagmus which is provoked by the unphysiological stimuli to appear as a secondary phase nystagmus.

Even when identical stimuli are used, a perfect symmetry between the left and the right ear and between left-beating and right-beating nystagmus is practically never found. When the percentage formula, as used by Jongkees (1948), is applied for determining whether a directional preponderance is present, more than 50% of our test subjects show this phenomenon. However, to accept a certain percentage or a certain fixed difference between left- and right-beating nystagmus as the threshold of a specific situation called directional preponderance, is completely arbitrary. The statistical method of twice the standard deviation from the mean value is generally accepted as a reliable method for determining normal limit values; provided the distribution is normal, only 5% of persons will then have values which fall outside these limits. We applied this method to the values obtained from our test subjects. It was then found that considerable variations in the difference between left-beating and right-beating nystagmus values are still within normal limits. This demonstrated that the phenomenon of directional preponderance is a normal finding in normal persons.

*Normal limit values.*

Considerable variations in the magnitude of the response to a caloric stimulation occur in normal individuals. In addition we found that the responses to the cold water irrigations in a caloric test are slightly larger than those due to the hot water irrigations.

It is impossible to lay down hard and fast rules in judging whether a person reacts in a normal way when subjected to a caloric test. This is due to the varied responses found when examining normal persons. However, with the aid af the statistical analysis performed on the results obtained from our test subjects, we suggest the following maximum values for the difference of the responses elicited from the two ears, i.e. $(1+3)-(2+4)$, when our method of recording the nystagmus and performing the Fitzgerald-Hallpike technique is used :

Duration : 125 seconds.

Total amplitude : 850°.

Total number of beats : 130.

Maximum speed of the slow phase : 13°/sec.

The probability of a normal person showing values outside these limits will be approximately 5%.




*SUMMARY.*

The Caloric Test, introduced by Bárány (1906), is now one of the basic methods by which the vestibular organ can be examined. Unfortunately this test is carried out in so many different ways by various investigators, that the results obtained when examining normal persons are not yet standardized. This makes it extremely difficult to decide whether a person's caloric reaction is abnormal or still within normal limits.

The main differences between the various methods employed lie in the size of the stimulus and the measuring of the response. The latter can be done either by observing or by recording the mystagmus.

In this investigation electronystagmography was employed and the following investigations were done on normal persons:

1. A comparison between the methods according to Fitzgerald & Hallpike (1942), Veits (1928) and Kobrak (1918).
2. The values obtained compared with those found by other investigators who used comparable methods.
3. A comparison between the occurrence of a directional preponderance in left-handed and right-handed individuals.
4. The influence of the temperature of the water, the quantity of water used and an obstruction in the external auditory canal by ear wax on the caloric reaction determined.

The nystagmograph consists of a D.C. amplifier from which the impulses are conducted to a two-channel, direct-writing electrocardiograph (Mingograf). The nystagmus was recorded with the eyes of the test subject closed. The eye movements as well as the speed of the eye movements were recorded simultaneously but on two separate recordings. The temperature of the water used was controlled by means of a thermostat. The errors of the method due to (a) changes in the cornea-retina potentials when the eyes are closed and (b) errors in the calibration were investigated and steps taken to keep the errors as small as possible.

Forty-seven normal test persons, of whom 23 left-handed, were subjected to a caloric test according to the technique of Fitzgerald & Hallpike. Ten of these test persons were again subjected to caloric tests according to the techniques of Veits as well as Kobrak. The turning sensation was determined when possible and the following properties of the nystagmus were measured: latency, duration, maximum speed of the slow phase, total number of beats and a secondary phase nystagmus recorded when it occurred. An interval of 30 minutes was allowed between successive irrigations.

The comparison between the three methods of performing the caloric test revealed that the Fitzgerald-Hallpike method is the most suitable method for investigating the vestibular organ, especially when recording the nystagmus.

The turning sensation, although sometimes perceived with fairly great accuracy, is too unreliable for determining the labyrinthine response.

A directional preponderance was a common finding in our test subjects and occurred to the same extent in both directions in right-handed and left-handed individuals. This phenomenon is revealed by the duration, maximum speed of the slow phase, total amplitude, total number of beats as well the secondary phase nystagmus.

A secondary phase nystagmus occurred frequently and its relationship to a directional preponderance could be established by means of a statistical analysis. A secondary phase nystagmus usually occurs in persons who show a directional preponderance, it has the same direction as the directional preponderance and it follows the small responses in a caloric test, e.g. in the case of a directional preponderance to the left, a secondary phase nystagmus to the left follows the cold water irrigation of the left ear and the hot water irrigation of the right ear. Jongkees (1953) is of the opinion that a directional preponderance is essentially a spontaneous nystagmus which remains latent. Our experiments revealed that a secondary phase nystagmus is probably a type of provoked nystagmus. As the secondary phase nystagmus is related to a directional preponderance, we define a directional preponderance as a latent spontaneous nystagmus which is provoked by the unphysiological



stimuli applied in the test to appear as a secondary phase nystagmus.

The values obtained from the Fitzgerald-Hallpike method were analysed statistically under guidance of Constance van Eeden of the Mathemitical Centre, Amsterdam. The methods employed in this analysis are described in the appendix (p. 117). The following results were obtained:

1. A response decline occurred in our experiments although an interval of 30 minutes was allowed between successive irrigations.
2. In normal persons a directional preponderance to the left occurs to the same extent as a directional preponderance to the right.
3. Considerable variations in the magnitude of the caloric reactions of normal persons occur. This makes it extremely difficult to determine the normal limit values. We determined the standard deviations of the values obtained from our test subjects and from these we arrived at values which can be used as a guide when determining whether a patient's caloric reactions are within normal limits.

A comparison between the values obtained from our test subjects and those obtained by Henriksson (1955), Aschan, Bergstedt & Stahle (1956) and Stahle (1956), who used comparable methods, was possible. In general the values corresponded, but our test subjects showed a bigger variation.

Experiments in which water at various temperatures was used as a stimulus, showed that the duration does not reveal the magnitude of the stimulation adequately. The maximum eye speed, total amplitude and total number of beats are more reliable properties of the nystagmus by which to determine the magnitude of the stimulation. This was especially demonstrated by experiments in which the external auditory canal was obstructed by ear wax. In these cases the duration remained the same, but the other properties of the nystagmus showed the effect of the obstruction on the caloric reaction, while the latency was doubled. Experiments with various volumes of water at the same temperature revealed that a 10 c.c. irrigation as used in the Kobrak method, was a much smaller stimulus than a 250 c.c. irrigation (used in the Fitzgerald-Hallpike method), while the latency remained the same. In addition the small volume of water did not elicit a secondary phase nystagmus and a directional preponderance to such an extent as the bigger volume of water.

The latency was found to be dependent on the temperature of the water and not on the volume of water used as a stimulus.

Nystagmography, as we employed it, proved to be satisfactory. Although nystagmography lengthens the time necessary for performing a caloric test, we recommend it as a routine method to determine the response, as more reliable information on the caloric reaction can be obtained. Recording of the speed of the eye movements (introduced by Henriksson) as well as the eye movemens themselves, simultaneously but on two separate recordings, is recommended as this facilitates the interpretation of the nystagmogram.

The Fitzgerald-Hallpike method is the most suitable method for clinical use, but an irrigation of 30 seconds is sufficient. An interval of at least 30 minutes between the successive irrigations is essential to prevent the occurrence of too great a response decline.



## SAMEVATTING.

Die Kaloriese Toets, wat deur Bárány in 1906 ontwerp is, is vandag een van die basiese metodes vir die ondersoek van die ewewigsorgaan. Ongelukkig word die toets volgens verskillende tegnieke uitgevoer, sodat die waardes wat by normale persone gevind word, nog nie gestandardiseer is nie. Daardeur is dit baie moeilik om te besluit wanneer 'n pasiënt se kaloriese reaksie nog binne normale perke is.

Die belangrikste verskille tussen die verskeie tegnieke waarvolgens die toets uitgevoer word, is die grootte van die prikkel wat toegedien word en die metode waarop die nystagmus waargeneem word.

In hierdie ondersoek is die nystagmus deur middel van elektronystagmografie waargeneem en die volgende ondersoeke is op normale proefpersone uitgevoer :

1. 'n Vergelyking tussen die metodes van Fitzgerald en Hallpike (1942), Veits (1928) en Kobrak (1918).
2. Die waardes wat deur ons verkry is, is vergelyk met die van ander ondersoekers wat vergelykbare metodes gebruik het.
3. Die voorkoms van rigtingsvoorkeur van die nystagmus („directional preponderance") by linkshandige en regshandige proefpersone is nagegaan.
4. Die invloed van veranderings in die temperatuur en volume van die water asook die invloed van 'n obstruksie van die uitwendige gehoorgang deur oorwas op die kaloriese reaksie is nagegaan.

Die nystagmograaf bestaan uit 'n wisselstroomversterker vanwaar die impulse na 'n twee-kanalige, direkskrywende elektrokardiograaf (Mingograf) gelei word. Die proefpersoon se oë is geslote tydens die registrasie. Die oogbewegings en die spoed van die oogbewegings is gelyktydig op twee aparte kurwes geregistreer. Die temperatuur van die water is noukeurig gekontroleer met behulp van 'n termostaat. Die metodefoute, o.a. as gevolg van veranderings in die cornea-retina potensiale en ykingsfoute, is ondersoek en stappe is geneem om dié foute so ver moontlik te beperk.

Sewe-en-veertig normale proefpersone is aan 'n kaloriese toets volgens die metode van Fitzgerald en Hallpike onderwerp. Drie-en-twintig van die proefpersone was linkshandig. Van hierdie 47 proefpersone is 10 weer ondersoek volgens die metode van Veits en dié van Kobrak. Waar moontlik is die draaisensasie nagegaan en die volgende eienskappe van die nystagmus is gemeet; latensie, duur, maksimum snelheid van die langsame fase, totale amplitude en totale aantal slae; wanneer 'n sekondêre nystagmusfase opgetree het, is dié geregistreer. Tussen die opeenvolgende spoelings is 'n pouse van 30 minute toegelaat.

Die vergelyking tussen die drie metodes waarvolgens 'n kaloriese toets uitgevoer kan word, het aangetoon dat die Fitzgerald-Hallpikemetode die mees geskikte vir die ondersoek van die ewewigsorgaan is, veral wanneer van nystagmografie gebruik gemaak word.

Alhoewel sommige persone die draaisensasie noukeurig kon waarneem, is hierdie subjektiewe gewaarwording te onnoukeurig vir 'n kwantitatiewe bepaling van die kaloriese reaksie.

Rigtingsvoorkeur van die nystagmus het dikwels by ons proefpersone voorgekom. Die linkshandige en regshandige proefpersone het die nystagmusvoorkeur eweveel vertoon en ook eweveel na links en regs. Die nystagmusvoorkeur is deur die duur, die maksimum snelheid van die langsame fase, die totale amplitude en ook deur die sekondêre fase van die nystagmus vertoon.

'n Sekondêre fase van die nystagmus het dikwels voorgekom. Deur middel van statistiese ontleding kon die verband tussen 'n nystagmusvoorkeur en 'n sekondêre fase van die nystagmus vasgestel word. Daar is aangetoon dat 'n sekondêre fase van die nystagmus gewoonlik aangetref word in persone met 'n nystagmusvoorkeur, dat dit in dieselfde rigting as die nystagmusvoorkeur is en dat dit volg op die klein reaksies in 'n kaloriese toets, bv. in die geval van 'n nystagmusvoorkeur na links, volg 'n sekondêre fase van nystagmus op die koue prikkeling



van die linkeroor en op die warm prikkeling van die regteroor. Jongkees (1953) het die mening uitgespreek dat nystagmusvoorkeur in wese 'n latente spontane nystagmus is. Uit ons eksperimente het dit geblyk dat 'n sekondêre nystagmusfase moontlik 'n tipe uitgelokte nystagmus („provoked nystagmus") is. Aangesien die nystagmusvoorkeur in verband staan met 'n sekondêre nystagmusfase, definieer ons 'n nystagmusvoorkeur as 'n latente spontane nystagmus wat deur die onfisiologiese prikkelings van die kaloriese toets uitgelok word om as 'n sekondêre nystagmusfase te verskyn.

Die waardes wat deur die toepassing van die Fitzgerald-Hallpike metode verkry is, is statisties ontleed onder leiding van Constance van Eeden van die Matematiese Senter te Amsterdam. Die metodes wat vir hierdie analise gebruik is, word in die byvoegsel beskryf. Die volgende resultate is verkry:

1. 'n Opeenvolgende vermindering van die reaksies („response decline") het opgetree ten spyte van 'n tussenpose van 30 minute tussen die spoelings.
2. Geen verskil is gevind tussen die voorkoms van nystagmusvoorkeur na links en nystagmusvoorkeur na regs nie.
3. Die grootte van die kaloriese reaksie by normale persone varieer baie. Daardeur is dit moeilik om die normale spreiding vas te stel. Die standaard deviasie („standard deviation") van die reaksies van ons proefpersone is bepaal en met behulp daarvan is waardes bepaal wat as 'n leidraad kan dien wanneer vasgestel moet word of 'n pasiënt se kaloriese reaksies binne normale perke is.

'n Vergelyking van die waardes wat van ons proefpersone verkry is met dié deur Henriksson (1956), Stahle (1956) en Aschan, Bergstedt & Stahle (1956) verkry, was moontlik, aangesien hulle vergelykbare metodes gebruik het. Oor die algemeen kom ons waardes met hulle waardes ooreen, maar die waardes van ons proefpersone vertoon 'n groter spreiding.

Uit die eksperimente waarin water van verskillende temperature as prikkel gebruik is, blyk dat die duur nie die grootte van die prikkel goed weergee nie. Die maksium snelheid van die langsame fase, die totale amplitude en die totale aantal slae weerspieël die grootte van die prikkel wat gebruik is baie beter. Dit blyk veral uit die eksperimente waarin die uitwendige gehoorgang met oorwas gevul was. In hierdie gevalle het die duur van die reaksies dieselfde gebly, maar die ander eienskappe van die nystagmus het die effek van die oorwas wel aangetoon, terwyl die latensie tweemaal so lank was. Die vergelyking van die Kobrakmetode met die Fitzgerald-Hallpike-metode het aangetoon dat 10 c.c. water (Kobrakmetode) 'n kleiner prikkel is as 250 c.c. (Fitzgerald-Hallpikemetode) van dieselfde temperatuur, terwyl die latensie dieselfde gebly het. 'n Kleiner volume water veroorsaak ook nie 'n nystagmusvoorkeur en 'n tweede nystagmusfase tot dieselfde mate wat 'n groot volume water dit doen nie. Verder is daar gevind dat die latensie afhanklik is van die temperatuur van die water en nie van die volume van die water wat gebruik word nie.

Ons metode van nystagmografie was bevredigend. Hoewel meer tyd in beslag geneem word wanneer nystagmografie in die kaloriese toets toegepas word, kan ons dit aanbeveel vir roetine gebruik, want dit verskaf meer betroubare inligting oor die kaloriese reaksie as wat met die visuele beoordeling van die nystagmus verkry kan word. Die gelyktydige registrasie van die oogbewegings sowel as van die spoed van die oogbewegings (lg. soos deur Henriksson beskryf) op twee aparte kurwes, word aanbeveel, want dit vergemaklik die beoordeling van 'n nystagmogram.

Die Fitzgerald-Hallpikemetode is die mees geskikte metode vir kliniese gebruik, maar die toediening van die prikkel vir slegs 30 sekondes in plaas van 40 sekondes, is voldoende. Dit is noodaaklik om ten minste 30 minute tussen die verskillende spoelings te wag, opdat 'n belangrike vermindering van die reaksies („response decline") voorkom kan word.



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# *APPENDIX*

by

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## 1. *Introduction.*

In this appendix a description will be given of the statistical methods used in Chapter IV. These methods are WILCOXON's two sample test (cf. section 3), WILCOXON's test for symmetry (cf. section 4) and the method of the 2 x 2-table.

## 2. *Testing a hypothesis.*

A test for a hypothesis $H_0$ is based upon a number of observations $x_1, \ldots, x_n$ of one or more random variables [2]) and is executed by means of a *test statistic* **u**, which is a function of the observations. Supposing $H_0$ to be true, the probability distribution of **u** can be calculated.

A set $Z$ of possible outcomes of **u** is chosen in such a way that the probability that **u** assumes a value in $Z$, supposing $H_0$ to be true, is equal to or smaller than a given number $\alpha$ (the so-called *level of significance)*. This set Z is called the *critical region* of the test; the true probability that **u** assumes a value in $Z$ if $H_0$ is true is called the size of Z. The size of Z is not always equal to $\alpha$ owing to the discrete character of the values **u** can take.

The hypothesis $H_0$ is rejected if the value of **u** calculated from the observations, lies in Z. The probability that this will happen if $H_0$ is true is equal to the size of $Z$ and thus smaller than or equal to $\alpha$.

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2) Random variables will be distinguished from numbers (e.g. from the values they take in an experiment) by printing their symbols in bold type.

The result of a test may also be expressed in the so-called *tail probability* $k$; this is the size of the smallest critical region containing the result. Using a level of significane $\alpha$, $H_0$ is rejected if $k \leq \alpha$.

3. *Wilcoxon's two sample test.*

By means of WILCOXON's two sample test (cf. [4] and [5]) the hypothesis $H_0$ may be tested that two samples $x_1, \ldots, x_m$ and $y_1, \ldots, y_n$ are observations of two random variables ($\mathbf{x}$ and $\mathbf{y}$) possessing the same probability distribution.

The statistic $\mathbf{W}$, used for this test, is calculated from the observations as follows. We determine the number of observations in the second sample which are larger than the $i$-th observation $x_i$ of the first sample; let this number be $u_i$. Then we determine the number of observations in the second sample which are equal to $x_i$: let this number be $v_i$ $(i = 1, \ldots, m)$. Then

$$W = 2u_1 + v_1 + \ldots + 2u_m + v_m = \sum_{i=1}^{m} (2u_i + v_i).$$

Tables of the distribution of $\mathbf{W}$ under the hypothesis $H_0$ may be found in [4] for $m$ and $n \leq 10$. For large values of $m$ and $n$ this distribution may be approximated by a normal distribution with mean

$$\mu = mn$$

and variance

$$\sigma^2 = \frac{mn}{3N(N-1)} \left\{ N^3 - (t_1^3 + \ldots + t_h^3) \right\},$$

where $N = m + n$, $h$ is the number of ties in the pooled samples and $t_i$ $(i = 1, \ldots, h)$ is the number of observations in the $i$-th tie. (A tie is a group of equal observations).

If $H_0$ is not true $\mathbf{W}$ will assume large or small values according to $\mathbf{y}$ being systematically larger or smaller than $\mathbf{x}$. Therefore a two-sided critical region consisting of large values of $| W - \mu |$ is used if one wants to test $H_0$ against the alternative hypothesis that $\mathbf{y}$ is systematically larger or smaller than $\mathbf{x}$. If $H_0$ is tested against the alternative hypothesis that $\mathbf{y}$ is systematically larger (resp. smaller) than $\mathbf{x}$ a one-sided critical region is used consisting of large (resp. small) values of $W$.



4. *Wilcoxon's test for symmetry.*

By means of WILCOXON's test for symmetry (cf. [1], [5] and [6], the hypothesis $H_0$ may be tested that the random variables $\mathbf{z}_1, \ldots, \mathbf{z}_m$ are all distributed symmetrically with respect to zero. The test statistic $\mathbf{T}$ of this test is calculated as follows. The observations which are equal to zero are omitted. Now let $x_1, \ldots, x_{n_1}$ denote the positive observations and let $y_1, \ldots, y_{n_2}$ denote the absolute values of the negative observations. Then if $W$ is the test statistic of WILCOXON's two sample test applied to $x_1, \ldots, x_{n_1}$ as the first sample $y_1, \ldots, y_{n_2}$, as the second sample then $T$ is defined by

$$T = W - n_1 n_2 + \tfrac{1}{2}(n+1)(n_1 - n_2),$$

where $n = n_1 + n_2$.

Tables of the distribution of $\mathbf{T}$ under the hypothesis $H_0$ may be found in [1] for $n \leq 20$. For $n > 20$ this distribution may be approximated by a normal distribution with mean

$$\mu = o$$

and variance

$$\sigma_2 = \frac{3n(n+1)^2 + n^3 - (t_1^3 + \ldots + t_h^3)}{12}$$

where $h$ is the number of ties in the non-zero values assumed by $|\mathbf{z}|, \ldots, |\mathbf{z}_m|$ and $t_i$ $(i = 1, \ldots, h)$ is the size of the $i$-th tie.

The two-sided critical region consists of large values of $| T |$; the one sided critical regions consist of large positive (resp. negative) values of $T$.

5. *The method of the $2 \times 2$-table.*

Let $\mathbf{x}$ and $\mathbf{y}$ simultaneously possess a two dimensional probability distribution and let each take two values, say $z_1$ and $z_2$. By means of the method of the 2 x 2-table the hypothesis $H_0$ may be tested that $\mathbf{x}$ and $\mathbf{y}$ are distributed independently.

The observations consist of $N$ independent pairs of observations of **x** and **y**, which may be summarized as follows.

| | | Number of times **x** takes the value $z_1$ | $z_2$ | Total |
|---|---|---|---|---|
| Number of times **y** takes the value | $z_1$ | $a$ | $b$ | $n$ |
| | $z_2$ | $c$ | $d$ | $m$ |
| Total | | $r$ | $s$ | $N$ |

The test statistic of this test is **a**, thus the number of pairs of observations $(z_1, z_1)$ For small values of $N$ the distribution of **a** under the hypothesis $H_0$ may easily be calculated (cf. [2] and [3] p. 96) and for large values of $N$ this distribution may be approximated by a normal distribution with mean

$$\mu = \frac{n\,r}{N}$$

and variance

$$\sigma^2 = \frac{n\,m\,r\,s}{N^2\,(N-1)}.$$

A two-sided critical region consisting of large values $|a - \mu|$ is used if $H_0$ is tested against the alternative hypothesis that **x** and **y** are positively or negatively correlated. If $H_0$ is tested against the alternative that **x** and **y** are positively (or negatively) correlated then a one-sided critical region is used consisting of large (resp. small) values of $a$.

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*STELLINGEN.*

1.

Voor het herstel van de visus bij een afsluiting van de Vena centralis retinae zijn collaterale verbindingen op de papil essentieel.

2.

De recidieven van een rectum carcinoom die ontstaan in het perineale litteken of in de vaginawand na een abdomino-perineale operatie, kunnen curatief behandeld worden.

3.

Collagénome éruptif (Colomb) dient tot de bindweefselnaevi te worden gerekend.

(Dermatologica, *114*, 81, 1957).

4.

Bij een lijder aan bronchus carcinoom dient regelmatig de centrale veneuze druk bepaald te worden.

5.

Het basale membraan is geen betrouwbaar criterium bij de histologische diagnose van goed- of kwaadaardige groei van plaveisel epitheel.

(Zeitschr. f. Krebsforschung, *61*, 240, 1956).

6.

Het gebruik van dionosilolie bij bronchographie is gevaarlijk. (Acta Radiologica, *47*, 177, 1957).

7.

Palliatieve Röntgenbestraling bij inoperabele bronchus carcinoom is van grote waarde bij aanwezigheid van atelectase of een Vena Cava syndroom.

8.

Als bij een clinische ileus een negatief of zwak positief Röntgenologisch beeld aanwezig is, dient rekening gehouden te worden met een totaal gestranguleerde dunne darmlis.

(Acta Radiologica, *25*, 480, 1944).

9.

Voordat een wetenschappelijk onderzoek, waarbij de resultaten statistisch bewerkt moeten worden, uitgevoerd wordt, is overleg met een statisticus noodzakelijk.

10.

Een „internship" van een jaar na het afleggen van het artsexamen moet verplicht gesteld worden.