POSTUROGRAPHY IN THE TILTING ROOM
J.W.P. ROOS

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VRIJE UNIVERSITEIT TE AMSTERDAM

POSTUROGRAPHY IN THE TILTING ROOM

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Promotor : prof. dr. L. Feenstra
Copromotor : dr. W. Bles
Referent : prof. dr. J.M.B.V. de Jong

Voor Marielys

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Abbreviations

ANOVA	-Analysis of Variance
COR	-Cervico-ocular reflex
CNS	-Central Nervous System
CT	-Computer Tomography
CZS	-Centraal Zenuw Stelsel
ENG	-Electronystagmography
HNP	-Hernia Nuclei Pulposi
HOL	-Head tilted towards Left Shoulder
HOR	-Head tilted towards Right Shoulder
MRI	-Magnetic Resonance Imaging
OCR	-Ocular Counterrotation
OH	-Objective Horizontal
OV	-Objective Vertical
RMS	-Root Mean Square
SH	-Subjective Horizontal
SV	-Subjective Vertical
VOR	-Vestibulo-ocular reflex

Contents

Chapter I

THE TILTING ROOM AND SCOPE OF THE STUDY

I.1 Postural control and equilibrium examination

Maintaining posture and balance for a healthy subject is taken for granted even in a diversity of circumstances. Also standing in the upright position is in general not looked upon with great astonishment or admiration. Yet, maintaining the desired upright position or any other desired posture asks for a constant activity of the whole body to cope with the never ending changes in its labile balance. In fact, standing is a dynamic process and it is no surprise, that standing has been defined as 'moving on a fixed spot' [Hellebrandt and Franseen, 1943].

The input for these continuous postural adjustments is an abundant flow of sensory information to the central nervous system (CNS). The information does not only concern the position and movement of the body as a whole with respect to gravity and the environment, but it also concerns parts of the body itself. The main sensors involved are the visual, the vestibular and the somatosensory system. The output responses of the CNS are motor impulses to muscles in various parts of the body: The final result of processing, integrating and weighing of the sensory input.

A malfunctioning of the sensory systems involved may disturb the process of maintaining postural control. A vestibular deficit [Bles et al., 1983], an incorrect visual input [Brandt et al., 1986 a] as well as an impaired proprioceptive system [Nashner, 1970; Mauritz and Dietz, 1980], all have a negative effect on postural stability. Within the CNS, integration of the sensory information takes place especially in the brain stem and in the cerebellum [Parker, 1980; Precht, 1979]. Disorders in these parts of the brain often result in an increased instability due to an incorrect weighing and integrating of the sensory information [Purdon Martin, 1967; Brandt et al., 1986 b; Dichgans and Diener, 1986].

Exposure to extreme, non-physiological conditions may also have serious negative effects on posture and equilibrium maintenance [Haines, 1974; Bles, 1988].

The current examination of patients with complaints about vertigo or disturbances of equilibrium consists mainly of a registration of spontaneous or induced eye movements (nystagmus) by electro-nystagmography. Most of the attention is focused on caloric irrigation and rotating chair examination. Obviously only part of the vestibular system is involved in this examination: It concerns mainly the function of the horizontal semi-circular canals. The function of the superior and posterior semi-circular canals and especially the sacculus and utriculus otoliths are seldom tested and thus not adequately dealt with in the routine examination of the vestibular system. The functioning of the CNS is examined by testing gaze control, optokinetic nystagmus, pursuit movements and suppression of the vestibulo-ocular reflex (VOR) by visual fixation.

In clinical practice caloric irrigation is the most important test to reveal a left/right vestibular imbalance despite the fact that only the horizontal semicircular canals are examined.

Because of the above-mentioned limitations of the current examination of the vestibular system of patients with vertigo complaints or imbalance it is no surprise that no objective findings can be demonstrated, despite the complaints of the patients. The clinician should therefore state no abnormalities can be demonstrated rather than that vestibular function is normal.

Consequently, examination of postural balance may offer valuable additional information about the (mal)functioning of the equilibrium system. Such an examination of posture by means of, for instance, a stabilometer and a tilting room is unfortunately rarely done. This is surprising since a lot of patients do not only complain about dizziness but also about gait disorders or difficulties in maintaining their upright posture. This is most likely due to the fact that these tests require specialised and usually expensive equipment. Furthermore, dynamic tests are often rather time consuming. In the Netherlands, at this very moment, this equipment is available only in the Academic Hospital of the Free University in Amsterdam. In this hospital a stabilometer has routinely been used in the vestibular examination for many years. Also the dynamic examination of selected patients in a tilting room is becoming more and more a standard part of the routine examination.

I.2: History of tilting room examination

In 1973 de Wit [de Wit, 1973] placed a subject in a dark room in front of a dimly illuminated inverted pendulum. Movements of this pendulum influenced upright stance of the subjects. This system was improved by extension to two dimensions, a tilting screen [Bles and de Wit, 1976], and finally to three dimensions, the tilting room [Bles, 1979]. It was demonstrated that upright stance of healthy subjects was only slightly influenced by the tilting visual surrounding despite marked effects of the room movement on their perception of the horizontal [Bles, 1979]. Patients with vestibular abnormalities, however, could easily lose their balance which was in most cases correlated to a different perception of the test condition: They often perceived the tilting room as stable and the stable stabilometer platform as tilting [Bles et al., 1983]. These phenomena were interpreted in terms of otolith-visual interactions. More recent research added the neck in these interactions since it was found that patients suffering from a whiplash trauma also had a declined orientation to the horizontal [de Jong and Bles, 1986].

I.3: Scope of the present study

A standard procedure to examine patients in the tilting room was set up in 1978. The aim of this present study is to evaluate and further review the tilting room examinations of different well-defined patient groups which have been carried out since then, with the purpose to identify systematic idiosyncrasies in postural behaviour.

Furthermore, some basic research has been done with normal subjects in order to obtain more insight in the interaction of the different sensory systems in spatial orientation, especially in relation to the tilting room concept. Finally, certain pragmatic questions have been asked such as the relation between age and postural behaviour and the effect of repeated examinations in the tilting room on posture.

The outline of this study is as follows: Chapter II is concerned with the relevant anatomical and physiological aspects of upright stance. The problems of examining postural control in a clinical context are discussed as well. In chapter III the relevant equipment and measurement methods for this study are discussed. The attention is focussed on the tilting room, the stabilometer and the tilting chair. In chapter IV some pilot experiments will be discussed which are relevant for the interpretation of the results obtained from the main experiments with different patient groups described in the subsequent chapters. Chapter V deals with tilting room examination of healthy subjects, in order to establish a reference according to which the results obtained from the different patient groups can be reviewed and interpreted. In chapter VI postural behaviour in the tilting room of patients with a uni- or bilateral loss of vestibular function is discussed. The tilting room is also used to assess the level of compensation. Chapter VII deals with the postural stability of patients with an acoustic neurinoma when examined in the tilting room. Chapter VIII shows the results of a group of patients who suffer from cervical ataxia due to a whiplash trauma. In the final chapter IX, a proposal for a model is presented which might explain the behaviour of the different patient groups in the tilting room.

Chapter II

UPRIGHT POSTURE AND CLINICAL POSTUROGRAPHY

II.1: Introduction

For optimal postural control an adequate functioning of the vestibular, the visual and the afferent somatosensory system is required. Subsequently, a correct integration and relative weighing of this abundant sensory information by the CNS is necessary. Finally, the assignments of the CNS need to be carried out correctly by the locomotor apparatus. If this entire system works normally, alterations in posture, gait or the environment will be dealt with adequately. During maturation, the process of maintaining upright stance shifts gradually from conscious control to automatism. The regulation mechanism of the adult equilibrium therefore finally has a reflex-like character.

II.1.1: Anatomy and physiology of upright posture

Since for this study especially the connections between the CNS and the involved sense organs are of importance as well as their mutual interactions, the most relevant neuro-anatomy and neuro-physiology of upright stance will be dealt with first in this chapter: For detailed information reference is made to the literature [Handbook of Sensory Physiology, Kornhuber, H.H. (ed), Vol. III, VI and VIII; Atlas of Human Anatomy, Sobotta and Bechner, Vol. III].

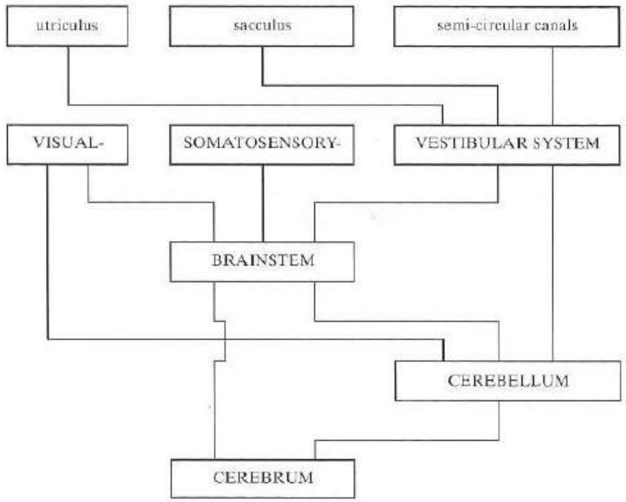


Fig. II.1: Simplified outline of the mutual connections of the different sense organs and the central nervous system.

The vestibular system, composed of the three semi-circular canals, the utriculus otoliths and sacculus otoliths, is located in the inner ears. By means of the cupula-endolymph system of each canal angular accelerations are detected and coded in neuronal impulses. Since the canals are mutually perpendicular, each angular rotation can be detected. The working of the utriculus and sacculus otolith is due to the detection of the shear of the otolith layer on top of the macula as a result of the difference in specific weight of the otoconia layer and the endolymph. This system is mainly involved in the orientation with respect to the gravity vector. Because of the multidirectional sensitivity of each otolith and the fact that they are almost perpendicular to each other, the system allows detection of each linear acceleration. The role of the sacculus in this respect is still unclear.

The primary afferent nerve fibers of the vestibular nerve tracks find their roots in the ganglion cells of the ganglion vestibularis Scarpae, situated in the internal acoustic meatus. These nerve fibers together compose the vestibular nerve, which fibers almost exclusively end in the four homolateral vestibular nuclei located in the brainstem. A minority of these fibers run directly to the lobulus flocculo-nodularis of the cerebellum. The homolateral nuclei are mutually connected to the heterolateral nuclei.

The vestibular nuclei receive their impulses from the vestibular system, the cerebellum, the reticular formation, the longitudinal fascicle and the spinal cord. The longitudinal fascicle connects the vestibular nuclei to the extrapyramidal system and to muscles of the eyes and the neck.

Vegetative symptoms in motion sickness due to vestibular stimulation may be explained because of the connection between the formatio reticularis, which has a connection with the vestibular nuclei and the dorsal vagal nucleus.

The cerebellum is connected to the vestibular nuclei via the cerebello-vestibular tract. This tract is partly transformed in the lateral vestibular nucleus and runs as the vestibulospinal tract to the spine. The vestibulocerebellar tract links the vestibular nuclei and the nodulus and flocculus of the cerebellum. The cerebellum integrates the vestibular impulses with information from visual, oculomotor and somatosensory nerve tracks and coordinates the responses to cope with equilibrium changes. The vestibular nuclei again are influenced by the cerebellum which modifies the reflex-activity of the labyrinth.

Vestibular impulses which are of importance to maintain posture, run via the lateral and medial vestibulo-spinal tracks to the spine. The fibers of the lateral track are ordered topographically and give their impulses to motorneurons. The effect is an excitation or facilitation of the extensor motory system and an inhibition of the flexor motory system. This leads to an activation of the muscles working against gravity. The medial vestibulo-spinal track is part of the medial longitudinal fascicle and cooperates with the lateral vestibulo-spinal track.

Via subcortical pathways the visual input reaches the vestibulocerebellum and the vestibular nuclei, where interaction with the vestibular and somatosensory information takes place. The vestibulo-ocular reflex interacts with the stimulation of the retina.

The somatosensory input gives information about the position of different parts of the body relative to each other by registrating the length and tension of different muscles. This information is of great importance in order to respond adequately to a postural disturbance. The proprioceptive system consists of Golgi tendon bodies, muscle spindles, Pacini bodies, free nerve endings in muscles and connective tissue and receptors in joint capsules. A great number of muscle spindles are located in the neck muscles. In addition, a directional signal may be derived from tactile information and pressure receptors located in the skin.

Finally, the vestibulo-cortical projections, via the thalamus to the heterolateral cerebral cortex, establish the awareness about the postural position relative to the environment. In parallel the cerebral cortex guides the cortical motor responses. The result is an adequate reaction on - and dealing with - alterations in the direction of gravity, body position or other potential equilibrium disturbances.

II.1.2: Plasticity in postural control and clinical evaluation.

The scheme shown in Fig. II.1 indicates the close relation between the sense organs involved and the CNS. If one of the sources of sensory information fails partially or completely, postural control will be affected.

In case of a complete loss of sensory information of one system, it makes a great difference whether the loss was acute or gradual. For instance, an acute vestibular deficit, as in a neuritis vestibularis, has far more impact on posture and gait than the gradual loss of function in case of an acoustic neurinoma. This observation indicates that the plasticity of the CNS eventually deals adequately with alterations in the sensory input. However, plasticity and adaptation of the CNS take their time and are limited, therefore abrupt changes in sensory input cause a postural imbalance. The process of rearranging the available remaining sensory information implies that the relative weight of the remaining input increases as compared to the affected sensory system. During this rearranging period, postural stability is affected in many situations.

Postural examination in the clinic tries to find the cause of a case of postural imbalance. From the above it is clear that the plasticity of the CNS may cover up some deficit, which may lead to a misinterpretation of the test results. Another difficulty is the many systems involved. This hampers a straightforward identification of the deficit occasionally. Only vision can simply be excluded by closing the eyes. The otoliths and the somatosensory system are not to be silenced, being stimulated constantly by the gravity. It is not surprising therefore that the usual test of postural stability is the one with the simple conditions of eyes-open and eyes-closed. This test is known as the Romberg test [Romberg, 1846]. As expected, the body sway is more pronounced when the eyes are closed [Edwards, 1946]. Introduction of the Romberg quotient [Njiokiktjien and van Parijs, 1976] allowed a quantitative evaluation of different patient groups. With some patients indeed a significant increase of postural sway is noticed when the eyes are closed, the specificity of the Romberg being rather low however.

More recently the visual system was stimulated by moving the visual surrounding and the somatosensory system by manipulating the foot support. The idea behind these tests is that the sensory systems are played off against each other allowing insight in the strategies used by the CNS. In most test conditions, motion of the visual surrounding resulted in a sensation of self-motion into the opposite direction together with a postural sway into the direction of the visual motion [among others: Kapteyn and Bles, 1977; Dichgans et al., 1976; Berthoz et al., 1975]. Such a body movement may be understood as a reaction on the visually induced sensation of body motion.

These tests proved useful in clinical testing. Abnormal postural behaviour could be demonstrated in patients with disorders of the vestibular system [de Wit, 1973a] and the somatosensory system [Duchenne, 1958; Kotaka et al., 1986]. Central disorders proved to have a destabilizing effect on posture as well [Dichgans et al., 1976; Purdon Martin, 1967].

II.1.3: Lateral versus fore-aft stimulation

Studying the fore-aft body sway while pitching the foot support and/or the visual surrounding under different sophisticated test conditions is practiced more and more [Nashner et al., 1982; Allum and Keshner, 1986]. Fore-aft body sway is chosen as this movement is less complicated to describe than a lateral sway, even if the body is not seen as a single, but multi-segmented inverted pendulum.

The tilt of the visual surrounding in the tilting room used in our study is in the lateral direction. Although fore-aft stimulation with the tilting room is possible, the symmetry of the lateral sway was found to be more practical to interpret the test results. In addition, the subject's perception of the test situation by simultaneously recording the subjective horizontal by the test subjects is less complicated for lateral

than fore-aft tilt [Bles and de Wit, 1976; Bles et al., 1977; Bles, 1979].

Kapteyn [1973] described a model for the left-right body sway: With a lateral displacement of the body, the trunk remains initially vertical because of the parallelogram formed by the ankle joints and the hip joints (for this reason a lateral shift of the centre of gravity is not expressed in degrees but in millimeters in the following chapters). More lateral displacement causes inclination of the vertebral column as well. Analysis of video recordings of head movements and of stabilometric recordings during tilting room stimulation indicates that for common stimulus patterns the Fourier component of the stabilogram and of the head position at the stimulus frequency were quite similar [Bles and de Wit, 1976] (see also Chapter III.3).

Chapter III:

EQUIPMENT AND METHODS

III.1: Introduction

In this chapter the stabilometer and the tilting room are described, together with the applied data analysis and test procedures. In the last section the tilting chair is described, an apparatus especially constructed for the experiments on perception of the subjective horizontal (SH) and on ocular counterrotation (OCR) with sitting subjects.

III.2: The stabilometer

The stabilometer [Kapteyn, 1973] consists of two plates with a diameter of 50 cm each (see Fig. III.1). A bar of 12 cm length connects the centres of the two plates. A subject standing on the top plate, with his feet in recesses on this plate (position 'five minutes to one'), will exert a certain torque on the plate and the bar, and thus bend the bar, all be it to a minimal extent. This bending of the bar can be recorded with the use of straingauges [Kapteyn and de Wit, 1972]. The maximal bending of the bar is not perceivable for the subject on the stabilometer. The resonance frequency of the system is over 70 Hz. [van Waveren, 1978]. With this system the torques exerted on the stabilometer are resolved in the anterior-posterior and the left-right directions and in the

Fig. III. 1: Picture of the stabilometer.

present study recorded as a function of time: The stabilogram [Kapteyn and de Wit, 1972]. Apart from high frequency components due to muscle activity in the lower limbs, the stabilogram closely resembles the movements of the centre of gravity of the subject's body [Kapteyn, 1973; Bles and de Wit, 1976; Norré and Forrez, 1983]. In the static test conditions the Root Mean Square (RMS) of the stabilograms was computed over the last 50 seconds of each recording of 60 seconds. The RMS is an adequate measure of stability [Kapteyn, 1973].

In certain experiments the stabilometer platform is covered with a layer of foamrubber (height 10 cm, spec. wt. 40 g/dm3). The layer of foamrubber again is covered with a rigid plate which also has recesses in which the subject places his feet [Bles et al., 1980]. Because of the foamrubber, the exteroceptive information of the ankle joints becomes less effective in maintaining postural balance: This becomes even more clear when the eyes are closed.

III.3: The tilting room

The tilting room (manufactured by Toennies, Würzburg) is a closed cabin measuring 2.5 by 2.5 by 2.0 metres (see Fig. III.2). The whole room tilts from the base laterally about a front-back axis with a maximum amplitude of 10 degrees to either side. The axis is at level with the subject's ankles. The room has a hole in the centre of the floor to admit a horizontally fixed stabilometer platform on which the subject stands. Tilting of the room does not affect the position of the stabilometer. The distance from the centre of the stabilometer to the backwall of the room is 1.5 metres. The back wall of the room is accented with vertical lines in a contrasting colour to the rest of the room. The other walls, as well as the floor and the ceiling of the room, are of a homogeneous colour, completely covering the whole visual field including the retinal periphery. This is important, because the retinal periphery plays a major part in spatial orientation [Brandt et al., 1973]. If the subject involved looks away from the back wall of the room, he still only sees a tilting visual surrounding. The tilting room is illuminated by four lamps of 60 Watt each, mounted to the ceiling. These lights can be dimmed, or switched off and the laboratory in which the tilting room is located, can be darkened completely if desired. However, the effect of the tilting room is not dependent on the level of illumination of the room itself [Kapteyn et al., 1976]. In darkness of course, the tilting room looses its effect because the optic stimulation is missing in such a situation.

The tilting room may be driven by different stimulation patterns. Routinely a sinusoidal stimulus is used at frequencies of 0.025, 0.05, 0.1 and 0.2 Hz, resulting in periods of resp. 40, 20, 10 and 5 seconds. The amplitude of these stimuli is 5 degrees to the left and to the right for all the applied frequencies. The duration of the actual examination in the tilting room only takes about six minutes (see Table III.1).

For the analysis the first period at each frequency is neglected in order to avoid transient effects.

The effect of an increasing amplitude of room tilt on the left-right stabilogram has been shown [Bles, 1979]. When the room tilt exceeds 5 degrees, the lateral body sway saturates. For this reason, all the routine examinations with the tilting room are carried out with a maximum of 5 degrees lateral tilt to either side.

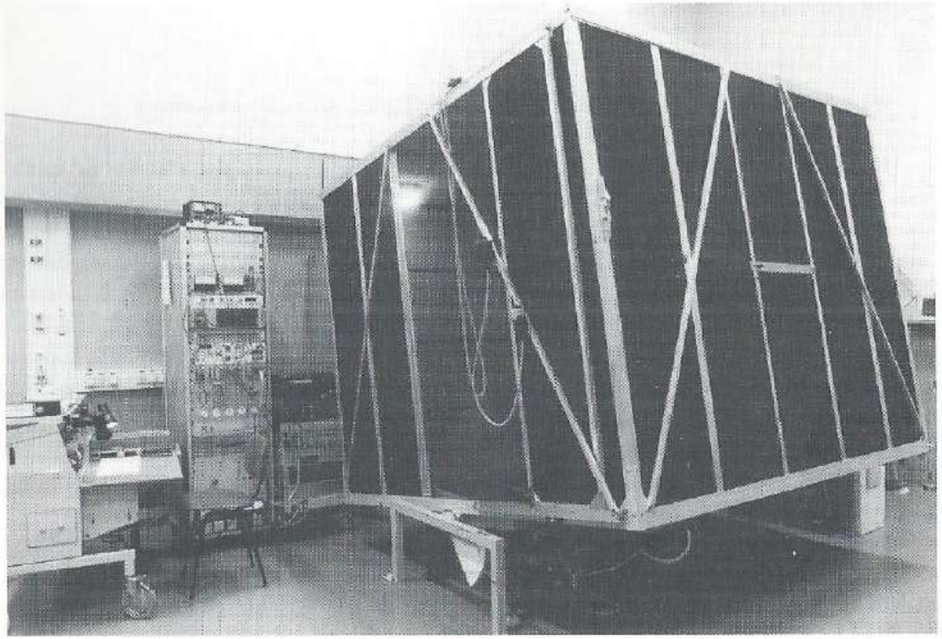


Fig. III. 2: Picture of the tilting room.

Table III.1: Scheme of stimulation of the tilting room.

1	stimulus 0.025	Hz: 4 periods /	160 sec
2	stimulus 0.05	Hz: 6 periods /	120 sec
3	stimulus 0.1	Hz: 6 periods /	60 sec
4	stimulus 0.2	Hz: 6 periods /	30 sec
		total:	370 sec

At eye level on the back wall of the tilting room a by LED's illuminated bar is connected which can be manipulated by the subject with a hand held potentiometer. With this bar the subject indicates his subjective horizontal during lateral room tilt. During the experiment, the subject stands on the stabilometer platform facing the back wall of the room. His feet are placed in recesses in the stabilometer platform. These recesses ensure that the feet are always in the same - "five minutes to one" - position, not only during the ongoing examination, but also during the examinations which follow thereafter.

III.3.1: Quantification of postural control and perceptual consequences

If in darkness a horizontal luminous line is projected into a tilted luminous frame, this horizontal line is no longer perceived as horizontal, but as tilted into the opposite direction as the tilt of the frame. This phenomenon is known as the 'rod and frame effect' [Witkin and Asch, 1948; Gupta, 1973; Ebenholtz, 1977a, 1977b] and is due to 'visual directional induction' [Bisschof, 1974]. When a horizontal line is perceived as tilted in the above described situation, it is obvious that the subjective horizontal (SH) is tilted into the direction of the frame tilt: Bisschof suggests that the tilt angle of the SH with respect to the real horizontal (which is perpendicular to the gravity vector) depends on the weighing of the otolith signal and the visual signal. When the tilting room is tilted it is a massive 'frame' and it is therefore no surprise that the SH estimates during static room tilt are found to be inclined into the same direction as the room tilt [Bles, 1979].

In the dynamic situation of the tilting room, the weighing of the otolithic and visual information should take place as well, but is then dependent on the dynamic characteristics of the room tilt. For the sake of argument the two extreme options, a pure otolithic (1) and a pure visual (2) option, will be discussed:

Option 1: According to the otolithic information, there is no change in the direction of the gravitational vector during room tilt, so the room should be perceived as tilting and no adjustment of posture is needed.

Option 2: According to the visual information, the tilting room represents the vertical and should therefore be perceived as stable. Postural adjustments are required to align the body with the vertical structures of the room.

Therefore the amplitude of the induced left-right body sway is one of the parameters of interest, because it reveals which is dominant: The otoliths or vision. It is analyzed by calculating the Fourier component at the stimulus frequency, taking into account the weight of the subject [Bles, 1979].

In most present experiments with healthy controls, foamrubber is used on top of the stabilometer to enhance the postural sway: Some postural instability is required to demonstrate an effect of training. The foamrubber diminishes the exteroceptive information of the ankle joints. This increases the sensory weight of the visual information for postural control. However, the visual surrounding in the tilting room is manipulated in conflict with the otolith information which affects postural balance as demonstrated in section IV.2. Of course, in addition, the left-right body sway, the antero-posterior sway increases also. Increased postural imbalance allows us to demonstrate improvement of postural stability, for instance after repeated exposure. Two experiments will be described, one with short (hours) and one with long (weeks and a year) test intervals.

Since during the movements of the room the subjects attempt to adjust the bar at the back wall to the real horizontal, analysis of that signal should reveal the weighing of the visual and otolithic information in their perception of the horizontal. It turns out, however, that only well-trained subjects can perform this task [Bles and van Raaij, 1988]. Normal controls and patients have extreme difficulties in making reliable estimates. After these findings, the recordings of the bar were no longer analyzed. This task, however, remained part of the test since it focussed the attention of the subjects on the backwall of the room. Instead of analyzing the bar estimates the subjects were invited to give their opinion about the fixed and moving parts of the test situation. Earlier studies of Bles and co-workers with the tilting room showed the two above mentioned options, sometimes in combination with different sensorial weights. To our surprise, occasionally neither room tilt nor platform tilt were reported.

For reasons of simplicity in the following chapters the percepts in the normal tilting room examination will be classified into four categories. The classifications were obtained by verbal reports of the subjects during the examination.

1. the room is perceived as moving (r+) and the platform as stable (p-),
2. the platform is perceived as moving (p+) and the room as stable (r-),
3. both platform and room are perceived as moving (r+,p+),
4. both platform and room are perceived as stable (r-,p-).

III.3.2: Subjective horizontal estimation

It is conceivable that one of the causes of a visual dominance is a disturbed perception of the SH in the absence of vision, for instance as in case of acute labyrinthine disorders [Bles et al., 1984]. In order to get more insight into the behaviour in the tilting room and possible deviations of the SH from the true horizontal, each tilting room examination was followed by a test in which the SH was determined in the dark. The subjects were then sitting on a chair at a 2m distance from the bar at the back wall, with their eyes on a level with the bar. Six estimates of the SH were obtained, alternatingly with an initial left or right tilt of the bar. In between the measurements the subjects had to close their eyes. The SH values presented in the following chapters are the means of these six estimates. In the chapter on cervical ataxia this test was extended by examining the SH of these patients also when their heads were tilted towards the left and right shoulder.

III.4: The tilting chair

With the tilting chair independent adjustments of lateral head or body tilt are possible up to 15 degrees to either side in steps of 5 degrees. The tilt of both the trunk and the head is about the subject's x-axis through the neck (see Fig. III.3). It is possible to adjust the height of the seat to bring the level of the neck to the same level as the tilt axis. The head of the subject is firmly fixed in an adjustable head rest. If necessary, the trunk of the subject is backed by inserting pieces of foam rubber between the subject and the arm rests. This keeps the trunk straight in position, even during tilt. The chair is firmly fixed to the floor of the tilting room at such a position that the subject faces the bar at the backwall of the room at a distance of 1.25 m. Since the chair is fixed to the tilting room, tilt of the room also causes a tilt of the chair. By proper manipulation of room tilt, chair tilt, head tilt and the lights in the room, it is possible to play off the otolithic, the visual and the neckproprioceptive system against each other. This combination of tilting chair and tilting room allows for insight in the weight contributed by the different sensory systems in the determination of the SH.

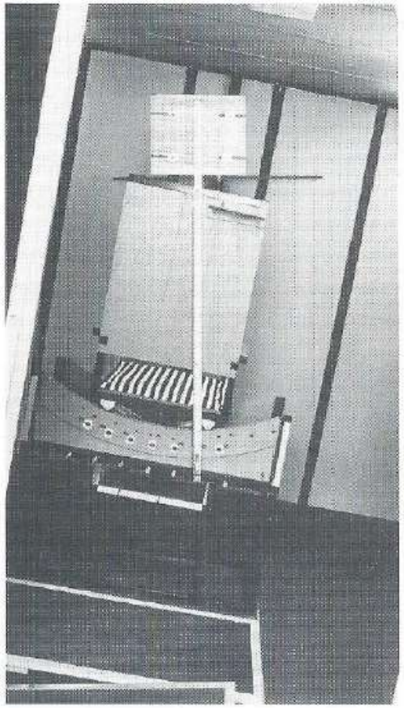


Fig. III. 3: Experimental set-up of the tilting chair placed in the tilting room.

The experimenter adjusts the tilt of the trunk and the headrest manually, and the tilting room by means of a potentiometer: The tested subject indicates his SH by positioning the bar at the back wall by a hand-held potentiometer. The settings have an accuracy of 0.1 degree.

A directly related phenomenon of interest in this context is the ocular counter-rotation (OCR). This is measured with the goggle system developed by Vogel [Vogel, 1986]. For the present experiments this system has been slightly modified: One eye is covered by the actual measuring device, the other eye is free to look into the tilting room. The measuring device concerned a dimly illuminated rotatable line: A bright flash behind the line projected the line on the retina resulting in an after-image.

The OCR measurements require for the subject to first sit in upright position in the dark. Then an after-image is produced, after which the subject is brought into the test position. Adjustment of the line to the after-image by the subject by rotating the measuring device finally admits the experimenter to note the amount of rotation which corresponds to the OCR.

Chapter IV

PILOT EXPERIMENTS ON TRAINING AND SENSORY INTERACTIONS IN THE TILTING ROOM

IV.1 : Introduction

In the studies with the tilting room, Bles and co-workers always used a sinusoidal stimulus pattern. One may ask if such a stimulus is a correct one. It may be possible to anticipate on a single sinusoid, which may have its consequences on the resulting body sway. One could argue that as one cannot anticipate on a complex stimulus pattern, such a stimulus would result in a larger body sway.

Another question is whether repeated examinations with sinusoidal or complex stimulation would reduce the body sway amplitude. This is also of importance in a clinical context: If improvement of posture is demonstrated on repeated examinations, interpretation of the test results in terms of a better response of the patient is perhaps incorrect. These two questions on complex or sinusoidal stimulation and on the aspects of repeated exposure in the tilting room will be discussed in sections IV.2 and IV.3.

In section IV.4 some experiments will be described concerning the tilting chair in combination with the tilting room. This allows for study of the interactions of the visual, vestibular and cervical systems in the perception of the horizontal, which is of particular interest for the interpretation of the findings in the subsequent chapters.

IV.2 : Repeated examination with complex and sinusoidal stimuli

Sinusoidal stimulation of the tilting room often shows a considerable postural destabilisation in patients. At re-examination an evident improvement can sometimes be seen. May be such an improvement is due to training or adaptation instead of treatment. The question arises whether the same would have been found with a non-sinusoidal, non-predictable stimulation of the tilting room. In order to answer this question, 12 healthy subjects have repeatidly been examined with a complex stimulus of the tilting room.

IV.2.1: Methods

The complex stimuli are composed of sinusoidal patterns of different frequencies and amplitudes in such a way that the frequency characteristics of the resulting stimuli are compatible with the conventional stimulation of the tilting room (< 0.2 Hz). Three different stimuli have been composed by adding different sinusoids conform table IV. 1.

For comparison of the results between complex stimulation and those of sinusoidal stimulation, the maximum amplitude of the room tilt for all complex stimuli was kept at

7 degrees, whereas the sinusoidal room tilt was kept at the conventional 5 degrees to either side.

Fig. IV.1 shows the complex stimuli 1, 2 and 3. The resulting room movement with complex stimulation is in case of complex stimulus 1 more or less a sinusoidal tilt, i.e. very much alike the normal room stimulation. With complex stimulus 2, the room is tilted to the left or right for a longer period of time without much variation. Complex stimulus 3 causes a highly irregular movement of the room with both slow and fast components.

Table IV. 1: Complex stimuli of the tilting room

stimulus 1:	freq.(Hz)	relative ampl.
	0.0085	1
	0.08	10
	0.15	8
	0.2	4
stimulus 2:	freq.(Hz)	relative ampl.
	0.008	1
	0.02	6
	0.04	9
	0.01	5
	0.18	4
	0.2	4
stimulus 3:	freq.(Hz)	relative ampl.
	0.0085	1
	0.06	8
	0.09	8
	0.2	4

Twelve healthy subjects, with a mean age of 29, participated. They were subjected to four tests: A control measurement without room stimulation, followed by two tests of sinusoidal room stimulation at 0.025 and 0.2 Hz. and finally a test with one of the complex stimuli (Table IV. 2). These tests were repeated 3 times at 15 minutes' intervals, with the modification of the subjects standing on a layer of foamrubber covering the stabilometer. The complex stimuli were balanced as much as possible over these three tests.

The left-right body sway, induced by the lateral varying tilt of the room, is registered and the subjects were also asked to indicate their perceptions of the test situation in the tilting room.

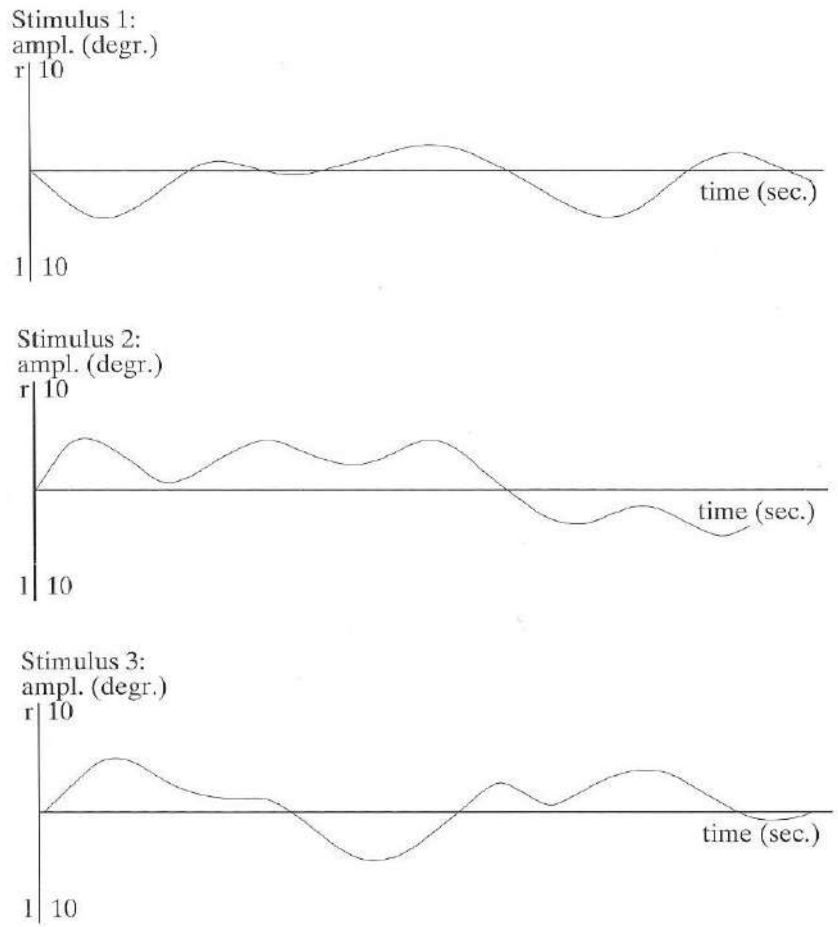


Fig. IV.1: Complex stimuli of the tilting room composed conform Table IV. 1.

Table IV. 2: Testcycle composed of both sinusoidal and complex stimulation of the tilting room.

Testcycle:	time (sec.)
A- control measurement (no room stimulation)	15
B- 0.025 Hz. sinusoidal room stimulation	120
C- 0.2 Hz. sinusoidal room stimulation	25
D- complex room stimulation with 1, 2 or 3	120
	total: 280

IV.2.2: Results and discussion

For this particular test the left-right body sway of the subjects is expressed in RMS-values (arbitrary units) and the mean RMS values are presented in Table IV.3. The result of test 1 is the situation without room stimulation and therefore comparable with the stabilometry condition 'eyes-open'.

Table IV. 3: RMS-values of the left-right body sway at repeated examination with different stimuli of the tilting room.

	Control:	Stim. 0.025 Hz:	Stim. 0.2 Hz:
test	1: 9 RMS	1: 12 RMS	1: 11 RMS
	2: 11	2: 102	2: 82
	3: 15	3: 69	3: 52
	4: 14	4: 66	4: 3
	Complex 1:	**Complex 2:**	**Complex 3:**
test	1: 9 RMS	1: 9 RMS	1: 9 RMS
	2: 65	2: 68	2: 131
	3: 27	3: 50	3: 94
	4: 24	4: 41	4: 61

Apparently there is little effect of foamrubber in the control condition. This is different for the sinusoidal and complex stimulation patterns: An increase of the RMS value is seen, indicating postural destabilization. Also an obvious stabilization with tests 3 and 4 is noticed, indicating a learning effect in coping with the destabilizing effect of the foamrubber. The effect of repeated examinations on the left-right body sway for the different stimuli is clear when looking at the relative stability for each part of the testcycle. If the second test result, i.e. the first examination with foamrubber on the stabilometer, is taken as 100%, the differences in the subsequent examinations are evident (see Fig.IV.2). The rate of improvement appears to be equal for both sinusoidal and complex stimuli.

The subjects' perception of the test situation was one of room tilt and a stable platform (r+,p-). Occasionally a combination of platform and room tilt in opposite direction was felt (r+,p+). No control ever perceived a tilting stabilometer platform without room tilt (p+,r-) or no movement at all (p-,r-). Table IV.4 gives the percentage of subjects perceiving stabilometer tilt in combination with room movement. It is interesting that the addition of foamrubber, increasing the instability, runs parallel to an increase in the perception of a tilting platform. However, this changes with tests 3 and 4 in favour of the perception of only room tilt. Apparently, the sensation of platform movement is accompanied with a larger body sway.

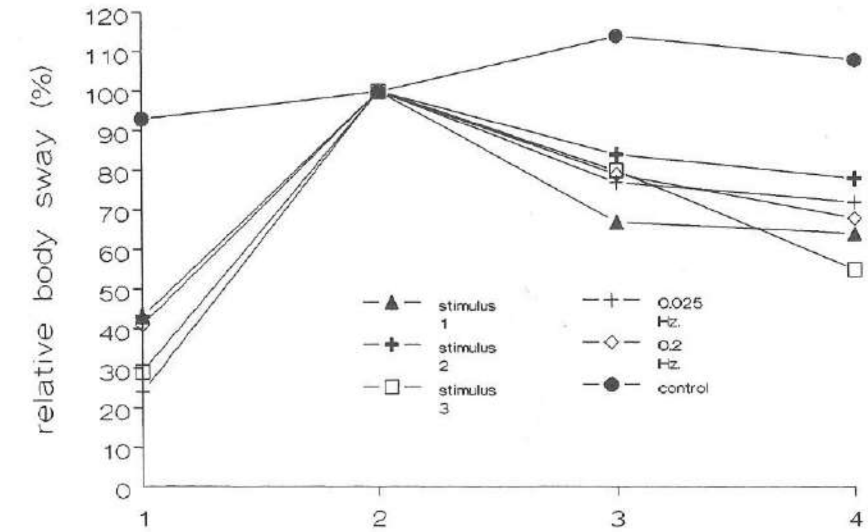


Fig. IV. 2: Relative stability of the controls (%) at different stimuli with tests 1 - 4; the result of test 2 is set at 100%.

Table IV.4: Perception of combined room and stabilometer movement, (r+,p+) (N=12).

		0.025 Hz	0.2 Hz	complex 1-3
test 1	no foam	33.3 %	33.3 %	25.0 %
2	with foam	50.0	33.3	50.0
3	with foam	33.3	16.6	41.6
4	with foam	8.3	16.6	8.3

Summarizing at this point, repeated examinations with sinusoidal tilt of the room and complex stimulation both result in the same decrease in body sway. For different complex stimuli the effect of repeated examinations on postural stability was of the same order.

IV.3 : Effect of test intervals on postural stability

The effect of repeated examinations in the tilting room on the left-right body sway is important in order to assess correctly the effect of therapy. If improvement is found at repeated examinations in the tilting room, this might be due to an effect of therapy or of repeated examinations itself, i.e. training.

In section IV.2 postural stability was improved at test intervals of 15 minutes. Brandt and co-workers also demonstrated an effect of training on postural imbalance: Postural stability improved when subjects trained to stand on a layer of foamrubber [Brandt et al., 1981; Brandt et al., 1986]. However, after a period of approximately 40 days, the stability obtained through training had disappeared almost completely. Bles observed training effects with astronauts of the German D1 Spacelab Mission after repeated exposure to the tilting room when standing on foamrubber [Bles, 1988]. This same effect was found with intertrial intervals almost as large as those used by Brandt to show the end of the retention period. Apparently, different mechanisms are involved in these two tests. These contradicting results let us to pay attention to the effects of repeated examinations. Regarding the results of the study of Brandt and co-workers and the astronaut findings, the time interval between tests is of great influence.

IV.3.1: A test interval of hours

Four healthy subjects were submitted to the conventional sinusoidal tilting room stimulation with an amplitude of 5 degrees to either side and at four stimulus frequencies (0.025, 0.05, 0.1 and 0.2 Hz) with foamrubber on the stabilometer. They were tested five times within six hours. Fig. IV.3 shows the results of repeated examinations at these short time intervals.

The layer of foamrubber on the stabilometer clearly causes an increased initial left-right body sway, most outspoken at low frequencies of room stimulation: An Analysis of Variance (ANOVA) confirms a main effect for the stimulus frequencies ($p < 5\%$). More interestingly, the ANOVA revealed that the measurements taken at different times not all produce the same effect ($p < 5\%$). A post-hoc Newman-Keuls analysis showed that the results at t= 0 hours were significantly different from those at t= 4 and t= 6 hours. At the fourth re-examination, after six hours, the average body sway of the controls was reduced to values slightly higher than the median body sway in the condition without foamrubber on the stabilometer (see chapter V).

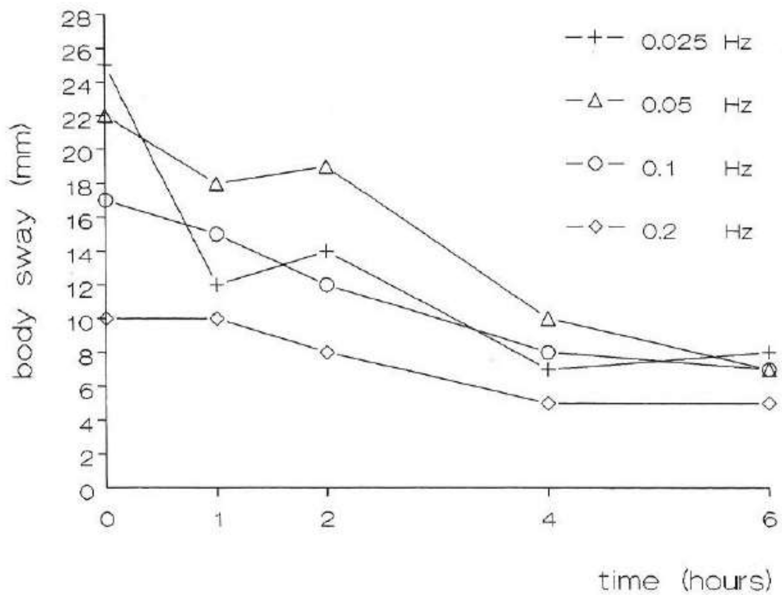


Fig. IV. 3: Mean left-right body sway (mm) of 4 healthy controls with a layer of foamrubber on the stabilometer at repeated examinations.

The subjects had a correct perception of the test situation in the tilting room at every examination. They always perceived room tilt, sometimes with platform tilt. Never exclusively only platform tilt or no movement at all was felt.

Repeated examinations has its greatest effect on the low frequencies of room stimulation. This is in line with the finding of Brandt and co-workers who also found the largest effects of training in cases of large initial instability.

IV.3.2: A test interval of hours with drugs

The data of section IV.3.1 were the placebo data obtained from a preliminary double blind study on the effects of anti-vertiginous drugs in the tilting room. It is generally felt that anti-vertiginous drugs in patients with acute dizziness relieve the vertigo and nausea problems, but hamper recovery. As these drugs might also have an effect on postural stability and training in the tilting room, an anti-vertiginous drug was given in one dose at t=0 hours. Re-examination followed with the same intervals as in section IV.3.1. The results of this experiment are given in Fig. IV.4.

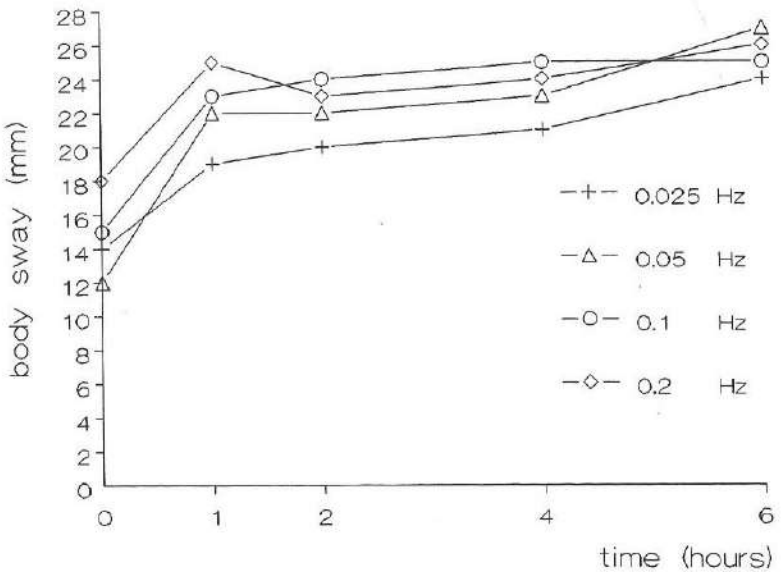


Fig. IV.4 : Mean left-right body sway (in mm) of 4 subjects after taking of an anti-vertigo drug in one dose at time t=0 hours.

Fig. IV.4 shows that the taking of drugs causes no improvement at repeated examinations. On the contrary, the left-right body sway increases. Apparently, the CNS does not know how to cope with the new situation and relies completely on the visual information instead.

The findings of this experiment are in accordance with the hampering effect of anti-vertiginous drugs on recovery after a sudden loss of vestibular function, although of course the drugs relieve dizziness and nausea.

IV.3.3: Test intervals of weeks and of one year

Ten subjects were examined in the tilting room standing on a layer of foamrubber (see section III.2) with the conventional stimulation (see section IV.3.1) at t = 0, 3, 6, 58 and 61 (weeks). This means time intervals of three weeks and of one year. The results of this experiment are given in Fig. IV.5.

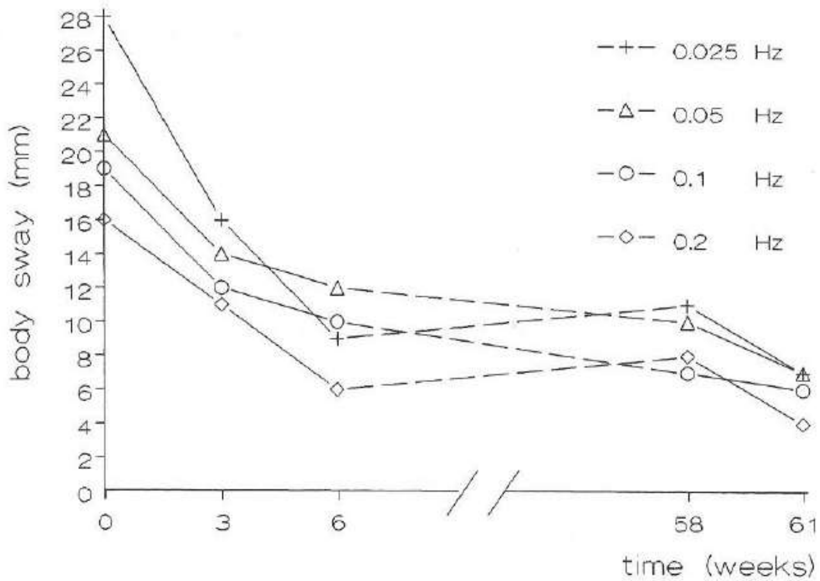


Fig. IV.5: Mean left-right body sway (mm) of 10 healthy controls standing on a layer of foamrubber on the stabilometer at repeated examinations.

An ANOVA on these data revealed highly significant main effects for time ($p< 0.01$), stimulus frequencies ($p< 0.01$) and subjects ($p< 0.01$). Of particular interest in the present context is, that post-hoc Newman Keuls analysis showed a stability at t=0, different from all other test conditions, a stability at t=3 weeks also different from the stability at t=6, 58 and 61 weeks. On the other hand no difference was found between t=6, 58 and 61. The outcome demonstrates a lasting effect of postural improvement at repeated examinations, even after a test interval of one year. Again, the tilting room is perceived correctly as tilting by all subjects. None of them mentioned exclusively platform tilt or no movement at all. More subjects indicating exclusively room tilt without any platform movement were found at later examinations. In fact, this also suggests that a correct perception of the test situation, i.e. a tilting room and a stable platform, reduces postural sway.

The rate of postural improvement in the experiments of section IV.3.1 and in this section, are almost similar. This suggests that the retention has a definite character.

IV.3.4: Conclusions

The conclusion drawn from the series of experiments is that repeated examinations in the tilting room at intervals of up to one year imply a training effect which should be taken into account.

This process of training or adaptation can be hampered by drugs as demonstrated in section IV.3.2. Bles and de Jong (1986) observed that patients without labyrinthine functions, examined four times, at intervals of one year, persisted in their large body sway at high frequencies of room stimulation, even without standing on foamrubber. These patients always perceived the room as stationary and the platform as moving (p+,r-). It is possible that an incorrect perception prohibits the effects of training. After all, when the subject (the CNS) is convinced that the situation is correctly perceived, he has no reason to change his postural performance in the tilting room and therefore his postural balance will not improve. This accords with the observation in the previous sections that the more the perception is correct, the better the postural stability.

For clinical practice this implies that, if at re-examination in the tilting room postural instability remains on the same level level as the first examination, something must hamper adaptation to take place, even if re-examination is done after one year.

IV.4: The subjective horizontal and ocular counterrotation

IV.4.1 : Introduction

Visual information plays an important part in spatial orientation. The effect of a tilted visual frame on the subjective horizontal (SH) is strong by means of directional induction [Bisschof, 1974]. Normally the horizontal and vertical structures in the visual surrounding correspond to the objective horizontal (OH) and vertical (OV= gravity) respectively. If this holds true, then the SH is precisely in line with the OH, independent of the subject's body tilt.

In the absence of visual clues (i.e. in darkness), the SH depends on the head- or body tilt of a person. Depending on the degree of tilt, both over- and underestimation of the body tilt can take place. With a lateral tilt up to about 20°, subjects intend to overestimate the body tilt, with the result that their SH settings are tilted to the contralateral side. This is known as the Müller- or E-phenomenon [Müller, 1916]. With a body tilt exceeding 20°, subjects mostly underestimate the tilt, which means that their SH settings show an ipsilateral tilt from the OH: This is known as the Aubert- or A-phenomenon [Aubert, 1861; see also Howard, 1982]. It has been argued that these phenomena originate from the utriculus [Schöne, 1968], but the same phenomena were observed in patients with a complete bilateral loss of vestibular function [Krejcova et al., 1971; de Graaf, 1990]. Bles and co-workers found substitution of other somatosensory information for the missing vestibular input as a possible explanation for these phenomena.

It is obvious that a subject with a SH that deviates strongly from the OH cannot rely on that information for his postural control: It is more appropriate for him to use the visual information which is generally adequately available. In the tilting room, however, the visual information is instable: The subject therefore follows the tilt of the room with his body. A relation between the SH and the induced body sway in the tilting room is therefore expected. This is one of the reasons that the SH examination is incorporated in the tilting room examination.

In literature the effect of body tilt on the SH is mostly examined for a body tilt up to 180 degr. in steps of 30 degr. Further experiments regarding the SH for small tilt angles (like in the tilting room) are therefore of interest.

Another point of interest with respect to the perception of the test situation in the tilting room is the so-called ocular counterrotation (OCR). The OCR is known as a rotation of the eyes in their orbits around the visual axis in the opposite direction of the head or body tilt [Schöne, 1962; Miller et al., 1968]. The OCR is maximally ± 10% of the original head or body tilt. The utriculus is seen as the source of the static OCR since the OCR remains stable in time [Diamond and Markham, 1983; Miller et al., 1968]. The OCR can also be elicited by stimulation of the afferent neck proprioceptors or by tilt of the visual surrounding [Fisher, 1927; Wade, 1968; Schöne and Udo de Haes, 1968, 1969]. If the tilting room were to induce a prominent OCR, this OCR might have its consequences for the perception of the SH and consequently for the perception of the test situation.

The interactions of the sensory systems involved in the generation of the SH and OCR were therefore investigated. Two different groups of healthy controls participated. One group of 16 persons, aged 20-25, underwent SH measurements, another group of 12 subjects, aged 22-36, OCR measurements.

IV.4.2 : Experimental design and methods

A combination of the tilting room and the tilting chair makes it possible to examine the visual, neckproprioceptive (neck) and otolithic contribution to the SH and the OCR, apart from or in combination with each other (see section III.4 for technical details). Eight test conditions have been selected conform Table IV.5. It should be noted that stimulation of otoliths and neck is always present of course: Stimulation in the present context means a deviation of the head relative to the gravity vector for the otoliths, and for the neck a tilt of the head with respect to the trunk.

In condition 1 the room, chair and head holder are in the normal (upright) position and the room is darkened. In this condition are no visual, no neck and no otolithic inputs. Condition 1 therefore serves as a reference.

In condition 2 the trunk of the subject is laterally tilted over 10 degr. with the head upright. Again the room is darkened. This situation results in stimulation of the neck alone. So a SH or an OCR found in this condition should be of cervical origin.

Condition 3 is a stimulation of only the otolith system because here the chair as a whole is tilted 10 degr. laterally in the dark room. The altered direction, relative to the gravity vector should result in a vestibulary induced SH and OCR.

In condition 4 the trunk is in the upright position with the head tilted 10 degr. laterally and again the room is dark. Now both the otoliths and the neck proprioceptors will have their effect on the SH and OCR.

In condition 5 the light is switched on in the tilted room. The body and the head are in upright position. This should result in a visually induced SH and OCR.

In condition 6 the room is tilted over 10 degr. with the lights on and with an identical trunk tilt. The head, however, is in the upright position. Now both vision and the neck will contribute to the SH and the OCR.

Condition 7 is similar to condition 3 but for the lights, which in this case are switched on. Therefore both vision and otoliths contribute to the SH and OCR in this condition .

In condition 8 the situation is comparable to condition 4 but with the room lights on. Now all the involved sensory systems will contribute to the SH and OCR.

Table IV.5: Diagram of the 8 conditions for measurement of the SH and OCR. [-] means no stimulation and [+] means stimulation of that particular sensory system. Stimulation means an angle of 10 degr with respect to the normal situation.

vision -				vision +			
otol. -		otol. +		otol.-		otol. +	
neck-	neck+	neck-	neck+	neck-	neck+	neck-	neck+
1	2	3	4	5	6	7	8

The subject was asked to indicate when his afterimage faded and if necessary a new afterimage had to be created in the upright position (condition 1). For each subject the sequence of the conditions was balanced according to a latin square design [Wagenaar, 1969] in order to avoid unwanted sequential effects. During the experiment it occasionally proved to be necessary to interrupt the test sequence with several subjects to create a new afterimage. Sometimes the afterimage already faded after a couple of seconds, and two controls could not be used in this experiment because it proved to be impossible to create an afterimage. None of the subjects was able to hold his first afterimage for the duration of the whole experiment, although it lasted no more than 10 minutes. Increasing the intensity of the light flash appeared to be impossible in this particular version of the goggle system.

IV.4.3 : Results

Of the SH and OCR measurements both the mean and median values have been calculated for the mean values including the standard deviation and for the median values the range between the 10th and 90th' percentile (see Table IV.6). Where necessary, the data have been normalized for a 10 degr. head tilt because this tilt correlated with the tilt of the bar on the backwall of the room instead with the OCR. The SH and OCR settings obtained from the situations where an outcome to the left was expected were manipulated in order to treat the data as one group.

Table IV.6: For left and right tilt normalized data of the Subjective Horizontal (upper part, N=16) and Ocular Counter Rotation (lower part, N=12) for conditions 1-8 (+ means tilt to the right, - tilt to the left, both in degrees)

cond.	mean	±	1 SD:	median,	10p	to	90p	(range)
SH:								
1	-0.1	±	0.88	-0.1	-0.8	to	0.6	(1.4)
2	0.2	±	1.74	-0.2	-1.6	to	2.6	(4.2)
3	1.1	±	2.54	1.1	-2.1	to	5.7	(7.8)
4	1.3	±	2.12	0.8	-1.2	to	4.0	(5.2)
5	9.9	±	0.63	10.0	8.9	to	10.8	(1.9)
6	9.8	±	0.75	9.9	8.5	to	10.7	(2.2)
7	0.4	±	0.35	0.5	-0.1	to	0.9	(1.0)
8	0.2	±	0.40	0.3	-0.4	to	0.9	(1.3)
OCR:								
1	-0.4	±	0.84	-0.3	-1.3	to	0.3	(1.6)
2	0.8	±	3.45	1.5	-2.3	to	4.1	(6.4)
3	4.6	±	3.08	5.0	1.1	to	7.9	(6.8)
4	4.8	±	2.55	4.9	2.6	to	7.5	(4.9)
5	4.0	±	4.89	5.6	2.7	to	9.1	(6.4)
6	4.5	±	3.09	4.8	0.3	to	7.7	(7.4)
7	3.3	±	3.09	2.6	1.5	to	7.8	(6.3)
8	5.4	±	3.18	5.2	1.5	to	9.7	(8.2)

In condition 1 the SH is conform the OH (see Table IV.7). The subjects have an accuracy of less than one degree. Apparently the absence of visual clues doesn't hamper the settings. The OCR measurements reveal the accuracy of the measuring method: The OCR data are quite similar to the SH data indeed, indicating a sufficient accuracy.

The data obtained in condition 2 show that the afferent neck proprioceptors have no systematic effect on either the SH or OCR. The median and mean values hardly show any deviation from the reference level, whereas only the standard deviation and the 10-90th percentile range increase.

In condition 3 the vestibular influence on the SH is seen. The tilt seems to be slightly overestimated (E-phenomenon) but the estimated SH is not significantly different from the OH. The OCR in this situation is different from the reference level ($p<0.01$) which must be due to the otoliths.

The data obtained in condition 4 show that there is no significant additional effect of the neck on the OCR or the SH in comparison to condition 3.

In condition 5 the SH almost completely matches the lateral tilt of the visual surrounding. The conflicting vestibular information is apparently not taken into account. The OCR data show that indeed there is a visually induced OCR ($p<0.01$).

In condition 6 the data show no additional influence of the cervical input on the visually induced SH and OCR.

In condition 7 is seen that combined visual and otolithic stimulations do not lead to a larger OCR (cf. condition 3 and 5), whereas the SH of course is still perceived correctly.

Finally, in condition 8 the OCR due to stimulation of all sensory systems involved is not different from stimulation without the neck proprioceptors. Moreover, stimulation of vision or the otoliths alone would result in a similar OCR. As might be expected, the SH settings are very close to the OH. The large interindividual variability of especially the OCR is noteworthy (see Table IV.6).

IV.4.4 : Discussion

From these results it may be deduced that there is a systematic OCR due to stimulation of the visual system. This visually induced OCR is much larger than the OCR found by de Graaf [1990]. It is not clear what causes the difference but it could be due to the measuring method: With Vogel's goggle system the afterimage is presented on one eye, whereas the rotating line is in front of the other eye. De Graaf presented the afterimage on two eyes and his subjects just looked into the tilted room with two eyes. It is not clear why this should result in a different value, but otherwise the test conditions were identical.

There was no systematic OCR due to stimulation of the neck proprioceptors. A puzzling finding is that it apparently doesn't matter how many systems are involved: The OCR does not increase when more systems are involved.

Since the goggle system was no longer available the exact relation between SH and OCR could not be investigated. Replication of the de Graaf method and the Vogel method with the same subjects was therefore not possible.

Another interesting finding of de Graaf was that patients with a bilateral loss of vestibular function had OCR values of the same magnitude as the OCR of the controls [de Graaf, 1990]. De Graaf found similar OCR values for head tilt and for whole body tilt: He assumed that this OCR was due to neck stimulation (in case of head tilt) or to somatosensory stimulation, of the trunk on the tilted chair (in case of whole body tilt). If this explanation was true, the somatosensory system should be taken into account in the design of Table IV.5. It is noteworthy that in that case, in condition 2 for instance, a somatosensory induced OCR would counteract a cervically induced OCR, so the fact that no OCR was found in that condition would not necessarily mean that there was no cervically induced OCR, since the somatosensory and cervically induced OCR are supposed to be of the same magnitude. The same holds true for comparison of conditions 3 and 4: With head tilt the neck adds to the otolithic OCR, whereas with whole body tilt the somatosensory system adds to the otolithic OCR. It is very difficult to separate the two systems, perhaps that in under water conditions the somatosensory contribution and the true cervically induced OCR can be established.

IV.4.5 : Conclusion

In conclusion, all systems contribute to the SH and, if de Graaf is correct, also to the OCR. It means that in patients an abnormal SH (in the dark) could be due to the malfunctioning of both the otolith system and the neck, or other proprioceptive cues. It may therefore be helpful to understand the behaviour of the patients in the tilting room if information on the SH and the OCR is also available. The methods for the SH measurement are available but the techniques for OCR measurements are rather awkward at the moment and only applicable in static conditions. If video oculography becomes available, it will be possible to measure the OCR in dynamic conditions as well.

IV.5 : Summary and conclusions

Before one is able to assess the effect of any kind of treatment by means of repeating the initial examination, it is first of all necessary to establish the effect that repeating the examination has by itself. The first section in this chapter argues an effect of repeated examinations, resulting in an increased postural stability. This training could only be demonstrated after the initial left-right body sway had been enlarged to give room for adaptation. The enlarged body sway was obtained by placing a layer of foamrubber on the stabilometer platform which caused the afferent propriocepsis of the lower limbs, especially of the anklejoints, to become less effective. At repeated examinations in this condition, a healthy control will show a clear effect of a diminishing lateral sway. In contrast with the findings of Brandt and co-workers, the obtained improvement of posture is lasting, even if the repeated examination takes place at a time interval of up to one year [Brandt et al., 1986; Roos et al., 1988]. It appears that adaptation c.q. improvement only occurs if the perception of the test situation in the tilting room is correct. This means that the person involved must eventually notice a room tilt in combination with platform tilt. On the other hand, if the perception of the testcondition is not correct, the person involved will not notice any room movement. The absence of this perception indicates that this person does not realise that he actually is making a mistake and therefore will find no reason to change his behaviour in the tilting room. This is in line with the findings in patients with a bilateral loss of vestibular function [Bles and de Jong, 1986].

The same effects of training are also seen when the stimulation of the tilting room is not sinusoidal but complex with unpredictable room movements.

The results from the repeated examinations after the use of an anti-vertigo drug show the effect of an altered sensory input on upright posture in the tilting room. The same effect was seen at re-examination of the astronauts of the D-1 space lab mission after return to earth. The absence of gravity during their flight increased the relative weight of the visual information at the expense of the vestibular input. For patients a longer period of bedrest has a comparable negative effect on upright posture due to the change in sensory information [Haines, 1974]. The increase in postural imbalance could not be explained by atrophy of the muscles of especially the lower limbs.

The essence in the tilting room experiment turns out to be the perception of the test situation. The results of the SH and OCR measurements in the condition with a tilt of the visual surrounding (condition 5) do not explain the incorrect perception of the test situation in the tilting room.

At this moment it may be concluded that improvement of posture in the tilting room is possible if the initial body sway is large enough, and the perception is correct. In that case, effects of training should be taken into account if the tilting room examination is repeated. This postural improvement is even visible if re-examination takes place after a considerable period of time. It is interesting that the same effects are found with a complex stimulation of the tilting room. These findings allow the use of four sinusoidal stimulations of the tilting room at the earlier mentioned frequencies. In the next chapter the effect of the tilting room on healthy subjects will be demonstrated and the results will be used as reference for the results of the patients' examinations.

Chapter V

THE TILTING ROOM AND HEALTHY SUBJECTS

V.1: The control group

In order to establish the effect of a tilting visual surrounding on postural stability, 67 healthy subjects aged between 17-62, with a median of 32 years, were examined in the tilting room. Out of this group, 51 subjects were also examined on the stabilometer in the conditions 'eyes-open' and 'eyes-closed', both with the head held in the upright position. Examination on the stabilometer was added to the test in order to record the influence of congruent visual information on postural stability (Romberg test) [Romberg, 1846]. None of these subjects had a history of dizziness. The results of a part of this group have already been published in other studies [Bles et al., 1983; de Vries et al., 1985]. In order to establish the effect of age in the tilting room, the control group was enlarged with elderly people up to 62 years of age .

V.1.1: Procedure of the tilting room examination

After the subject has been informed in detail about the tilting visual surrounding and about the fact that the platform on which he is standing is fixed, the actual examination in the tilting room is carried out. The two extremest possible options of the perception of the test situation are also mentioned: The subject may perceive a dynamic visual surrounding with a stable stabilometer platform or a stable visual surrounding in combination with a tilting stabilometer platform. Other possibilities such as 'no movement at all' or tilt of both the room and the stabilometer are explained as well.

While standing on the stabilometer in the tilting room with his feet in the recesses, the subject is asked to stand relaxed and to avoid unnecessary movements. First the effect of the visual information on posture is tested in two conditions: Head-upright/eyes-open and head-upright/eyes-closed. During this test the examinator stands behind the patient to prevent him from falling over.

The examination continues with the dynamic part of the test. The subject takes the potentiometer in his hand which enables him to adjust the illuminated bar on the backwall of the room to his subjective horizontal during active room tilt. Again, the examinator stands behind the subject. The tilting room is used at four frequencies of 0.025, 0.05, 0.1 and 0.2 Hz. of which the amplitudes are 5 degrees to either side. The test always starts at the lowest frequency. At each frequency, the patient is asked about his perception of the actual situation. The final part of the examination consists of measuring the SH with the head in the upright position according to the method described in chapter III.3.2. The whole examination (posturography, dynamic tilting and measurement of the subjective horizontal) takes no more than 20 minutes per patient.

V.1.2: Subjective horizontal

The SH measurements, according to the procedure described previously, of the subjects (N=46) with their head in the upright position show a mean value of 0.2 degr. tilted to the left with a standard deviation of 1.1 degr.. The results of the SH measurements are depicted in Fig. V.1. It is interesting to notice that the subjects estimate their SH with a consistency of less than one degree at repeated examinations.

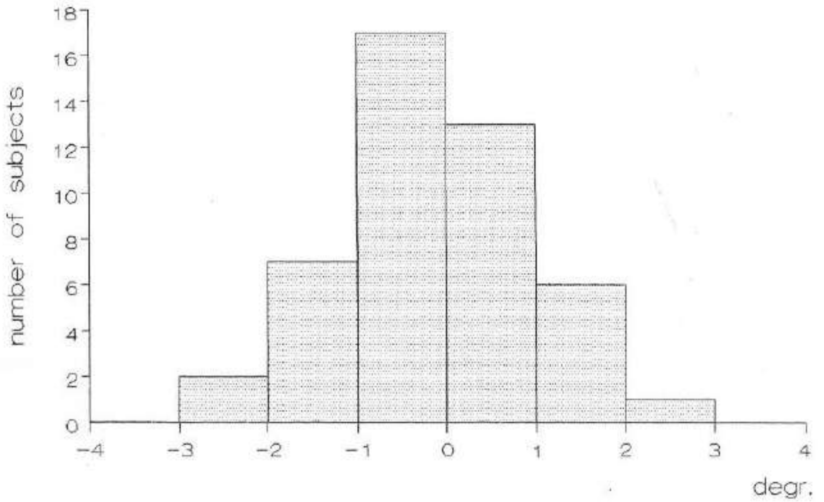


Fig. V.1: Subjective horizontal of 46 subjects with the head in the upright position. Mean = -0.2 degr., SD = 1.1

The subjective vertical (SV) and to a lesser extent the SH have been the subject of many studies [Witkin and Asch, 1948; Schöne and de Haes, 1968; Lechner-Steinleiter et al., 1979]. Several different test conditions were incorporated. The present study in general concerns the integration of the visual-, otolith- and to a lesser extent the somatosensory information. All these sensory systems proved to have an effect on the SH or OCR. A deviation of the SH, for instance, may be related to a dysfunction of the otolith system. In the conflicting situation of the tilting room, a dysfunction of the otolith system will lead to a relative dominance of the visual information and therefore to an increased left-right body sway. A point of interest is whether this statement holds true and if, in case of an intact otolith system (and thus a correct SH), the postural sway is not affected in the tilting room.

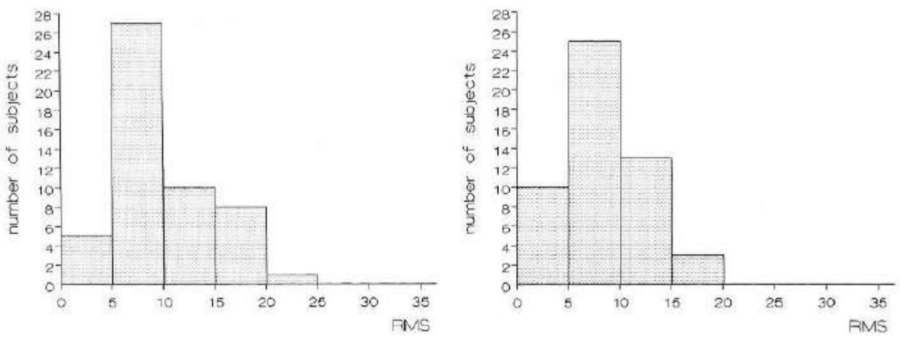
Therefore one could draw the conclusion that a healthy subject is capable of indicating his SH very precisely and consistently even in the absence of visual information. The otolith information must be responsible for this accurate setting of the SH. If in the tilting room these controls rely on their otolith information and SH, instead of on their visual input, the left-right body sway will hardly be influenced by the movements of the tilting room. In view of the results of the SH measurements, a deviation of the SH exceeding the range of the mean value of 0.3 degr. +/- two times the standard deviation (2.2 degr.) is looked upon as abnormal.

V.1.3: Stabilometry

Postural stability of 51 subjects was tested on the stabilometer in two conditions: Eyes open and eyes closed, both for a period of 60 seconds. Again the earlier described procedure was followed. The postural sway was determined in two directions: Left-right and antero-posterior. Of the last 50 seconds of these stabilograms the root mean square (RMS) values were calculated [Kapteyn and Bles, 1976]. From these RMS values the Romberg quotient was determined: RMS (eyes-closed) / RMS (eyes-open) [Njiokiktjien and Van Parijs, 1976]. This quotient indicates the stabilizing effect of adequate visual information on postural stability. This effect of vision will be more pronounced if the otolith information is incorrect or even absent. Since the SH was indicated correctly by most of the controls, it is to be expected that closing of the eyes will only have a small destabilizing effect on posture.

The median values of the antero-posterior and left-right body sway in the eyes-open condition are 9.4 and 9.0 RMS with 90th percentiles of 17.2 and 14.9 respectively (see Fig. V.2). For the eyes-closed condition the median values are 11.8 and 10.1 RMS with 90th percentiles of 20.9 and 16.0 (see Fig. V.3). The Romberg quotient proved to be 1.26 and 1.12 for the antero-posterior and left-right body sway respectively.

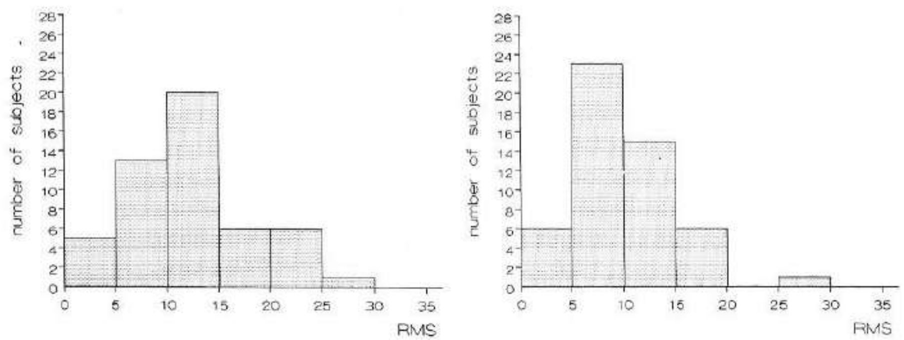
Closing the eyes in healthy controls leads to an increased postural sway in both lateral and antero-posterior directions. The effect is more pronounced in the antero-posterior direction because of the mechanical limitations of both the ankle and hip joints. None of the controls, however, needed support to prevent them from falling over in the eyes-closed condition. Without visual information, a healthy subject is apparently able to maintain his upright posture at an adequate level without much difficulty (see Fig. V.3).



Antero-posterior body sway
median RMS = 9.4

Left-right body sway
median RMS = 9.0

Fig. V.2: Stabilometry results of 51 healthy subjects. Condition eyes-open.
RMS = Root Mean Square: measure of stability.



Antero-posterior body sway
median RMS = 11.8

Left-right body sway
median RMS = 10.1

Fig. V.3: Stabilometry results of 51 healthy subjects. Condition eyes-closed.
RMS = Root Mean Square: Measure of stability.

V.1.4: Dynamic tilting room examination

The subjects were tested in the tilting room according to the method described previously (V.1.1). Four frequencies of room stimulation were used: 0.025, 0.05, 0.1 and 0.2 Hz. Because of the outcome of the SH and stabilometry examinations, a limited effect of the tilting room on the left-right body sway of the controls is to be expected.

Median values of the left-right body sway proved to be 6.8, 5.7, 4.3 and 3.2 mm respectively with 90th percentiles of 16.0, 15.3, 14.1 and 9.8 mm at increasing frequencies (see Fig. V.4 - 7). During this part of the examination, none of the subjects lost his balance completely, nor did they need any support to prevent them from falling.

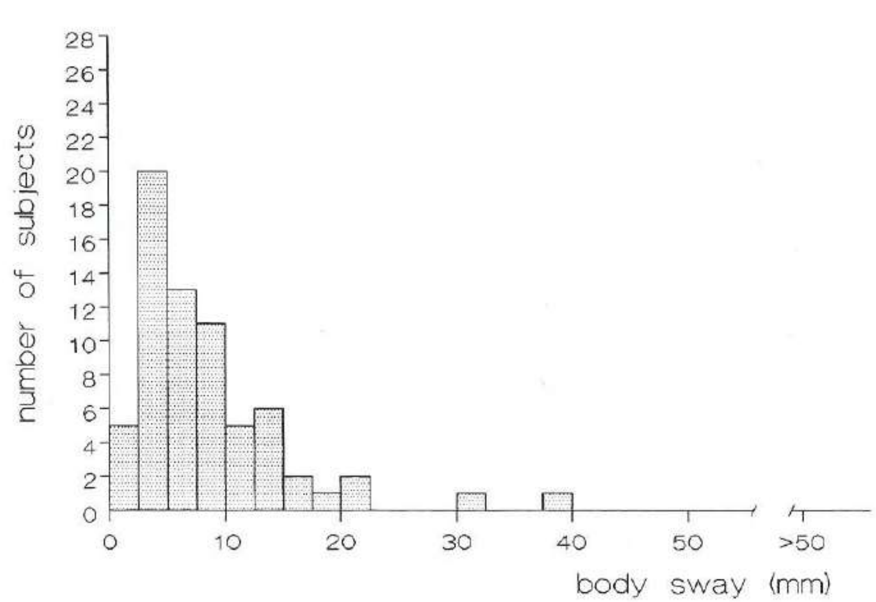


Fig. V.4: Amplitude of left-right body sway (mm) in a healthy control group. N = 67.
Stimulus frequency of the tilting room is 0.025 Hz.
Median = 6.8 mm., 90th percentile = 16.0 mm.

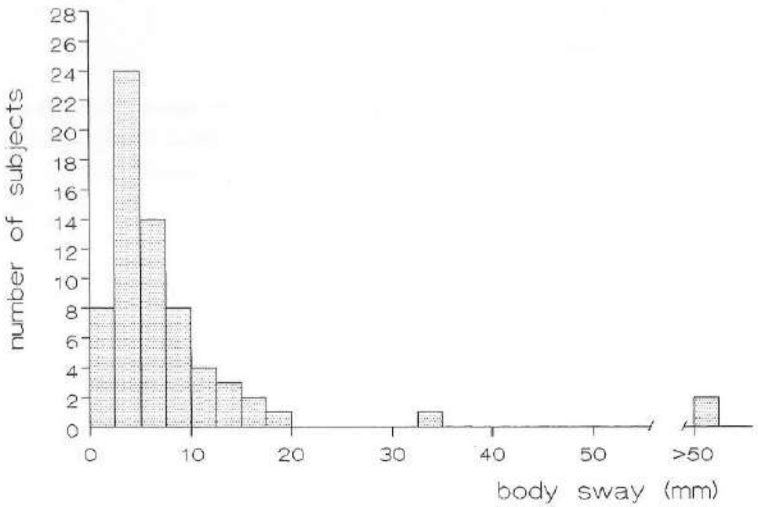


Fig. V.5: Amplitude of left-right body sway (mm) in a healthy control group. N = 67. Stimulus frequency of the tilting room is 0.05 Hz. Median = 5.7 mm., 90th percentile = 15.3 mm.

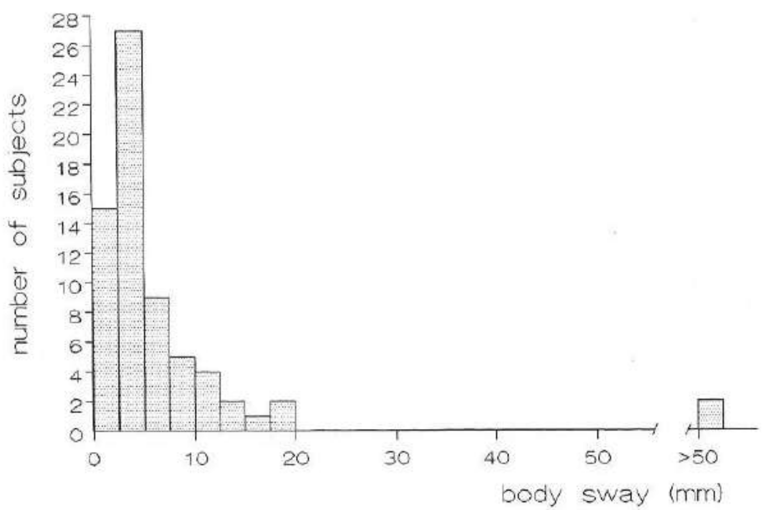


Fig. V.6: Amplitude of left-right body sway (mm) in a healthy control group. N = 67. Stimulus frequency of the tilting room is 0.1 Hz. Median = 4.3 mm., 90th percentile = 14.1 mm.

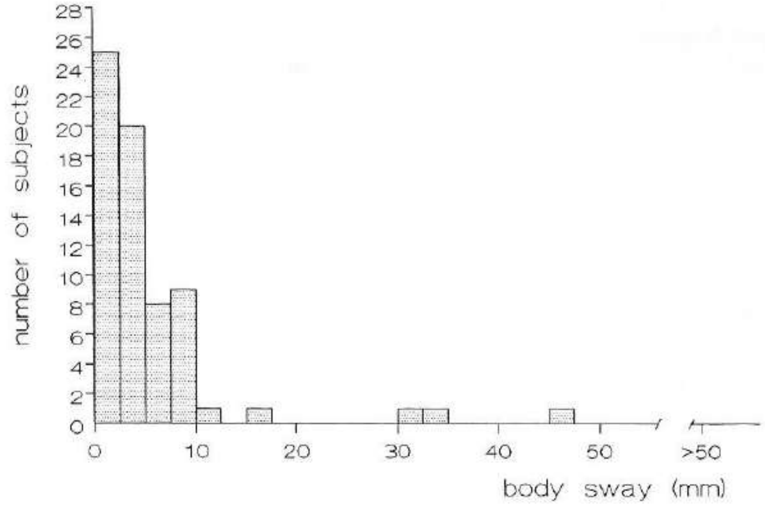


Fig. V.7: Amplitude of left-right body sway (mm) in a healthy control group. N = 67. Stimulus frequency of the tilting room is 0.2 Hz. Median = 3.2 mm., 90th percentile = 9.8 mm.

Table V. 1: Perception of the test situation in the tilting room in a healthy control group (%).

Freq. Hz.	-	P	B	R
0.025	0	4.5	16.5	79
0.05	0	1.5	21	77.5
0.1	0	0	15	85
0.2	0	0	18	82

- = no movement at all
P = platform tilt
B = room and platform tilt
R = room tilt

The left-right stability of healthy subjects is hardly influenced by the laterally varying tilt of the visual surrounding in the tilting room. This effect diminishes even more at the higher frequencies of room tilt. In line with this finding is the increasing number of subjects with a correct perception of the test situation (see Table V. 1). At 0.025 Hz. only 3 subjects indicated platform tilt without room tilt. At the highest frequency of 0.2 Hz., none of the subjects reported pure platform tilt. The median value of the left-right body sway at 0.025 Hz. of the subjects reporting only platform tilt is 14.0 mm. Subjects indicating both room and platform tilt have a median sway of 9.0 mm, whereas the body tilt of those perceiving only room tilt is not more than 6.0 mm.

At the highest frequency of 0.2 Hz., the median body sway of the subjects reporting both room and platform tilt is 6.5 mm. The subjects indicating only room tilt have a median sway of 3.0 mm. It appears that a correct perception of the test situation in the tilting room is accompanied by a smaller left-right body sway.

V.2 : Summary and conclusions

A healthy subject finds no difficulty in maintaining his upright posture, as recorded on the stabilometer, with or without visual information. The only effect after closing of the eyes is a slight increase in postural sway, resulting in a Romberg quotient of no more than 1.26 for the antero-posterior body sway. Influences on the left-right stabilogram are even fewer (Romberg quotient is 1.11). Furthermore, none of the subjects lost his balance completely after closing the eyes.

If a healthy subject is asked to adjust an illuminated bar according to his subjective horizontal in a dark room, he will do so with only a small deviation as compared to the objective horizontal (mean = -0.2 degr., SD = 1.1 degr.) and with a small range of up to one degree at repeated examination. This implies that the absence of visual information hardly affects the results of this task.

So far it may be concluded that a healthy subject is able to maintain his upright posture without much difficulty, even if in certain conditions the visual information is lacking. The absence of the visual input is easily replaced in the CNS by relying on the vestibular and somatosensory information. The situation in the tilting room, however, is different. As a result of the laterally varying tilt of the visual surrounding, the visual information is not simply absent, as it is after closing of the eyes, but it is in conflict with the otolith information. But even in this situation upright posture of a healthy subject is hardly affected: The median lateral body sway at 0.2 Hz. is 3.2 mm only. Moreover, it appears that the body sway is related to a correct perception of the test situation in the tilting room. In this control group, at the lowest frequency of room tilt, 3 subjects indicate platform tilt only without room tilt and 11 subjects both room and platform tilt. Fifty-three subjects indicate only room tilt. At the higher frequencies, the number of subjects indicating room tilt increases whereas the number indicating platform tilt or both room and platform tilt decreases. None of the subjects ever indicated no movement at all. The improvement of perception is accompanied by a decreasing left-right body sway at increasing frequencies of room tilt.

Therefore it may be concluded that a healthy subject, in case of a sensory conflict between the visual and otolith information, increases the relative weight of the otolith input at the cost of the visual input. This strategy leads to the perception of a tilting visual surrounding in combination with a stable stabilometer platform. As a result, the

left-right postural sway is hardly affected. None of the subjects lost his balance completely although some of them exhibited a large body sway on the stabilogram at the different frequencies and, in accordance, indicated not only room tilt but both room and platform tilt or platform tilt only.

The findings in this chapter show that in healthy subjects, the left-right body sway is not seriously influenced by the tilting room. On the other hand, if a subject has been exposed to micro-gravity, held his bed for a longer period or took a drug because of vertigo problems, his left-right body sway will increase when examined in the tilting room. One way or the other, all these conditions give rise to a change in the sensory information. The use of the tilting room clearly indicates the shift in the relative weight of the sensory information in case of a conflict between the otolith and the visual information. If indeed the relative weight of the vestibular information increases, the strategy must be different when the otolith information is absent as in a vestibular deficit. If this is true, upright posture of patients with a vestibular deficit should be affected by the varying lateral tilt of the visual surrounding in the tilting room and therefore they should exhibit a large visually induced left-right body sway. The influences of a bilateral and unilateral vestibular deficit on behaviour in the tilting room will be discussed in the next chapter.

Chapter VI

TILTING ROOM EXAMINATION AND VESTIBULAR PATHOLOGY

VI.1: Introduction

An acute disorder or deficit in vestibular function leads to a serious disturbance of posture and gait even in several daily-life situations. Maintaining upright posture is impossible or at least very difficult during the first few days following the loss of vestibular function. The general condition of the patient does not allow an adequate equilibrium examination for some days because of severe dizziness and nausea complaints [Barany, 1906; Katsarkas and Outerbridge, 1981]. After a couple of days, the diagnosis of a uni- or bilateral vestibular deficit is easily confirmed with the aid of electro-nystagmography and the use of a rotating chair or with caloric irrigation of the horizontal semi-circular canals [Oosterveld, 1972; Jongkees, 1974]. The vestibular deficits of the patients in this study were diagnosed accordingly. If, with electro-nystagmography, a bilateral loss of vestibular function has been confirmed, repeating this procedure for follow-up in case of a persistent vestibular loss is of little value. It may only give information about any spontaneous recovery of vestibular function. With this method, it is not possible to establish the level of compensation in case of a persisting bilateral loss of vestibular function. Only a gradually diminishing spontaneous nystagmus or improvement of the vestibular-ocular reflex (VOR) in case of a unilateral vestibular deficit, has a predictable value regarding the process of central compensation.

Vestibulo-spinal reflexes are only rarely registered in the evaluation of peripheral vestibular disorders, even though they may reflect the actual level of equilibrium very well. Although at a certain stage a spontaneous nystagmus is absent, many patients - even with a unilateral vestibular deficit - keep complaining about posture and gait disorders for a longer period than generally is expected [Baloh and Honrubia, 1979]. Therefore, it is likely that the process of compensation has not yet completed. This observation makes it interesting to look for other methods to establish the level of compensation after a sudden uni- or bilateral loss of vestibular function.

Since for patients and clinicians alike, it is important to know whether the process of compensation has already been completed, many tests have been described to evaluate this process. Especially gait deviation, as a result of a unilateral vestibular loss of function, is the subject of interest in many stepping tests [Babinski and Weill, 1913; Unterberger, 1938; Peitersen, 1974; Fukuda, 1983; Bles et al., 1984]. In this study the tilting room [Bles et al., 1983; Bles and de Jong, 1986] in combination with stabilometry [Kapteyn and de Wit, 1972] and the subjective horizontal (SH) [McCabe et al., 1972; Fisch, 1973] will be used to establish the process of compensation after a sudden uni- or bilateral loss of vestibular function.

In principle, two different compensating mechanisms may be employed by the CNS to cope with a sudden loss of vestibular function [Schaefer and Meyer, 1974; Courjon and Jeannerod, 1979; Igarashi, 1986]. First, redressing of an imbalance between the left and right vestibular apparatus, and secondly, substitution of the impaired vestibular function with somatosensory and visual information. It is evident that in case of a bilateral loss of vestibular function only the second compensation mechanism is of relevance whereas in case of a unilateral loss both compensation mechanisms can be employed by the CNS.

The previous chapter showed the strategy of normal subjects. When examined in the tilting room they rely primarily on their vestibular and somatosensory information and, to a certain extent, deny the conflicting visual information. As a result of this strategy the tilting room hardly affects the left-right postural sway of healthy subjects [de Wit, 1973a; Bles and de Wit, 1976].

Because of the findings mentioned above, it is of interest to study the effect of the tilting room on those persons who have been deprived of their vestibular function. The vestibular dysfunction in this patient group is in most cases due to an infectious disease, a congenital abnormality, an ototoxic drug, a post-operative complication or the result of a trauma.

The absence of vestibular information demands a new strategy of the CNS to cope with the situation in the tilting room. It is also of interest to learn whether the compensation process can be assessed with the use of the tilting room, and whether the two compensation mechanisms mentioned above can be demonstrated.

A distinction should be made between an acute loss of vestibular function, as for instance due to meningitis, and a gradual loss, as in a slowly growing cerebellar pontine angle tumour. In case of the latter, it is likely that compensating activity must and will try to keep pace with the advancing gradual loss of the vestibular function. It is in line with this remark that complaints of hearing loss and tinnitus, rather than posture and gait disorders are heard from those patients who still are in the not-advanced stages of the disease.

The results of the two patient groups with a uni- or bilateral loss of vestibular function will be discussed separately in this chapter. Both patient groups have been examined in the tilting room according to the procedure described in chapter III. Surprisingly, also patients with an onset of their vestibular deficit of up to several years ago were examined because of persisting equilibrium disorders. This is in contrast to the general opinion that compensation, especially in young healthy people with a unilateral vestibular deficit, will be completed after a few weeks [Baloh and Honrubia, 1979].

VI.2: Results of tilting room examination in patients with a complete bilateral loss of vestibular function

Subjects of interest in this study are the SH, stabilometric results in the conditions 'eyes-open' and 'eyes-closed' and dynamic examinations in the tilting room. Parameters studied in the dynamic tilting room examination are the visually induced left-right body sway and the patient's perception of the test situation. Moreover, these parameters will be studied as a function of time, following the onset of the disease. Of relevance is also the effect of repeated examinations on these two parameters after a certain period of time [Roos et al., 1988]. Twenty-five patients with a bilateral loss of vestibular function have been examined.

VI.2.1: Subjective horizontal

In our examinations, the SH findings revealed a difference between 22 patients with a complete vestibular deficit and a healthy control group. The data of 3 patients were incomplete for further analysis. The SH of healthy subjects in the upright condition showed a mean value of 0.2 degr. tilted to the left with a standard deviation of 1.1 degr.. The subjects indicated their SH at repeated examinations with a consistency of less than one degree.

Patients with a bilateral vestibular deficit showed a mean value of their SH well in range within the subjective horizontal of the healthy control group: 0.25 degr. tilted to the left. The standard deviation, however, was larger than in the control group and proved to be 2.65 degr. (see Fig. VI.1).

A difference is not always found between the subjective vertical or horizontal of patients with a bilateral loss of vestibular function and healthy controls [Clark and Graybiel, 1963].

On the average the SH of the patients is in line with the findings of the control group although the standard deviation is larger in the patient group. In clear contrast, however, is the small range of less than 1 degr. at repeated examinations in the control group as compared to the much wider range of up to 12 degr. in the patient group. At least part of the disturbances in posture and gait are related to the deviation of the SH, and especially to the inconsistency of the SH in this group of patients at re-examination. The incorrect perception of the objective horizontal is another reason to shift sensory weight in favour of vision [Friedman, 1970].

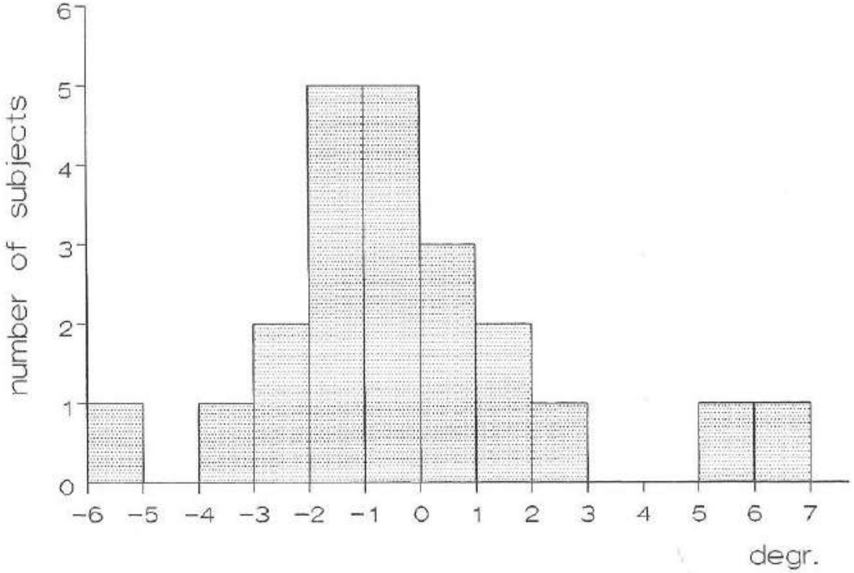
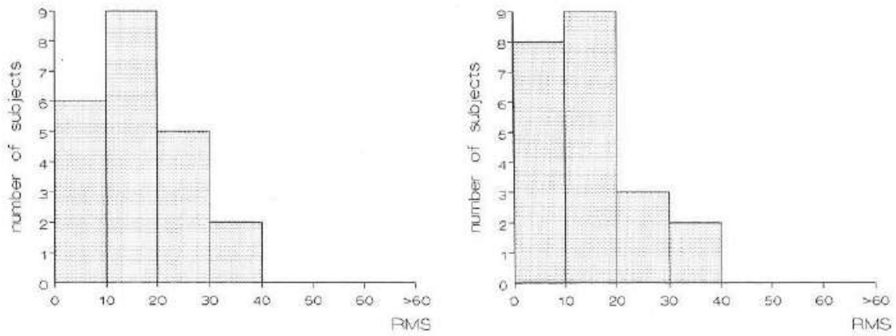


Fig. VI.1: Subjective horizontal of 22 patients with a complete loss of vestibular function. Mean = -0.25 degr., SD = 2.65

VI.2.2: Stabilometry

The stabilometric results of the control group showed median RMS values [Kapteyn and Bles, 1976] of the antero-posterior and left-right body sway in the condition eyes-open of 9.4 and 9.0 with 90th percentiles of 17.2 and 14.9 respectively. For the condition eyes-closed, the median RMS values proved to be 11.8 and 10.1 with 90th percentiles of 20.9 and 16.0 for the two directions of body sway. The Romberg quotient in the control group was 1.26 for the antero-posterior and 1.12 for the left-right body sway.

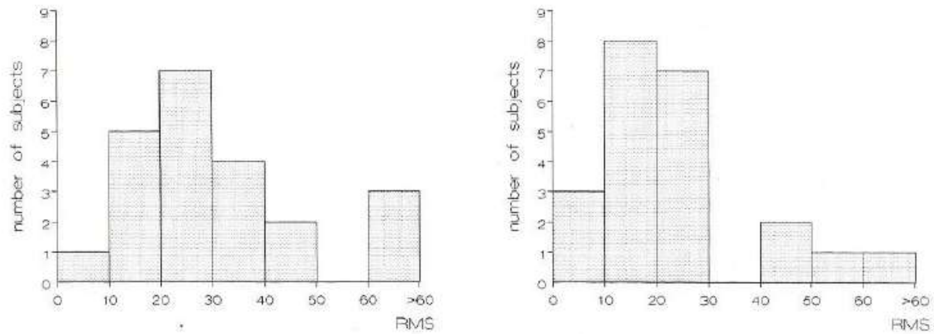
A total of 22 patients with a bilateral loss of vestibular function was tested accordingly. The data of 3 patients were incomplete for further analysis. In the condition eyes-open, the median RMS values of the antero-posterior and the left-right body sway proved to be 16.0 and 12.5 respectively (see Fig. VI.2). These median values were well within the range of the 90th percentiles of the control group. Still 36% of the patients exceeded the 90th percentile of the control group in this condition for both directions of body sway.



Antero-posterior body sway
median RMS = 16.0

Left-right body sway
median RMS = 12.5

Fig. VI.2: Stabilometry results of 22 patients with a bilateral loss of vestibular function. Condition eyes-open.
RMS = Root Mean Square: Measure of stability.



Antero-posterior body sway
median RMS = 25.5

Left-right body sway
median RMS = 21.0

Fig. VI.3: Stabilometry results of 22 patients with a bilateral loss of vestibular function. Condition eyes-closed.
RMS = Root Mean Square: Measure of stability.

In the condition eyes-closed, the median RMS values of the antero-posterior and left-right body sway are 25.7 and 21.2 respectively (see Fig. VI.3). This results in as much as 73% of the patients exceeding the 90th percentile of the body sway of the control group. The Romberg quotient of the stabilometric data of these patients is 1.59 for the antero-posterior and 1.68 for the left-right body sway.

In contrast to the control group, the relative increase of the left-right body sway is, with regard to the Romberg quotient, more outspoken when compared to the antero-posterior body sway in this patient group.

In case of a bilateral vestibular deficit, postural stability is seriously affected if the visual input is also missing [Brandt et al., 1986a]. On the other hand, none of the patients in this study lost his balance completely, thus indicating that the somatosensory information by itself is adequate enough to ensure a certain degree of postural stability while standing upright with the eyes closed. However, already in rather uncomplicated daily life situations the somatosensory information by itself is not sufficient, especially not in the dark. From these results, the contribution of the vestibular system in maintaining upright posture is evident.

VI.2.3: Dynamic tilting room examination

Again the same four frequencies of room stimulation are used: 0.025, 0.05, 0.1 and 0.2 Hz. Median values of the left-right body sway of the control group are 6.8, 5.7, 4.3 and 3.2 mm respectively with 90th percentiles of 16.0, 15.3, 14.1 and 9.8 mm (see chapter V.1.4).

At the given frequencies the 25 patients show median values of the left-right body sway of 10.8, 12.1, 20.2 and 28.8 mm at increasing frequencies (see Fig. VI.4-7). The percentage of patients exceeding the 90th percentile of the left-right body sway of the control group are 28, 36, 56 and 80% respectively at increasing frequencies. So, at the low frequencies, the patients exhibit a left-right body sway well in range with the 90th percentile of the control group. Regarding the high frequencies, postural balance is far more affected. In contrast to the findings of the control group, the effect of the tilting room on upright posture in this group of patients increases with the high frequencies of room stimulation.

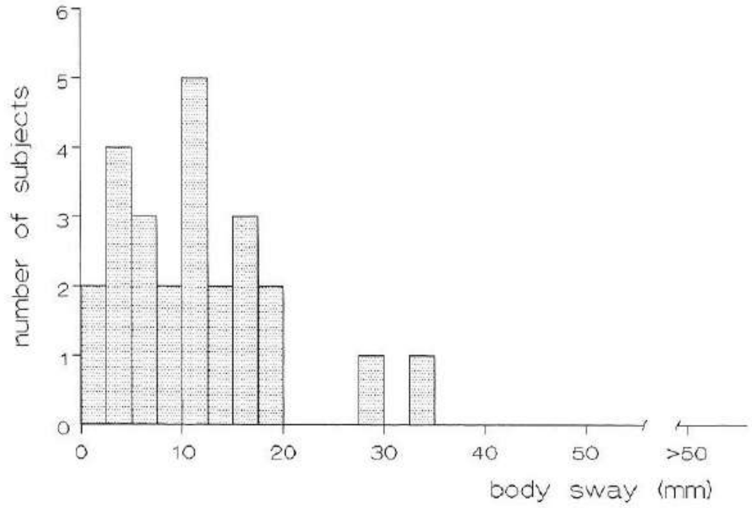


Fig. VI.4: Amplitude of left-right body sway (mm) in patients with a bilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.025 Hz. Median = 10.8 mm, 28% exceed 90th perc. of controls.

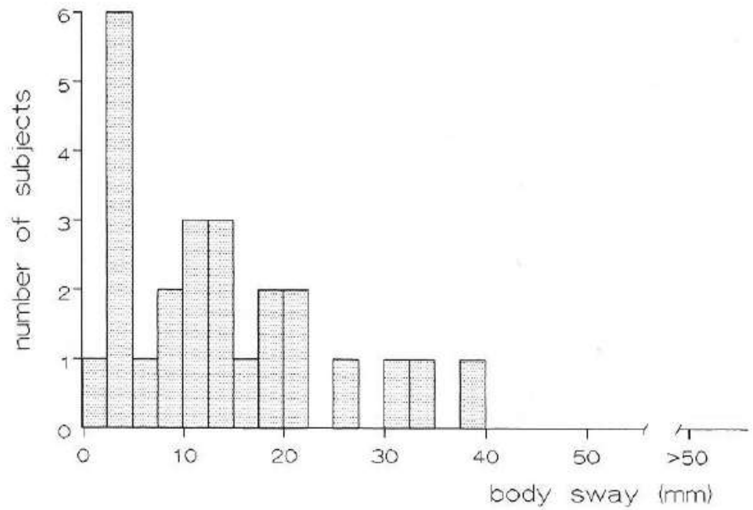


Fig. VI.5: Amplitude of left-right body sway (mm) in patients with a bilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.05 Hz. Median = 12.1 mm, 36% exceed 90th perc. of controls.

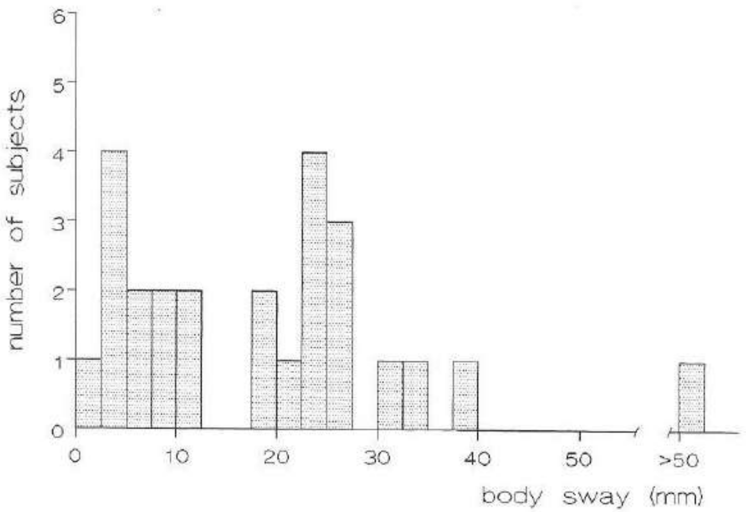


Fig. VI.6: Amplitude of left-right body sway (mm) in patients with a bilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.1 Hz. Median = 20.2 mm, 56% exceed 90th perc. of controls.

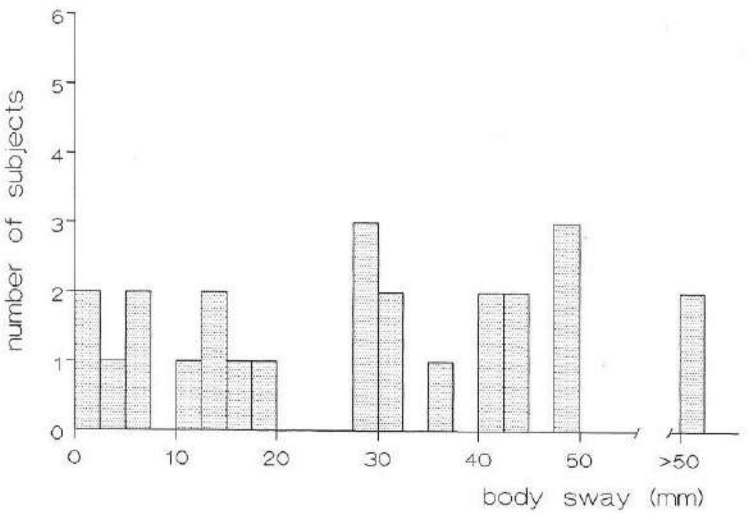


Fig. VI.7: Amplitude of left-right body sway (mm) in patients with a bilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.2 Hz. Median = 28.8 mm, 80% exceed 90th perc. of controls.

Regarding the perception of the test situation, patients tend to perceive a stable visual surrounding in combination with a tilting stabilometer platform or even no movement at all, the latter especially at the lowest frequency (see Table VI.1). At the higher frequencies, only room movement is mentioned in no more than 20% of the patients, compared to more than 80% of the controls. Still, at all four frequencies, most patients indicate only platform tilt. This perception is in line with a relative dominance of the visual information. At 0.2 Hz. two patients, quite surprisingly, still indicate no movement at all. Of the control group, none of the subjects ever perceived no movement at any given frequency (see Table V.1).

Table VI.1: Perception of the test situation in the tilting room in patients with a bilateral loss of vestibular function (%).

Freq. Hz.	-	P	B	R	
0.025	32	52	8	8	- = no movement at all
0.05	8	56	12	24	P = platform tilt
0.1	8	56	20	16	B = room and platform tilt
0.2	8	60	12	20	R = room tilt

In Fig. VI. 8 and 9 the left-right body sway of the patients is plotted as a function of time following the onset of the loss of vestibular function. It shows that at a time interval of up to several months, compensation is demonstrated, admittedly only at the low frequencies. At 0.025 Hz. all the patients, in the end, have a left-right body sway below the level of the 90th percentile of the control group. In line with this observation the perception of the test situation improves in such a way that more patients indicate a room tilt with or without platform movement.

Regarding the highest frequency of 0.2 Hz., patients remain, even after a longer period, above the 90th percentile level of the control group with their left-right body sway. The left-right body sway has hardly diminished when compared to the first examination in the tilting room.

In the end, all patients with a bilateral vestibular deficit tend to compensate at the low frequencies of room stimulation. If this compensation process does not take place, other (central) lesions of the equilibrium apparatus which influence the compensation process negatively, should be considered. After adequate treatment of the additional pathology, compensation may be possible but again only for the low frequencies.

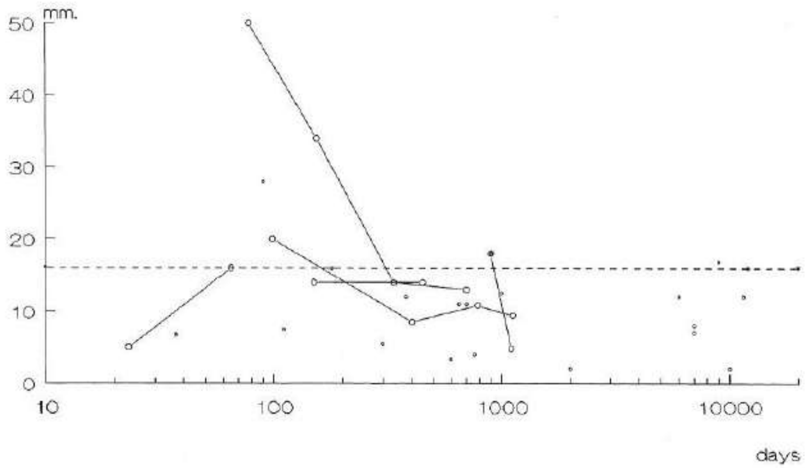


Fig. VI.8: Left-right body sway (mm) in the tilting room as a function of time. Dotted line is 90th percentile of controls (16.0 mm). Room frequency is 0.025 Hz.

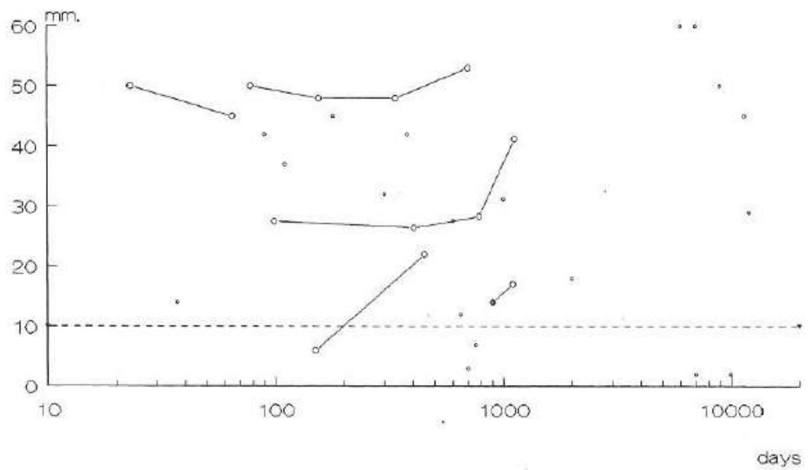


Fig. VI.9: Left-right body sway in the tilting room as a function of time. Dotted line is 90th percentile of controls (9.8 mm). Room frequency is 0.2 Hz.

Regarding the relative weight imparted by the CNS to the involved sensory systems, at first a dominance of the visual information is demonstrated in the tilting room at all frequencies. Therefore, in the early period after a bilateral loss of vestibular function, lack of this function is substituted by an increased relative weight of the visual input. However, as soon as compensation has been completed and the patients regain their postural stability, they tend to perceive room tilt, which indicates that from this moment on, the somatosensory information becomes important in maintaining upright posture. Again, this only holds true concerning the low frequencies. At high frequencies, every patient still exhibits a large left-right body sway and thus sticks to an increased relative weight of the visual input, even after the compensation being regarded as completed. In earlier studies [Kapteyn and Bles, 1977; Dichgans et al., 1976; Berthoz et al., 1975] it was confirmed that the otolith system and vision were particularly effective at the lower frequencies (<0.1 Hz.) and that at the higher frequencies (>0.1 Hz.) the semi-circular canal input became more effective [Smit, 1957; Nashner, 1970; Waespe and Henn, 1977]. It is interesting to note that also the distance between the eyes and visual objects was found to determine postural stability [Brandt et al., 1980]. The frequency dependent sensory input may explain the finding that no improvement could be demonstrated at repeated examinations for the highest frequency of room stimulation.

VI.3: Results of tilting room examination in patients with a complete unilateral loss of vestibular function

The group of patients with a unilateral vestibular deficit consists of 24 patients with a left sided and 16 patients with a right sided loss of vestibular function. Where necessary, the data of the right sided vestibular deficits are adapted in order to evaluate patients with a left or right sided vestibular deficit as one group. The cause of the unilateral loss of vestibular function is in most cases due to an infectious disease, a trauma, a post-operative complication or a congenital abnormality.

The diagnosis of a unilateral vestibular deficit is made by means of electronystagmography and caloric irrigation. If spontaneous recovery of the vestibular function occurs, this can very well be recorded by repeated caloric irrigation of the affected ear. In case of a persisting loss of vestibular function, repeated caloric irrigation is of no help in assessing compensation. Very often the process of vestibulo-ocular compensation, seen as a decrease of the spontaneous nystagmus, is also considered as a measure for the compensation of the vestibulo-spinal reflexes. The number of patients who still mention posture and gait disorders even though a spontaneous nystagmus is absent, suggests that a gradually disappearing spontaneous nystagmus is probably not an objective parameter to assess the level of compensation for a persisting unilateral loss of vestibular function in all patients. In this chapter another method to asses the level of compensation after a unilateral loss of vestibular function will be discussed.

VI.3.1: Subjective horizontal

The deviation of SH is often used as an indicator for the level of compensation because in the acute stage, patients with a unilateral loss indicate a SH tilted to the side of the affected vestibular apparatus, far beyond the range of the SH of healthy subjects [Schaefer and Meyer, 1974; McCabe et al., 1968; Katsarkas and Outerbridge, 1981]. Gradually, as compensation is taking place, the SH will return to normal values. The tilted SH in combination with a unilateral vestibular deficit makes it interesting to examine this group of patients in the tilting room.

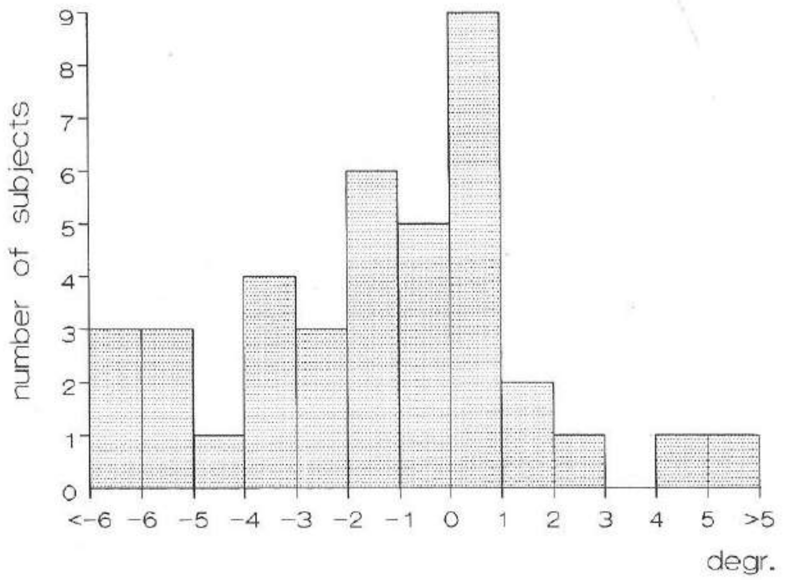


Fig. VI.10: Subjective horizontal of 39 patients with a unilateral loss of vestibular function. Mean = -1.4 degr., SD = 3.3

The mean value of the SH in this group is 1.4 degr. tilted to the left (see Fig. VI.10). On average, this value does not differ much from the results of the control group: Mean value 0.2 degr. tilted to the left. The standard deviation of 3.3 degr. in the patient group is larger than the SD of the control group (1.1 degr.). It is not surprising to find a larger deviation of the SH if the vestibular deficit is diagnosed shortly after the loss of vestibular function. Therefore, one can expect these patients to rely more on their visual information rather on their imbalanced vestibular input.

The presence of a pathologic spontaneous nystagmus appears not to run parallel with the deviation of the SH in all patients [Bles et al., 1983]. Often the spontaneous nystagmus has already disappeared while the patient with a unilateral vestibular deficit still complains about posture and gait disorders. In these cases, the finding of a deviated SH may indicate that the process of compensation has not yet been completed. Therefore, the registration of the SH and, as we will see later, examination in the tilting room is a more accurate method to evaluate the process of compensation after a unilateral loss of vestibular function.

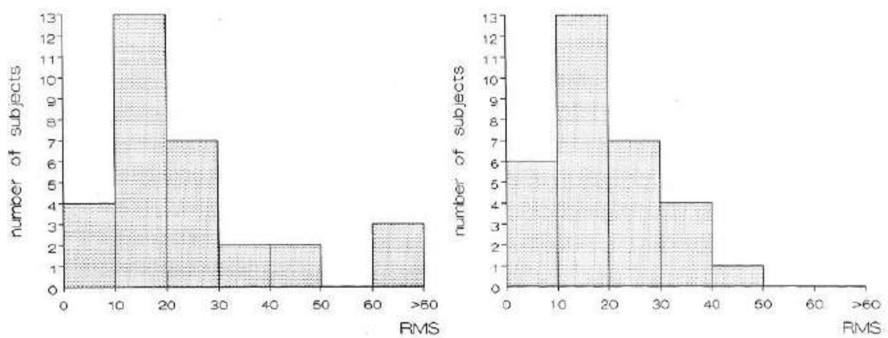
VI.3.2: Stabilometry

The results of the stabilometric recordings of 31 patients with a unilateral vestibular deficit are depicted in Fig. VI.11 and VI.12. In the condition eyes-open, the median RMS values of the antero-posterior and left-right body sway are 19.0 and 17.0 respectively. When compared to the control group, these median values exceed the 90th percentile of the healthy subjects (see chapter V.1.3). Fifty-eight percent of the patients exceed the 90th percentile of the antero-posterior body sway of the control group and 45% the 90th percentile of the left-right sway. A unilateral loss of vestibular function appears to have more effect on upright posture in the condition eyes-open, especially in the left-right direction, compared to patients with a bilateral loss.

After closing the eyes, the median RMS values in the patient group change to 29.0 and 21.5 for the antero-posterior and left-right body sway respectively. This results in a Romberg quotient of 1.52 for the antero-posterior body sway and 1.26 for the left-right body sway. When compared to the control group, 68% of the patients exceed the 90th percentile in both directions.

For both directions of body sway the Romberg quotient of patients with a unilateral vestibular deficit is just in between the Romberg quotients of the control group and the patients with a bilateral loss of vestibular function.

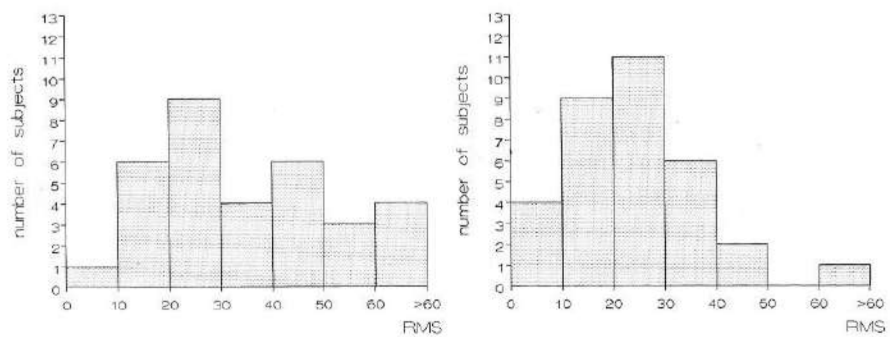
Regarding the Romberg quotient, the lack of visual information does not have the same negative effect on posture if the vestibular input is at least partly intact. The Romberg quotient is highest for the patients with a bilateral loss of vestibular function.



Antero-posterior body sway
median RMS = 19.0

Left-right body sway
median RMS = 17.0

Fig. VI.11: Stabilometry results of 31 patients with a unilateral vestibular deficit. Condition eyes-open. RMS = Root Mean Square: Measure of stability.



Antero-posterior body sway
median RMS = 29.0

Left-right body sway
median RMS = 21.5

Fig. VI.12: Stabilometry results of 31 patients with a unilateral vestibular deficit. Condition eyes-closed. RMS = Root Mean Square: Measure of stability.

However, the median values of both the antero-posterior and the left-right body sway in the group of patients with a unilateral loss are higher than the median values of body sway of patients with a bilateral vestibular deficit. This is probably due to the fact that a unilateral vestibular deficit is diagnosed at an earlier stage than for instance a congenital bilateral vestibular deficit.

VI.3.3: Dynamic tilting room examination

After a sudden onset of a unilateral loss of vestibular function, patients tend to exhibit a similar behaviour in the tilting room as patients with a bilateral loss of vestibular function. Everyone of them shows an increased left-right body sway at the four applied room frequencies. Median values of the left-right body sway are 14.0, 13.2, 15.9 and 17.0 mm respectively (see Fig. VI.13-16). In the control group, the median values of the left-right body sway are 6.8, 5.7, 4.3 and 3.2 mm respectively with 90th percentiles of 16.0, 15.3, 14.1 and 9.8 mm at increasing frequencies. Of the group of patients, percentages of 49, 41, 54 and 57 exceed the 90th percentile of the left-right body sway of the control group.

In contrast to the healthy controls, patients with a unilateral and also with a bilateral vestibular loss of vestibular function show an increasing body sway as the room frequency increases. In the control group, the left-right body sway decreases when the tilting frequency increases.

In accordance with the increased visually induced body sway, the perception of the testsituation is disturbed (see Table VI.2) as compared to the control group (see Table V.1). Especially at low frequencies, the patients indicate a stabilometer platform tilt, sometimes in combination with room tilt. Just room movement without platform tilt was mentioned by 9 patients only but this number increased to 14 at the highest frequency. Three patients registered no movement at all at the lowest frequency of room tilt. At the other frequencies, none of the patients indicated to perceive no movement at all. In general, the perception of the test situation in the tilting room is better in this group of patients than it is in patients with a bilateral vestibular deficit.

The results of the tilting room examination show that at first the CNS employs substitution as a compensation mechanism, in which the relative weight imparted to the visual information is increased. Redressing by the CNS of the vestibular imbalance itself apparently does not go fast enough to be used as a primary compensation mechanism.

Repeated examinations in the tilting room, even several months after the loss of vestibular function occurred, show a similar behaviour as with a bilateral loss of vestibular function regarding the low frequencies. At these frequencies, a left-right body

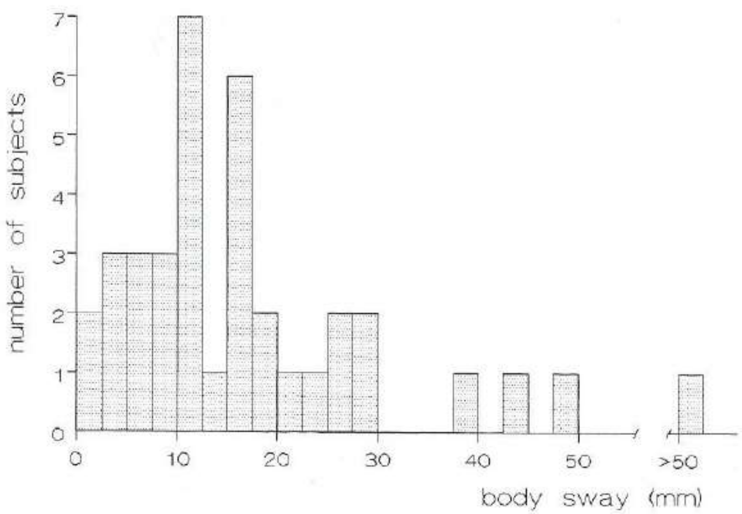


Fig. VI.13: Amplitude of left-right body sway (mm) in patients with a unilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.025 Hz. Median = 14.0 mm, 49% exceed 90th perc. of controls

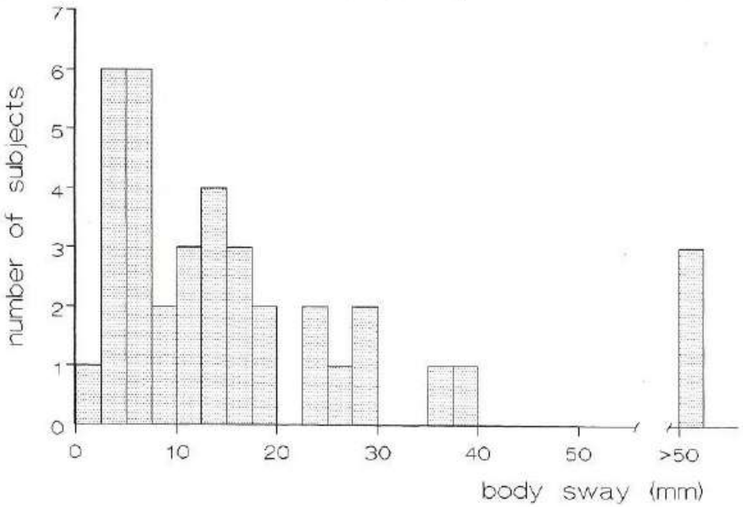


Fig. VI.14: Amplitude of left-right body sway (mm) in patients with a unilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.05 Hz. Median = 13.2 mm, 41% exceed 90th perc. of controls.

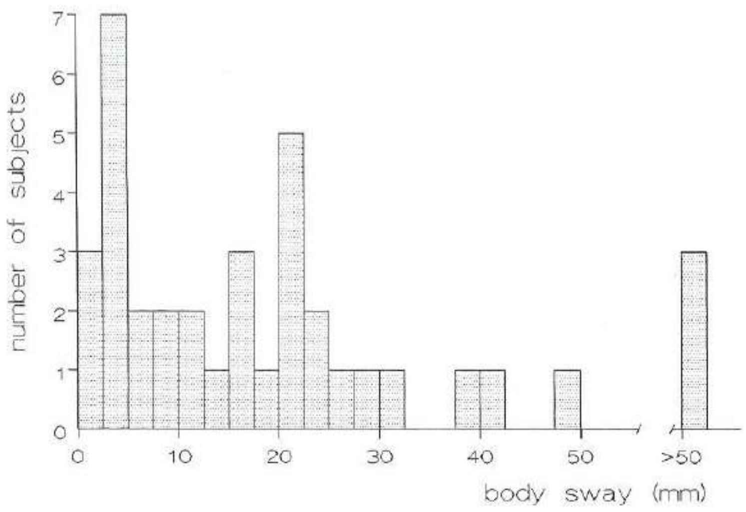


Fig. VI.15: Amplitude of left-right body sway (mm) in patients with a unilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.1 Hz. Median = 15.9 mm, 54% exceed 90th perc. of controls

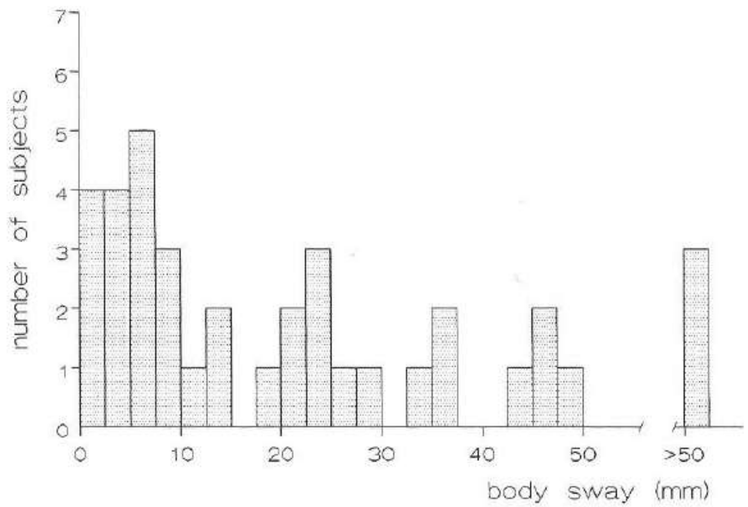


Fig. VI.16: Amplitude of left-right body sway (mm) in patients with a unilateral loss of vestibular function. Stimulus frequency of the tilting room is 0.2 Hz. Median = 17.0 mm, 57% exceed 90th perc. of controls sway is found comparable to the body sway of healthy subjects. Also the perception of the test situation has improved: Most patients indicate a stable platform in combination with tilting visual surroundings. In contrast to the findings with bilateral vestibular deficits, the left-right body sway also diminishes at the highest frequency to values in range with the controls. Eventually full compensation can be demonstrated but the process of compensation may take several months if we consider the postural stability in the tilting room as an objective measurement for the compensation process.

Very often, gradually disappearing of spontaneous nystagmus is taken as a proof of compensation. Normally the spontaneous nystagmus has disappeared after several weeks, and regarding the outcome of the tilting room examinations, it is not correct to state that the compensation has been completed after this relatively short period in all patients.

Table VI.2: Perception of the test situation in the tilting room in patients with a unilateral loss of vestibular function (%).

Freq. Hz.	-	P	B	R	
0.025	8	49	19	24	- = no movement at all
0.05	0	43	33	24	P = platform tilt
0.1	0	43	33	24	B = room and platform tilt
0.2	0	41	21	38	R = room tilt

VI.4: Value of tilting room examination in a uni- or bilateral vestibular deficit

As already has been stated, the diagnosis of a uni- or bilateral vestibular deficit is easily made without the use of a tilting room. On the other hand, the tilting room is of great value in assessing the level of compensation after the loss of vestibular function. Only in the first days following the loss of vestibular function, the general condition of the patient makes it impossible -as in other tests- to examine his postural behaviour adequately. During follow-ups and repeated examinations in the tilting room, both patients and clinicians will find that rehabilitation of the patient's postural stability is taking place. The frustrating experience, for patient as well as for clinician, of encountering a testbattery which is too difficult, even after a longer period, is avoided in this way [Graybiel and Fregly, 1966; Fregly, 1974]. A too difficult testbattery also makes it impossible to judge the positive effects of training on compensation [Igarashi et al., 1981; Brandt, 1984]. Follow-ups by means of repeated caloric irrigations are not useful since the results will permanently remain negative and thus give no indication whether compensation has been completed in case of a complete and lasting loss of vestibular function. The same holds true for repeated examinations with a rotating chair.

VI.4.1: Establishing compensation mechanisms

Because of the sensory interaction and central integration, the response of the patient in the tilting room clearly indicates which part of the sensory input relatively receives the most attention. A person, suddenly deprived of his vestibular information, at first substitutes this lack of sensory input by a relative dominance of the visual information. Accordingly, in most cases the patient perceives the situation in the tilting room as a stable visual surrounding in combination with a dynamic stabilometer platform. One of the compensation mechanisms of the CNS, substitution of visual and later also of somatosensory information for the missing vestibular information, is clearly demonstrated with the use of the tilting room. This is seen as an initially increased left-right body sway followed by a diminishing body sway in combination with an improvement of the perception of the test situation in the tilting room.

The results of repeated exposure in the tilting room as a function of time, both in uni- and bilateral vestibular deficits, show the level of compensation after a certain period. Finally, the relative dominance of the visual information is abandoned and replaced by an increased relative weight of the somatosensory information as far as the lower frequencies of room tilt are concerned. In case of a unilateral vestibular loss of function also the remaining vestibular input is used in regaining a new equilibrium. As to the higher frequencies, a remarkable difference persists between patients with an uni- or a bilateral loss of vestibular function. At these high frequencies complete compensation takes place in case of a unilateral loss of vestibular function, whereas in a bilateral loss visual information still prevales.

VI.5 : Summary and conclusions

In the conflicting sensory situation of the tilting room healthy subjects rely on their vestibular and somatosensory information. The misleading visual input is denied for the greater part. Therefore they exhibit a left-right body sway which is hardly affected due to this sensory conflict. During the process of central integration and processing of the available sensory information, a relatively increased weight is given to the vestibular input detrimental to the visual information.

In case of a sudden bilateral loss of vestibular function, the left-right body sway in the tilting room increases remarkably. As the body sway is in accordance with the lateral room tilt, the patients tend to rely on their visual information. This is in agreement with the perception of the test situation as a stationary visual surrounding together with a dynamic stabilometer platform. With the help of the tilting room, the process of compensation can be followed clearly. In the end, the patients exhibit a normal left-right body sway at the low frequencies, indicating substitution of their vestibular deficit by somatosensory information. At the higher frequencies they persist to show an increased left-right sway, indicating the use of visual information. It appears that the somatosensory input is not quite sufficient to deal with the high frequency stimulus of the tilting room. When compared to caloric irrigation or the use of a rotating chair, the use of a tilting room for follow-up examination is a superior method which enables accurate assessment of the process of compensation in case of a complete and lasting loss of vestibular function.

At low frequencies patients with a unilateral loss of vestibular function exhibit a similar behaviour in the tilting room as patients with a bilateral loss. Eventually, compensation at the highest frequency will also take place. In case of a unilateral vestibular deficit, the patients at first rely on their visual information. This is not surprising regarding their tilted subjective horizontal which is not suitable as a reference for the orientation on vertical and horizontal structures.

Also subjects with a temporarily disturbed vestibular input tend to shift the relative weight in favour of their visual information. This process of substitution was clearly demonstrated in astronauts in the D-1 Space Lab Mission [Bles, 1988]. Before launch they all displayed a normal left-right body sway in the tilting room. On their return to earth, after having been exposed to 0G gravity conditions for several days, they temporarily showed a visual dominance on examination in the tilting room. A similar effect was seen after prolonged exposure of the same astronauts and other healthy subjects to 3G gravity conditions. This situation also caused a disturbance in the vestibular information which made it necessary to temporarily rely more on visual information.

Although vestibular dysfunctions as discussed previously occur rather quickly, the effect is the same in all situations: The altered or lack of vestibular information is at first substituted by an upgrading of the visual information. Later, the relative weight imparted to the somatosensory input increases. This process of a shifting relative sensory weight as a means of compensation employed by the CNS in case of a vestibular deficit, may be readily demonstrated with the use of the tilting room.

The next question that arises is: What the effect of the tilting room will be on patients with a gradually increasing loss of vestibular function, for instance, a cerebellar pontine angle tumour. Such a tumour, like an acoustic neurinoma, grows slowly and therefore also slowly affects the ipsi-lateral vestibular input.

Chapter VII

TILTING ROOM EXAMINATION AND ACOUSTIC NEURINOMA

VII.1: Introduction

The findings of Friedman in patients with an acoustic neurinoma reveal a deviated subjective horizontal (SH) [Friedman, 1970]. The presence of an abnormal SH in this group of patients makes examination in the tilting room very interesting, as one would expect a visually induced left-right body sway. This behaviour should be the result of dominant visual information because the otolith input is not correct, and therefore not usable as a reference for upright posture.

An acoustic neurinoma is the most common (80%) cerebellar pontine angle tumour which arises from neurilemmal (Schwann) cells of the superior or inferior vestibular nerve and the cochlear nerve in the internal acoustic meatus. The localization of these neurinomas is the transitional area between the central and periferal part of the involved nerve. The part of the nerve which belongs to the CNS is covered likewise with glia tissue whereas the periferal part of the nerve is lined with Schwann cells. Of these nerves, the superior vestibular nerve is in most cases the origin of the acoustic neurinoma. Because of the limited space in the internal acoustic meatus, soon a gradually increasing pressure will arise on bloodvessels and nervi which in most cases affects both the vestibular and the cochlear nerve or even the trigeminal and the facial nerve. Eventually these neurinomas will expand towards the cerebellar pontine angle and thus give pressure on the cerebellum, the pons and the brainstem.

The relatively slow growth of these tumours gives rise, at least in the beginning, to a gradually progressive loss of function of both the cochlear and vestibular nerve. Regarding the cochlear nerve, at first an ipsi-lateral hearing impairment usually for the high frequency tones occurs in combination with tinnitus complaints. At a later stage also a low frequency hearing loss will be found at pure tone audiometry.

The gradual functional loss of both the superior and the inferior vestibular nerve shows a clinical picture which is completely different from a sudden loss of vestibular function. In case of an acute loss of vestibular function, the patients involved always complain about vertigo, accompanied with nausea and vomiting for the first days following the onset of the vestibular function loss, as well as about severe posture and gait disorders. At routine equilibrium examination with the use of electronystagmography, a spontaneous nystagmus with an asymmetrical vestibular response to caloric irrigation and rotational stimulation will be found. Furthermore, a deviation of the SH in combination with a disturbed upright posture both in the tilting room and on the stabilometer can be demonstrated in these patients [Bles et al., 1983]. The spontaneous nystagmus and the deviation of the SH will gradually diminish with time as compensation takes place [Bles and de Jong, 1986]. The disorders of posture and gait will eventually disappear almost completely too, when the process of compensation has been completed (see chapter VI.3).

With an acoustic neurinoma, patients seldom complain about posture or gait disorders. Hardly if any complaints about nausea or vertigo are reported, even though an ipsilateral loss of vestibular function is present [Janecke et al., 1972; Baloh et al., 1976]. At equilibrium examination, even when the unilateral loss of vestibular function is almost complete, no spontaneous nystagmus is recorded, although an asymmetrical response to caloric irrigation and rotational stimulation is found [Olsen et al., 1981; Olsen et al., 1984]. However, a deviation of the SH is often seen in these patients, in most cases deviated towards the side of the tumour, and depending on the size of the tumour [Friedman, 1970]. In contrast to these findings, an earlier study reported a deviation of the SH to either side, independent of the size of the tumour [de Vries et al., 1985]. The absence of a spontaneous nystagmus and vertigo complaints is likely due to the ability of the central nervous system to adequately compensate for a gradual unilateral loss of vestibular function. Therefore, patients with an acoustic neurinoma clinically present themselves at first with unilateral hearing complaints and tinnitus, instead of with dizziness complaints and a disturbed posture.

Whether a gradual unilateral loss of vestibular function will be met with the same strategy of a temporary relative dominance of the visual information as occurs in a sudden unilateral loss of vestibular function is a point of interest. It is possible that the gradual loss of vestibular function gives rise to a new approach to deal with the ongoing loss of vestibular function. It may be argued that the compensation process is capable of keeping pace with this ongoing loss of vestibular function. For that reason there is no need to increase the sensory weight of the visual information as the process of compensation is always in line with the loss of vestibular function. If this statement holds true, manipulation of the visual surrounding with the tilting room will, as in healthy subjects, hardly affect posture. On the other hand, if the level of compensation is not in pace with the ongoing loss of vestibular function, a dominance of the visual information must be notable in the tilting room. This may well be the fact, because the situation of a complete compensation is never achieved, even though actual complaints of a disturbed equilibrium are not outspoken.

VII.2 : Results of tilting room examination in patients with an acoustic neurinoma

In this study, 45 patients with an acoustic neurinoma were examined according to the earlier described procedure. Of the 45 tumours, 26 neurinomas were localized on the right and 19 on the left side. Eventually, all patients were operated upon and the diagnosis of an acoustic neurinoma was confirmed at postoperative histologic examination of the removed specimen.

Where necessary, the results of the patient examinations with a left sided acoustic neurinoma were adapted in order to evaluate all patients as one group.

VII.2.1: Subjective horizontal

Of the 45 patients with an acoustic neurinoma the data of 44 concerning the SH were available for further analysis. The data of one patient were incomplete. The results of the SH measurements are depicted in Fig. VII.1. The mean value of the SH in this patient group is 0.55 degr tilted to the right. This outcome is well in range with the results of the control group as demonstrated in chapter V.3.2. The standard deviation of 4.3 degrees, however, is in contrast with the findings of the control group (see chapter V). Furthermore, most patients, as in the control group, show a very consistent SH at repeated examinations with a range of just less than one degree.

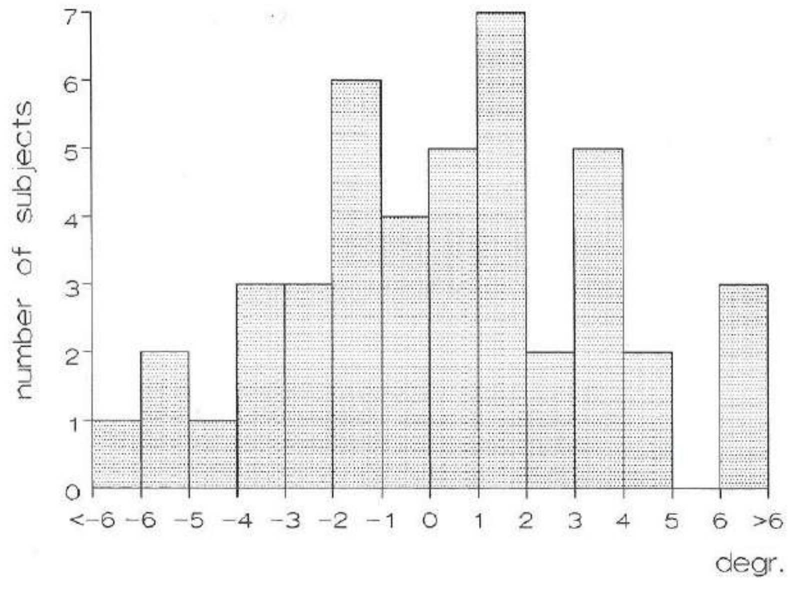
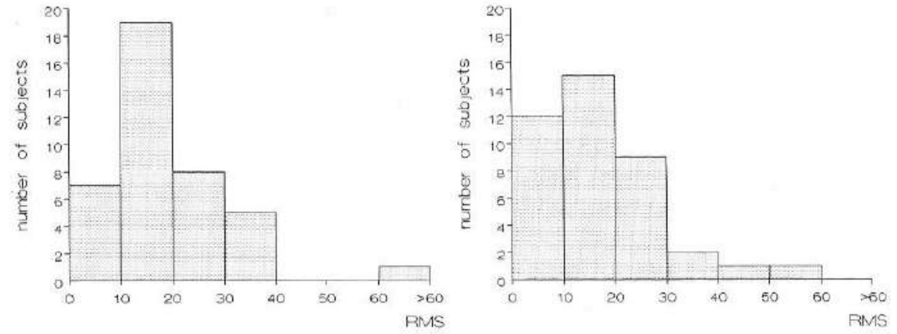


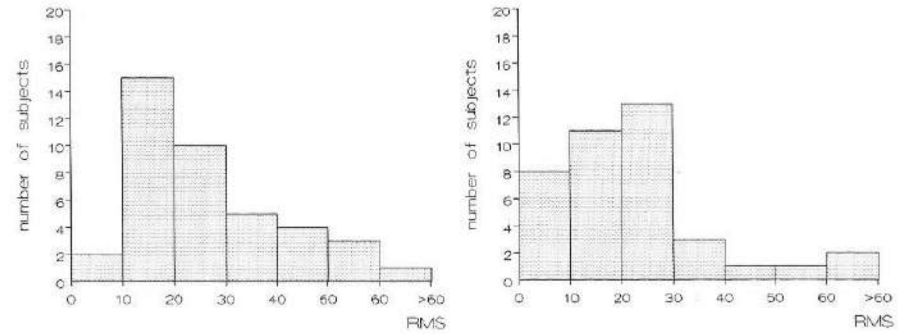
Fig. VII.1: Subjective horizontal of 44 patients with an acoustic neurinoma. Mean = 0.55 degr., SD = 4.31



Antero-posterior body sway
median = 16.5 RMS

left-right body sway
median = 15.5 RMS

Fig. VII.2: Stabilometry results of 40 patients with an acoustic neurinoma.
Condition eyes-open.
RMS = Root Mean Square: Measure of stability.



Antero-posterior body sway
median = 23.5 RMS

left-right body sway
median = 22.5 RMS

Fig. VII.3: Stabilometry results of 40 patients with an acoustic neurinoma.
Condition eyes-closed.
RMS = Root Mean Square: Measure of stability.

A total of 18 patients with an acoustic neurinoma showed a deviation of the SH beyond the range of +/- 2 SD (1.1 degr.) of the control group. In 10 patients the deviation of the SH was towards the side of the tumour, whereas in the other patients the deviation was towards the contralateral side. A deviated SH is usually seen in large tumours. The tilted SH might be due to pressure on the brainstem. A deviation to the contralateral side may be caused by increased pressure on the contralateral pons and brainstem. Not all patients with a deviated SH have an acoustic neurinoma of a size that presses on ipsilateral structures of the brain. In these cases, the deviation of the SH may be caused by a sudden partial ipsilateral vestibular function loss without a pathological spontaneous nystagmus, however. If this is the explanation, the deviation of the SH to the contralateral side should reflect a secondary phase in recovery of the SH.

As all patients were operated upon shortly after the diagnosis of an acoustic neurinoma, follow-ups regarding the SH could not be collected.

VII.2.2: Stabilometry

The postural stability of 40 patients with an acoustic neurinoma was measured on the stabilometer in the conditions 'eyes-open' and 'eyes-closed'. Three patients were not examined in all conditions on the stabilometer platform because of their instability. The data of two other patients were too incomplete for analysis. Of the remaining 40 stabilogram findings, the Root Mean Square (RMS) values and the Romberg quotient were calculated.

In the condition eyes-open, the median RMS values of the antero-posterior and left-right body sway are 16.5 and 15.5 respectively (see Fig. VII.2). After closing of the eyes, the median RMS values show a similar increase and become 23.5 and 22.5 for the antero-posterior and left-right body sway (see Fig. VII.3). This results in a Romberg quotient of 1.42 and 1.45 for the antero-posterior and the left-right body sway respectively.

Comparing these results with the data of the healthy controls, the 90th percentile of the controls in the condition eyes-open is exceeded by 48% of the patients regarding the antero-posterior body sway, and by 50% of the patients in the left-right direction. In the condition eyes-closed, 58% of the patients exceed the 90th percentile of the antero-posterior body sway of the controls, and 65% the 90th percentile of the left-right body sway. This also indicates an increased sensory weight of the visual information when the vestibular input has declined due to a gradual loss.

When examined on the stabilometer, patients with an acoustic neurinoma react like patients with a uni- and bilateral loss of vestibular function with respect to the median

RMS values of the antero-posterior and the left-right body sway as well as the Romberg quotient. Therefore, a gradual unilateral loss of vestibular function has the same destabilizing effect on upright posture in both the conditions eyes-open and eyes-closed as a sudden vestibular deficit. All patients already show an increased body sway in both the antero-posterior and left-right directions in the condition eyes-open. This clearly demonstrates the stabilizing effect on posture of the vestibular information, even in the presence of adequate and correct visual information. After closing the eyes, postural stability even diminishes. The Romberg quotient is much higher in the three patient groups than it is in the control group. The stabilizing effect of the visual information itself accounts for the significance of the Romberg test. However, in situations in which also the vestibular information is affected, the negative effects on posture are far more outspoken in patients with either a sudden uni-, or a bilateral loss of vestibular function. The same holds true in case of a gradual loss of vestibular function as in an acoustic neurinoma.

VII.2.3: Dynamic tilting room examination

Of the group of 45, 42 patients with an acoustic neurinoma were examined in the tilting room according to the procedure described in chapter III. The data of three patients were not available for further analysis. At the four frequencies of room stimulation, these patients show a median value of their left-right body sway of 14.2, 11.9, 18.1 and 31.5 mm respectively with 90th percentiles of 39, 60, 60 and 60 mm at increasing frequencies (see Fig. VII.4-7).

A left-right body sway of 60 mm indicates instability of the patient to such a degree that support is needed from the catcher standing behind him. If the left-right body sway exceeds 50 mm it becomes almost impossible to calculate the actual sway accurately because of chaotic body movements, necessary to maintain balance.

Therefore body sways exceeding 50 mm are not further specified but are noted as a left-right body sway of 60 mm. This accounts for the same 90th percentile values at the higher frequencies of room stimulation in this patient group.

The outcome of the dynamic tilting room examination in patients with an acoustic neurinoma indicates an increasing dominance of the visual information at increasing tilting room frequencies. The percentage of patients with an acoustic neurinoma exceeding the 90th percentile of the left-right body sway of the control group are 41, 48, 64 and even 81 % at increasing frequencies.

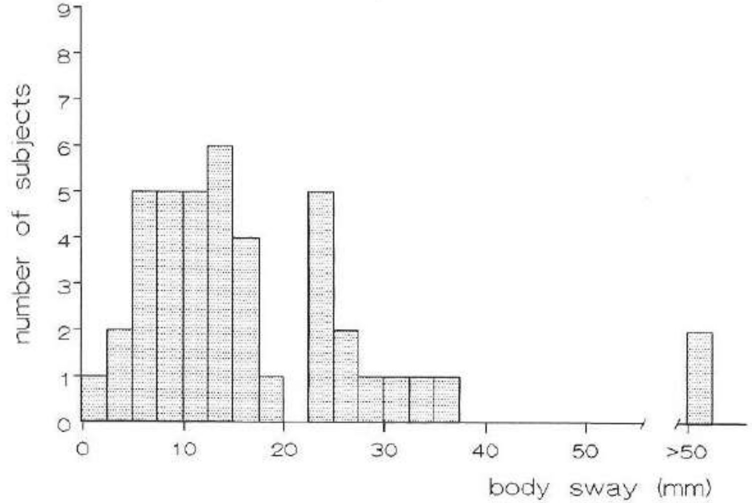


Fig. VII.4: Amplitude of left-right body sway. N = 42.
Stimulus frequency of the tilting room is 0.025 Hz. Visually induced body sway in mm. Median = 14.2 mm, 41% exceed 90th perc. of controls.

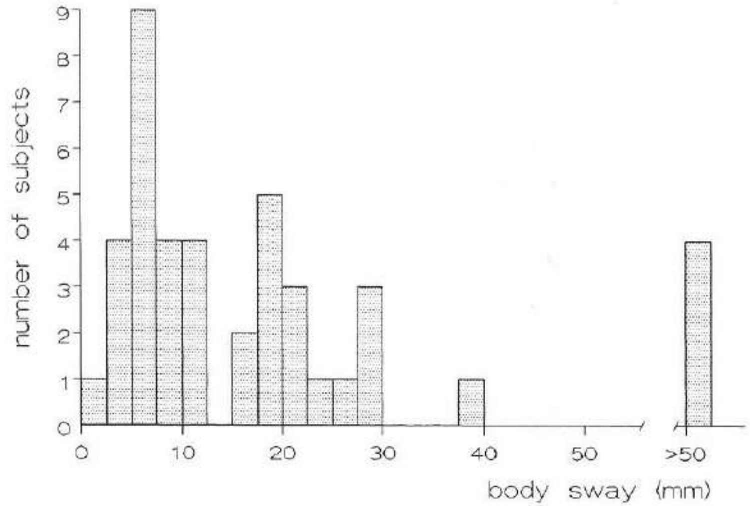


Fig. VII.5: Amplitude of left-right body sway. N = 42.
Stimulus frequency of the tilting room is 0.05 Hz. Visually induced body sway in mm. Median = 11.9 mm, 48% exceed 90th perc. of controls.

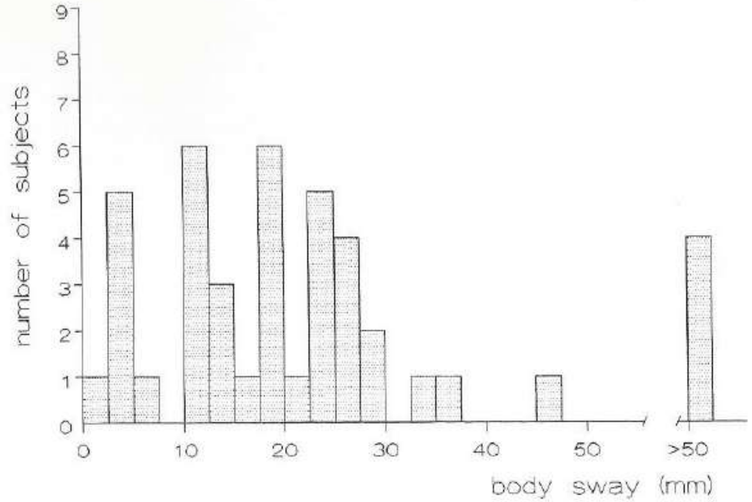


Fig. VII.6: Amplitude of left-right body sway. N = 42.
Stimulus frequency of the tilting room is 0.1 Hz. Visually induced body sway in mm. Median = 18.1 mm, 64% exceed 90th perc. of controls.

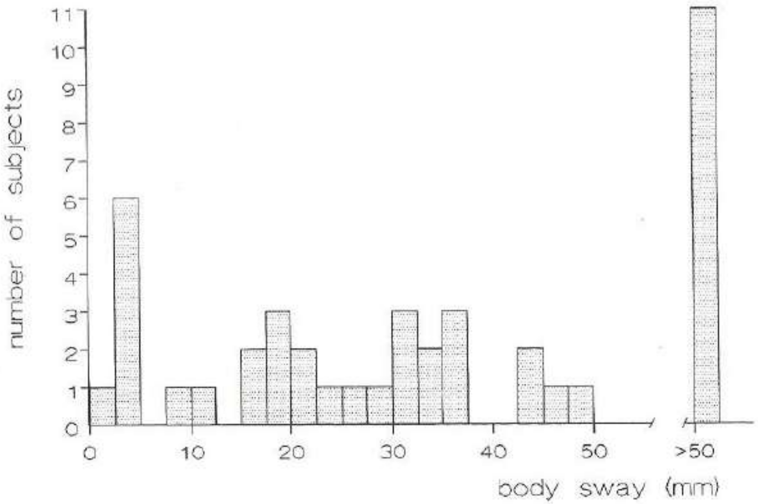


Fig. VII.7: Amplitude of left-right body sway. N = 42.
Stimulus frequency of the tilting room is 0.2 Hz. Visually induced body sway in mm. Median = 31.5 mm, 81% exceed 90th perc. of controls.

Table VII.1 shows the perception of the test situation in the tilting room of patients with an acoustic neurinoma. The relative dominance of the visual information can also be deduced from these data. All subjects in the control group report room tilt at high frequencies, sometimes in combination with platform tilt. None of the controls indicated to perceive exclusive platform tilt or no movement at all (see table V.2). Although more patients tend to perceive only room tilt at increasing frequencies, still most patients only report platform tilt with or without room tilt. The perception of no movement at all is mentioned only at low frequencies.

Table VII.1: Perception of the test situation in the tilting room of patients with an acoustic neurinoma (%).

Freq. Hz.	-	P	B	R	
0.025	14	60	7	19	- = no movement at all
0.05	5	64	12	19	P = platform tilt
0.1	0	55	21	24	B = room and platformtilt
0.2	0	38	26	36	R = room tilt

Comparing patients with an acoustic neurinoma with those having a complete uni- or bilateral loss of vestibular function (see chapter VI), the behaviour in the tilting room differs in some aspects. The median value of the left-right body sway is comparable for these three patient groups as far as the low frequencies are concerned. At the highest frequency of 0.2 Hz., patients with an acoustic neurinoma and patients with a bilateral loss of vestibular function both have a similar left-right body sway which is far higher than the left-right body sway of patients with a unilateral vestibular deficit. The perception of the test situation in the tilting room for these different groups of patients is similar with the exception of two patients with a bilateral loss of vestibular function. Those two patients still do not report to perceive any movement at all at the highest frequency of room stimulation.

VII.3 : Value of tilting room examination in patients with anacoustic neurinoma

The diagnosis of an acoustic neurinoma does not specifically require an examination in the tilting room. On the other hand the outcome of the examinations of the patient in this study are quite surprising. Although only a minority of these patients complain about posture and gait disorders, nearly all of them exhibit a disturbed postural control, both in the tilting room and on the stabilometer. The negative effects on upright posture are even more pronounced in this patient group when compared to the results of the patients with a sudden uni- or bilateral loss of vestibular function. In contrast to this finding is the small number of patients with an acoustic neurinoma actually complaining about equilibrium disorders.

Examination in the tilting room reveals the mechanism employed by the CNS to compensate for the gradual unilateral loss of vestibular function. Routine electro-nystagmography lacks this possibility. The increase in postural instability at stabilometry after closing of the eyes when compared to the condition eyes-open, as well as the increased left-right body sway in combination with the incorrect perception of the test situation in the tilting room clearly indicate the relative upgrading of the visual information in this patient group.

VII.4 : Discussion and conclusions

Routine vestibular examination of patients with an acoustic neurinoma with electro-nystagmography already gives relevant information. Audiometry examination of course is mandatory and highly relevant. Especially brainstem evoked response audiometry and pure tone and speech audiometry will be of great help to diagnose the existence of an acoustic neurinoma. A Ct-scan or MRI-imaging of the area concerned will further confirm the diagnosis of a cerebellar pontine angle tumour.

Although these patients usually do not complain about posture and gait disorders, serious abnormalities can be found when using the tilting room. Testing with a stabilometer already shows in the condition eyes-open an increased body sway in both antero-posterior and left-right directions. Accurate visual information is not sufficient to stabilize the patient in case of a gradual unilateral loss of vestibular function. If visual information is completely absent, this destabilizing effect is even more prominently notable, as can be concluded from the results in the condition eyes-closed.

The SH of patients with an acoustic neurinoma shows a mean value comparable to the SH of the controls. Eighteen patients, however, indicated a SH beyond the range of the controls. Only in 10 patients this deviation was towards the side of the tumor. Eight patients showed a deviation of their SH to the contralateral side. It is surprising to find a deviation of the SH without a pathological spontaneous nystagmus with electro-nystagmography. This must be caused by the relatively slow loss of vestibular function.

Examination in the tilting room reveals an increased postural sway at all frequencies for this patient group as compared to the control group. The left-right body

sway increases at the high frequencies of room tilt, whereas the body sway of the controls decreases. In line with this finding is also the incorrect perception of the test situation in the tilting room as perceived by this group of patients. Compared to patients with a sudden loss of vestibular function, the left-right body sway in the tilting room of patients with an acoustic neurinoma is largest, especially at the high frequencies.

A gradually proceeding loss of vestibular function has a serious impact on equilibrium, even though the patient involved does not complain about his posture and gait disorders at first. In most cases, a unilateral hearing impairment is the reason to visit a physician. The gradual loss of vestibular function is not completely compensated for by the CNS as can be concluded from the visual dominance in the tilting room and the increased body sway after closing of the eyes on the stabilometer. The employed strategy is in principle the same as in case of a sudden loss of vestibular function. Since compensation could not be demonstrated in this group of patients, the gradually increasing loss of vestibular function demands a persisting relative dominance of the visual information. Also, a re-adjustment of the vestibular imbalance is not a useful mechanism to adequately compensate for the gradual unilateral loss of vestibular function, because it never reaches a balanced state. The level of compensation is always behind in the creepingly increasing loss of vestibular and central nervous functions.

Chapter VIII

TILTING ROOM EXAMINATION AND CERVICAL ATAXIA

VIII.1: Introduction

Cervical ataxia is mostly encountered in patients suffering from a so-called whiplash injury, nowadays mostly due to a traffic accident. This whiplash injury is characterized by a rapid and extreme flexion of the cervical spine directly followed by a severe extension of the neck resulting in a variety of lesions, such as fractures of the cervical spine or soft tissue damage which even may result in a loss of consciousness. But even when no overt lesions are found, whiplash patients later often suffer from vertigo and ataxia. The complaints are mostly provoked by assuming certain head positions, especially extension of the head. Whether the neck proprioceptors are really the cause of these phenomena is still a controversial issue, since it is very difficult to provide evidence of involvement of the neck proprioceptors in humans [de Jong and Bles, 1986].

VIII.1.1: Anatomy and physiology of the neck

In the past century animal research already demonstrated that ataxia could be elicited for instance after transsection of the dorsal neck muscles [Bernard, 1858]. In more recent years, the results of the earlier experiments have been confirmed in several other animal experiments [Cohen, 1961].

The anatomic substrate of the afferent neck proprioceptors is the large number of muscle spindles in the deep muscles of the neck [Cooper and Daniel, 1963]. These muscle spindles are arranged in compartments with a separated nerve innervation for each compartment as demonstrated in different animal experiments [Abrahams et al., 1975]. Another source of the afferent neck propriocepsis are the joint receptors of the cervical spine and the receptors located in the intervertebral ligaments [Richmond and Abrahams, 1979].

The function of the afferent neck propriocepsis is to provide the CNS with information about the relative position of the head and the trunk, which information is necessary as the vestibular and visual system are located in the head [Kim and Partridge, 1969].

The functioning of the afferent neck propriocepsis is very often related to the cervico-ocular reflex (COR). The static COR can not be elicited in healthy humans, but only in patients with serious disorders of the CNS [Stenvers, 1918]. These findings, however, do not have practical clinical relevance. This does not apply to the dynamic cervical-ocular reflex. The dynamic COR can be elicited by rotation of the trunk under the stationary head. In case of a post-traumatic necklesion this may very well be painful for the patient and it is not without risks. In a number of subjects a nystagmus can be observed which consists of large saccades, generating an anti-compensatory 'Schlagfeldverlagerung' [Frenzel, 1928] and a small compensatory slow-phase. Bles and de Jong found that the dynamic COR in patients with cervical lesions is not different from the COR in healthy subjects. This is due to the fact that in healthy subjects the COR may be present or absent. Although the dynamic cervico-ocular reflex is weak in man, the illusion of circular vection is strong [de Jong et al., 1981]. The discussion whether the cervico-ocular reflex and the vestibulo-ocular reflex are complementary and also whether the gain of the cervico-ocular reflex increases to substitute a bilateral vestibular loss of vestibular function is still an open question [de Jong et al., 1981; Leopold et al., 1983; Bles et al, 1984]. According to the literature presently available on this subject, it is difficult to compare testresults, as the methods and the parameters used are considerably different in the examination of the COR.

However, the conclusion sometimes-heard that cervical vertigo cannot exist since there is no COR cannot be maintained: It has been shown that, although the mean dynamic cervico-ocular reflex is weak, the cervically-induced head motion sensation is stronger than the opposed vestibulary induced sensation [Bles and de Jong, 1982].

VIII.1.2 : Why use the tilting room in cervical ataxia

In view of the above we concluded that the COR was insufficient for the evaluation of the equilibrium function of patients suffering from cervical ataxia. Because of the particular complaints of these patients concerning vertigo and ataxia depending on head position, attention was focussed on measuring postural control in these patients.

With stabilometry a large postural instability, especially on head extension was observed in many patients as well as a visually determined postural sway in the tilting room [De Jong and Bles, 1986]. They also reported that some of their patients improved postural stability after re-education of the disturbed motor patterns through dispokinetic training and treatment of the cervicodorsal spine. This occured both during stabilometric examination with head extension as well as in the tilting room. It suggests that the cause of the instability could not be of otolithic origin but should be of cervical origin (afferent neck proprioceptors), since it is impossible that the particular treatment changed the otolithic system. However, because of the close interactions of the otolithic system and the neck, it is very well possible that lesions of the neck influence the output of the otolithic system. This would therefore again result in a dominance of the visual system in the process of weighing the sensory information, in the same way as described for the patients with vestibular lesions in chapters IV and V.

Consequently, a systematic study of a well defined group of patients suffering from cervical ataxia was initiated. The findings of tilting room examination, subjective

horizontal estimation and stabilometry of a group of 85 suitable patients suffering from cervical ataxia will be dealt with in this chapte

VIII.1.3 : The patients

The 85 patients participating in this study all had a history of a necktrauma. In addition to the main symptoms of pain, fatigue and diminished endurance, common complaints were dizziness, disturbed cervico-brachial sensation and problems with vision and hearing. As they met the selection criteria of having no fractures of the spine, no loss of consciousness after the accident, and no other neurological lesions, the diagnosis was a lesion of the afferent neck proprioceptors. They were subjected to neurological and radiological examination which took place at the Dept. of Neurology of the Academic Medical Centre in Amsterdam. The equilibrium examination was performed at the Dept. of Otolaryngology of the Free University Hospital in Amsterdam.

The routine equilibrium examination consisted of electro-nystagmography establishing the possible presence of a spontaneous-, positional- or gaze nystagmus. Thereafter the patient was examined in the rotation chair paying special attention to the vestibulo-ocular reflex. Central tests included the registration of the optokinetic nystagmus, the smooth pursuit and the fixation suppression test. The final part of the routine examination was the caloric testing of the vestibular apparatus. As a result of the examination, dysfunctions were found in about 5% of the patients which could not explain the patients' complaints. In most cases the dysfunctions proved to be a spontaneous nystagmus with a slow phase velocity of more than 5 degrees, an in-sufficient optokinetic nystagmus and fixation suppression resulting from central pathology. Also a difference in vestibular function of more than 25% found at caloric irrigation of the horizontal semi-circular canals was considered to be abnormal.

VIII.1.4 : Method

After the routine equilibrium examination the patients were subjected to an extensive complementary set of equilibrium examinations in order to reveal a cervical origin for their vertigo and ataxia complaints. At first the patients were tested on the stabilometer in six different static conditions. Since the complaints often correlate with a certain headposition, special attention was paid to the effect of different head positions on upright posture.

Subsequently, the patients were tested in the tilting room. A detailed description of the tilting room is given in chapter III. If the information of the afferent neck proprioceptors is relevant to maintain a normal posture, a disturbed posture will be found in the tilting room in case of a lesion of the neck propriocepsis.

Finally the SH was measured, again with different head positions in order to assess the influence of afferent neck proprioceptors.

VIII.2: Results of tilting room examination in patients with cervical ataxia

VIII.2.1: Subjective horizontal

At first the patients were examined on their perception of the horizontal. This was done according to the procedure described in chapter III. In addition the patients were also asked to indicate their SH with their head tilted on the left shoulder (HOL) and with the head tilted on the right shoulder (HOR) both four times. The patients did not get any information about their estimates. For a number of patients it was too painful to tilt their head in which case the test was omitted. The results of the SH

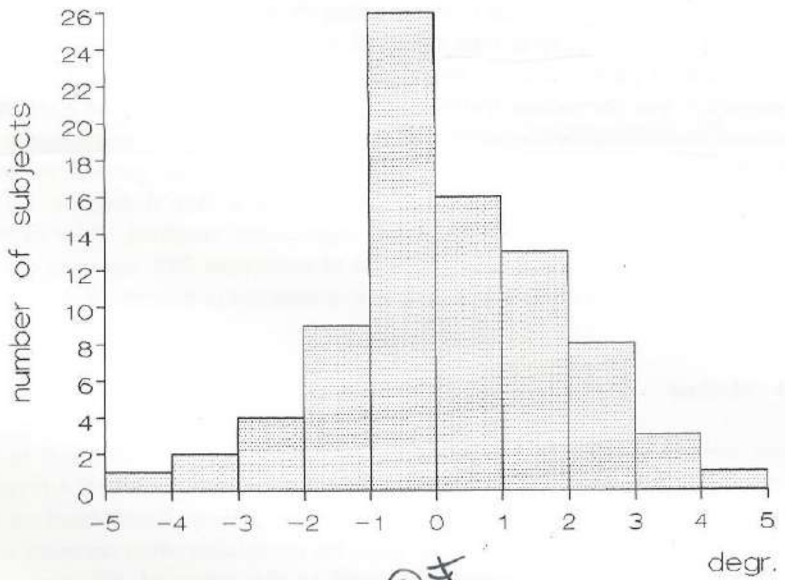


Fig. VIII.1: Subjective horizontal of 81 patients with cervical ataxia.
Mean = 0.15 degr., SD = 1.56

measurements are shown in Fig. VIII.1 for 83 patients. It is noted that 18% of the estimates are outside the normal range (cf. Chapter V).

From 34 healthy subjects the HOL and HOR estimates were obtained. In order to establish the effect of the neck, the HOL and HOR data were corrected for the SH estimates. These values were plotted against each other and showed a slope of the regression line of -0.66. This outcome is statistically different from 1. This means that there is a difference between HOL and HOR. For the patients the HOL and HOR data corrected for the SH were also plotted against each other. In this case the slope of -0.32 is also statistically different from 1.

Further analysis of the data indicated that the HOL and HOR data do not discriminate between controls and patients: The data of the controls scatter too much which may be due to the measuring method or to the presence of latent cervical problems in this group. Inspection of the data reveals that the patients show an even larger scatter than the controls.

VIII.2.2 : Stabilometry

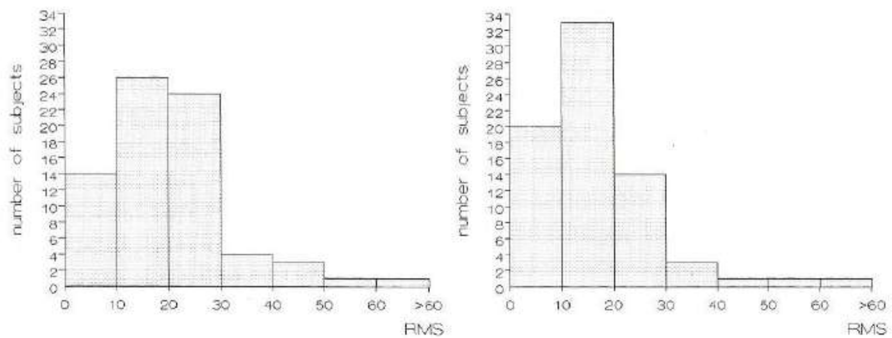
At first the patients were tested on the stabilometer in six different static conditions (see Table VIII.1). Each condition was examined for 60 seconds out of which the last 50 seconds were taken for analysis. From the A/P and the L/R stabilograms the RMS value was computed. Some patients could not assume the required head position in certain conditions or only for a shorter period. If this period was shorter than 20 seconds the data of that patient were discarded from further analysis. This left us with a complete data set of 75 patients.

For comparison with subjects without an acceleration trauma or any other for this topic relevant disorder in their history, the data of a group of 16 subjects having a similar age distribution as the patient group, were used.

Table VIII.1: Procedure of stabilometry testing with different headpositions in patients with cervical ataxia.

Condition 1: Eyes open, head upright
Condition 2: Eyes closed, head upright
Condition 3: Eyes closed, head in anteflexion
Condition 4: Eyes closed, head in retroflexion
Condition 5: Eyes closed, head rotated to the left
Condition 6: Eyes closed, head rotated to the right

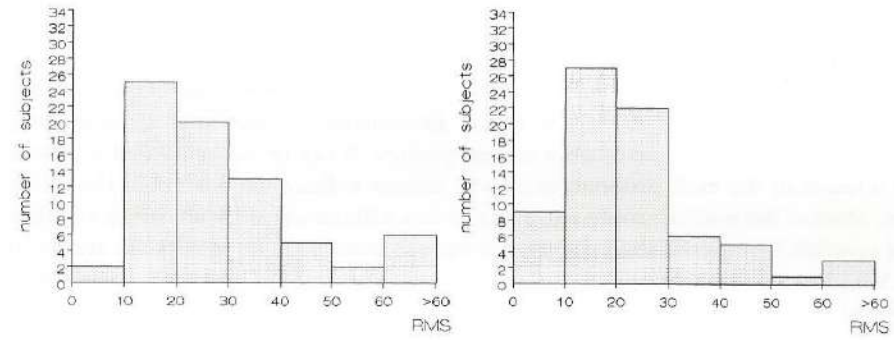
An ANOVA revealed that in the patient group there was a main effect in the conditions ($p < 0.001$, 8.4 % variance explained). Newman-Keuls analysis specified that the RMS in condition 1 was smaller and the RMS in condition 4 larger than in all other conditions ($p < 0.01$). For the control group only condition 1 and condition 4 differed significantly from each other ($p < 0.01$). The ANOVA also revealed that there was a systematic difference between the antero-posterior and the left-right body sway ($p < 0.01\%$): The antero-posterior sway is about 25% more pronounced than the left-right sway, especially in the head extension condition (42.9%). This is visualized in Fig. VIII.2-4, where histograms of the antero-posterior and the left-right stabilograms for condition 1, 2 and 4 are shown for the patient group.



Antero-posterior body sway
median RMS = 18.1

Left-right body sway
median RMS = 14.9

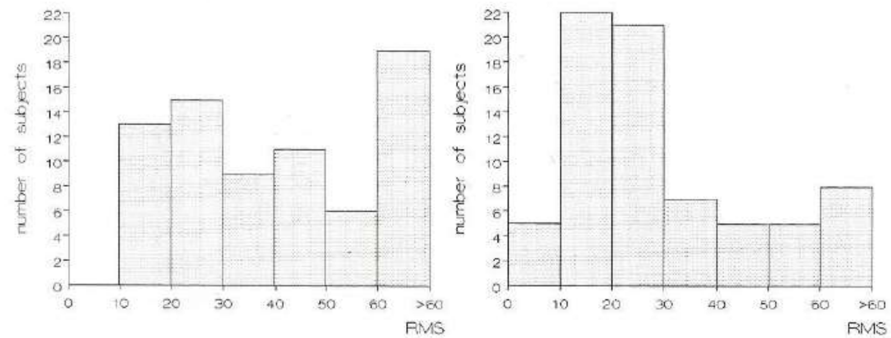
Fig. VIII.2: Stabilometry results of patients with cervical ataxia. Condition 1: Eyes-open, head upright.



Antero-posterior body sway
median RMS = 24.2

Left-right body sway
median RMS = 20.2

Fig. VIII.3: Stabilometry results of patients with cervical ataxia. Condition 2: Eyes-closed, head upright.



Antero-posterior body sway
median RMS = 39.8

Left-right body sway
median RMS = 28.0

Fig. VIII.4: Stabilometry results of patients with cervical ataxia. Condition 4: Eyes-closed, head extension.

VIII.2.3: Dynamic tilting room examination

Subsequently, the patients were tested in the tilting room in accordance with the procedure described in Chapter V. If the information of the afferent neck proprioceptors is relevant to maintain a normal posture, it can be expected that a patient with a lesion of the neck proprioceptors will assume a disturbed posture in the tilting room. Most of the patients could perform this test without any difficulty since no other head position is required than the normal upright position. The results are shown in Fig. VIII.5-8. The 90th percentiles of the controls are exceeded by 47, 47, 41 and 46% for the stimulus frequencies of 0.025, 0.05, 0.1 and 0.2 Hz respectively. The movement perception is shown in Table VIII.2 and differs from the perception of the controls (Table V.1): The room is often perceived as stationary and the stabilometer as tilting, especially at the lower frequencies and with the larger body sways.

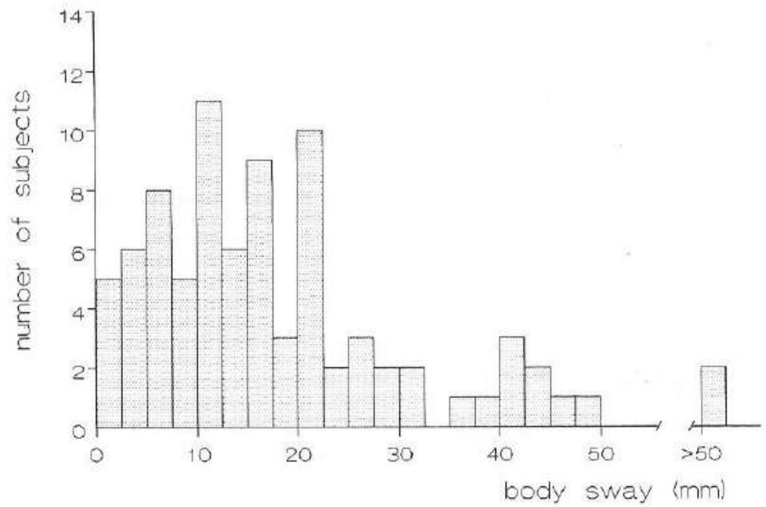


Fig. VIII.5: Amplitude of left-right bodysway (mm) in patients with cervical ataxia. N = 83. Stimulus frequency of the room is 0.025 Hz. Median= 15.2 mm., 47% exceed 90th perc. of controls

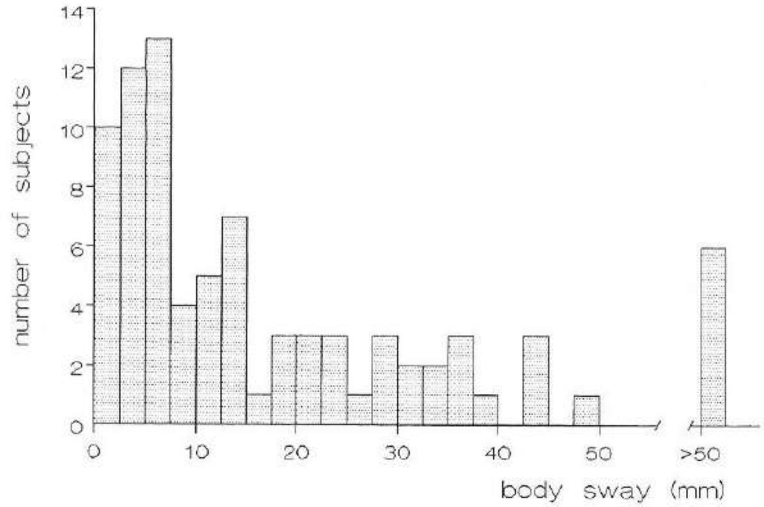


Fig. VIII.6: Amplitude of left-right bodysway (mm) in patients with cervical ataxia. N = 83. Stimulus frequency of the tilting room is 0.05 Hz. Median= 14.1 mm., 47% exceed 90th perc. of controls

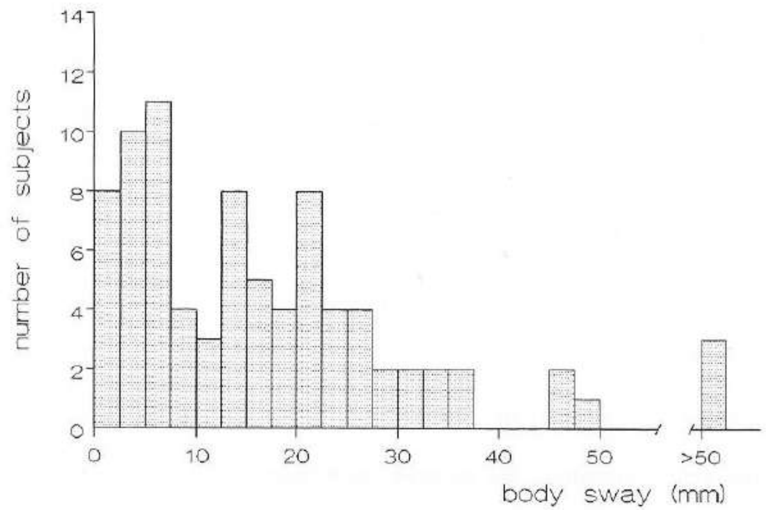


Fig. VIII.7: Amplitude of left-right bodysway (mm) in patients with cervical ataxia. N = 83. Stimulus frequency of the tilting room is 0.1 Hz. Median= 11.7 mm., 41% exceed 90th perc. of controls

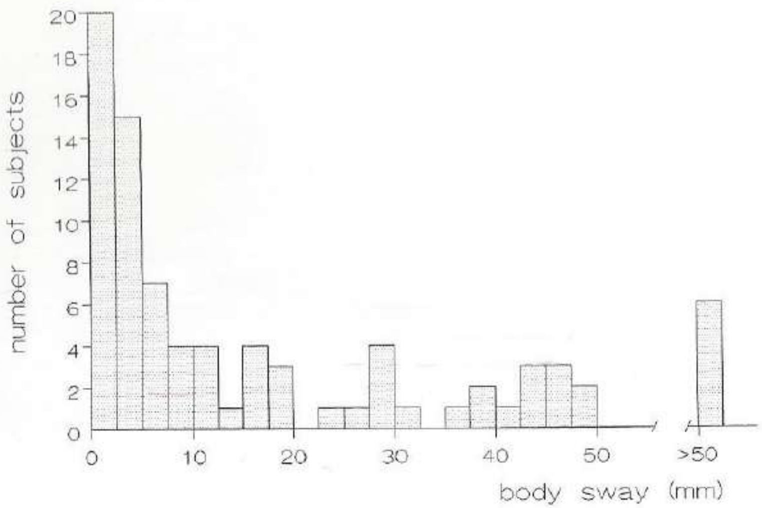


Fig. VIII.8: Amplitude of left-right bodysway (mm) in patients with cervical ataxia. N = 83. Stimulus frequency of the tilting room is 0.2 Hz. Median= 7.3 mm., 46% exceed 90th perc. of controls

Table VIII.2: Perception of the test situation in the tilting room of patients with cervical ataxia (%).

Freq. Hz.	-	P	B	R	
0.025	4	60	19	17	- = no movement at all
0.05	1	23	26	50	P = platform tilt
0.1	1	12	32	55	B = room and platform tilt
0.2	0	6	26	68	R = room tilt

VIII.3: Discussion and conclusions

A large differential diagnosis can be made with respect to vertigo complaints of patients suffering a whiplash injury. A vertebral artery insufficiency or a subclavian steel syndrome need to be excluded from this exercise. In these cases vertigo mostly is an accompanying symptom and not the main complaint as with cervical ataxia [Fisher, 1967]. Furthermore, osseous abnormalities of the cervical spine like osteophyts or spondylarthrosis need to be excluded from the diagnosis by means of identification through radiology examination. Arthrotic changes of the cervical spine, however, are found in more than 50% of the people over 50 years of age. Already at the age of 20 years 5% of the population shows radiologic evidence of arthrotic changes of the cervical spine. Without further examination, osseous abnormalities of the cervical spine may not be seen as the cause of the equilibrium disorders. Extensive atherosclerotic changes of bloodvessels may also cause a cervical syndrome. Benign paroxysmal position vertigo and the physiological head extension vertigo should be mentioned as differential diagnostics to be considerated [Dix and Hallpike, 1952; Brandt and Daroff, 1980].

The vestibulo-ocular findings at equilibrium examination of patients with a necktrauma and complaints of ataxia and vertigo are not conclusive. This might be due to the diffuse anatomic substrate of the afferent neck proprioceptors. A whiplash injury never leads to a complete and isolated unilateral lesion of these proprioceptors but the damage to the neck proprioceptors will be more diffusely spread in the whole region of the neck. Furthermore, a whiplash trauma will not only lead to a damage of the neck proprioceptors but it is likely that in a substantial number of patients, additional pathology will be caused by the same trauma. Especially damage of the brain itself is likely to occur in combination with a whiplash injury [Torres and Shapiro, 1961]. This can be diagnosed by means of an abnormal electro-encephalogram. Also an impaired vestibular function may be due to the experienced trauma. In order to reduce the influence of other pathology than lesions of the afferent neck proprioceptors on the diagnosis, patients with an overt disorder in their visual-ocular control or additional central disorders - possible also as an effect of their trauma - were excluded from the patients group. Patients with additional pathology were excluded from the investigation by identifying them by means of general neurologic examination, radiological examination of the cervical spine, caloric testing and ENG of the vestibular apparatus. Interference of the additional pathology is most probably the important reason for the discrepancy in the outcome between different studies dealing with cervical ataxia [Rubin, 1973; Toglia, 1976].

This study shows that with the use of the tilting room, in combination with stabilometry in different head positions and with measurement of the SH an involvement of the afferent neck proprioceptors can be demonstrated. In most cases no abnormalities were found during routine equilibrium examination in our patients. In cervical ataxia the disturbed sensory information leads to a shift in the relative weight of the sensory information in favour of vision. As already shown in the other patients groups, the same strategy is used. This results in a visually induced left-right body sway in the tilting room accompanied with an incorrect perception of the test situation.

The results of the stabilometry recordings with different head positions disclose an increased postural imbalance, especially with extension of the neck. As compared to the control group the increased body sway is far more pronounced. The increased postural sway following flexion and rotation of the head is less outspoken.

The SH measurements in this patients group show a mean SH well in line with the findings in the control group. However, the scattering in the former is much more pronounced, also in the conditions HOL and HOR.

In addition to be able diagnosing a lesion of the neck proprioceptors with this combination of tests, the effect of therapy can also be demonstrated with the use of the tilting room. If therapy results in a subjective improvement of the patients condition, this effect can be objectivated at re-examination with the tilting room . Fig. VIII.9 a and b and Fig. VIII.10 a and b show the effect of a certain type of physiotherapy on the visually induced body sway in the tilting room at 0.025 and 0.2 Hz before and after treatment in 12 patients suffering from cervical ataxia.

Sixty-seven percent of the patients exceeded the 90th percentile of the controls at 0.025 Hz. and 75% at 0.2 Hz. After treatment, these percentages are 25 and 17 respectively. In accordance with the diminished left-right body sway the perception of the test situation also improves. Re-examination in the tilting room will clearly demonstrate a positive effect of the applied therapy.

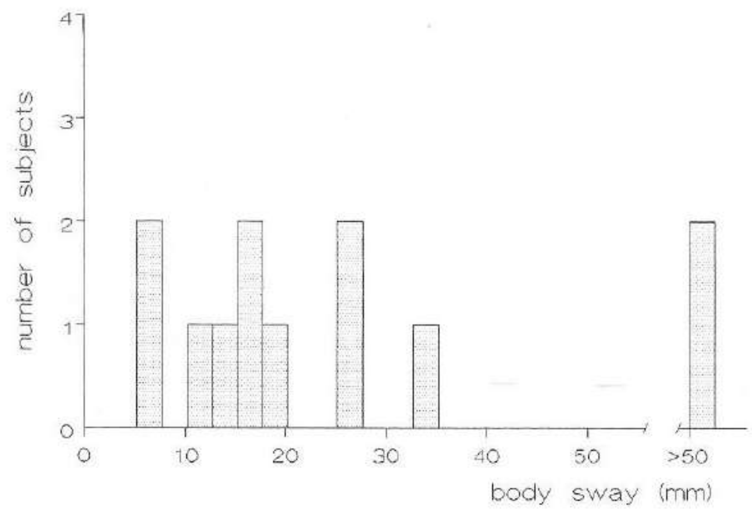


Fig. VIII.9a: Amplitude of left-right bodysway (mm) in patients with cervical ataxia before treatment. Stimulus frequency of the tilting room is 0.025 Hz

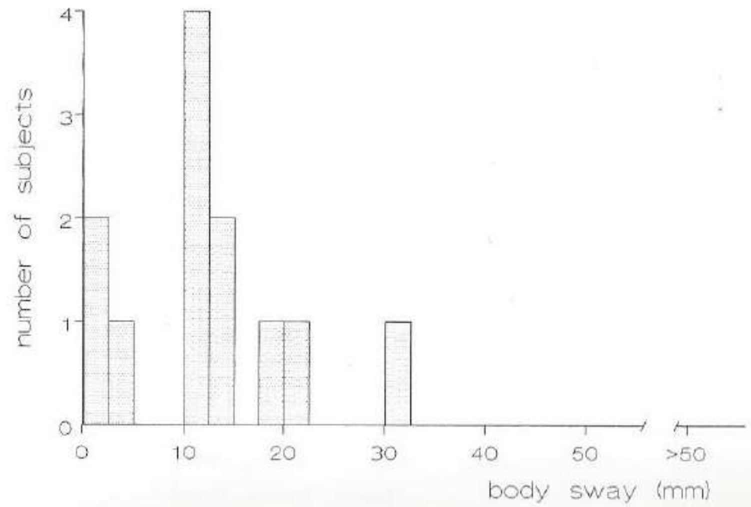


Fig. VIII.9b: Amplitude of left-right bodysway (mm) in patients with cervical ataxia after treatment. Stimulus frequency of the tilting room is 0.025 Hz

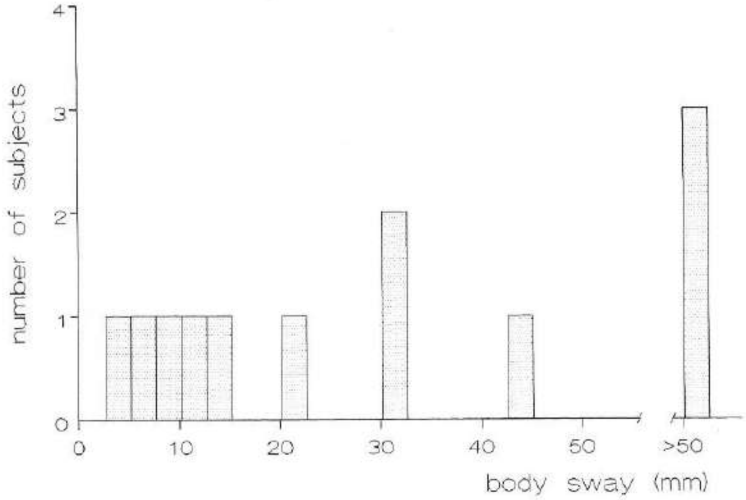


Fig. VIII.10a: Amplitude of left-right bodysway (mm) in patients with cervical ataxia before treatment. Stimulus frequency of the tilting room is 0.2 Hz.

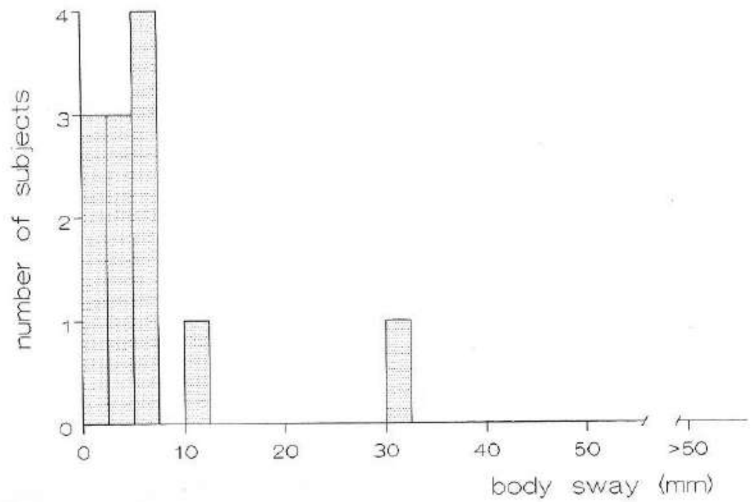


Fig. VIII.10b: Amplitude of left-right bodysway (mm) in patients with cervical ataxia after treatment. Stimulus frequency of the tilting room is 0.2 Hz.

Chapter IX

DISCUSSION AND CONCLUSIONS

Dynamic examination of posture compared to the classical type of equilibrium tests in patients with complaints of vertigo and posture and gait disorders has the advantage of testing the equilibrium system as a whole, instead of testing just an element of this complex system. Usually the examination of patients is limited to static testing of their equilibrium with the use of electro-nystagmography. With these tests most of the attention is focussed upon the horizontal semi-circular canals. Otolith function is not imparted in this type of examination. Dynamic equilibrium examination has the possibility of examining the otolith function. Unfortunately, dynamic tests are rarely used because they require specialized and expensive equipment. On the other hand, however, these test might give important additional information about the functioning of the equilibrium system.

In this study, dynamic examination with the use of the tilting room is performed both in healthy controls and in a variety of clinical disorders. Tilting room examination incorporates testing of postural balance with the use of a stabilometer in several conditions and measurement of the SH.

The sensory conflict between the otolith and visual information arising in the tilting room is adequately dealt with by healthy controls. The left-right body sway is limited to only a few mm. and diminishes at increasing frequencies of tilting room stimulation. In line with this small effect of a tilting visual surrounding on posture, the perception of the test situation is in accordance. This implies that the healthy controls in most cases perceive the room as tilting in combination with a stable stabilometer platform. This correct perception of the test situation is the result of the central weighing of the conflicting sensory information in favour of the otolith input. The visual information in this situation is at least partly denied. The perception of a stable visual surrounding in combination with a tilting stabilometer platform is the other possible option. Of course the two mentioned options are the extremes. At increasing frequencies of tilting room stimulation, the left-right body sway of the controls improves as compared to the sway at 0.025 Hz. room stimulation. Furthermore, the perception of the test situation is more often single room tilt. If manipulation of the visual surrounding is more outspoken (higher frequencies of room stimulation), the influence on posture is even less. The conflict between the visual and otolith information now is so evident which makes it is very easy to shift sensory weight. The effect of a tilting visual surrounding on posture is not linked to a sinusoidal movement. The same effects can be demonstrated with the use of complex stimulation of the room. After repeated examinations in the tilting room, an improved postural stability is seen at all frequencies. This improvement only occurs if the initial body sway is large enough to allow a certain degree of adaptation. In case of healthy subjects, this means the initial body sway needs to be enlarged with the use of a layer of foamrubber placed on the stabilometer. The foamrubber disturbs the exteroceptive information of the anklejoints and leads to an increased relative weight of the visual input. The effects of training are seen in all subjects with a correct perception of the test condition in the tilting room. Furthermore, this effect is lasting as demonstrated at re-examination after a time interval of up to one year. This finding is in contrast to the results of Brandt and co-workers who found an improved postural stability on the stabilometer with head extension, only as long as training was continued. Once training had ended, the original level of postural activity reappeared gradually. Within approximately 40 days, the effect of training leaked away completely. This makes the effects registered by Brandt and co-workers more or less a stand alone motor skill. In contrast to this observation, the tilting room requires cortical control in the sense that visual information is to be disregarded. This mechanism implies that once a correct weighing of the sensory information is established, this weighing remains cortically available as a recalibration skill. Imparted in this recalibration concept is that the process of weighing is subject to the plasticity of the equilibrium system. This plasticity could be demonstrated in the astronauts of the D-1 Spacelab Mission. During their flight they adapted to the absence of the gravity vector which reduced the weight of the vestibular information. On their return to earth, again they adapted by re-calibrating the vestibular weight factor. In certain astronauts this was seen as a temporary relative dominance of the visual information resulting in an increased left-right body sway in the tilting room. For one of the astronauts the perception of the situation in the tilting room had also changed: Before launch he always reported to perceive only room tilt at all frequencies but immediately after his return to earth he perceived no movement at all. A similar observation was made with HNP patients who were examined in the tilting room before and just after a ten days rest in bed. In these patients an increased sensitivity for the visual stimulus in the tilting room could be demonstrated after their bed rest.

The outcome of these experiments in the tilting room can be explained as a temporary change in the sensory weighing, necessary if one of the sensory inputs is missing, changed or incorrect. This implies that a period of altered sensory information may lead to a change in the neural store of the sensory weighing. The clinical relevance of this recalibration concept is that in general a correct perception of room motion is an essential input to the calibration mechanism. Because of the plasticity of the sensory weighing in the neural store, a disturbance of the sensory information may lead to a permanent or temporary change in the central weighing, mostly in favour of vision. The observation that healthy controls used the same mechanism after taking an anti-vertigo drug demonstrates that the building-up of the weighing factor is delayed because of the drug. This finding is in line with the general concept that anti-vertigo drugs in patients suffering from acute dizziness relieve the vertigo and nausea problems but hampers recovery.

So far the recalibration mechanism in healthy subjects. However, the different patient groups examined in this study, basically all exhibit the same strategy. At first instance, patients with either a uni- or a bilateral loss of vestibular function show a clear dominance of the visual input. As compensation takes place, this process of compensation can clearly be followed by repeated examinations in the tilting room. The absence of the VOR in a bilateral loss of vestibular function makes tilting room examination a superior method as compared to ENG measurements to establish the process of compensation. In the end, patients with a bilateral loss of vestibular function will compensate for the low frequencies of room tilt. They persist in exhibiting a large left-right body sway at the highest frequency. The period of time needed for this process is in general longer -up to several months- as is believed with respect to the outcome of the ENG measurements (several weeks). The process of compensation, as registered in the tilting room, also correlates very well with the well-being of the patients. The same holds true for patients suffering from a sudden unilateral loss of vestibular function except that these patients in the end also compensate for the highest frequency of room stimulation. Again, the results of the tilting room examination are in line with the compensation level. The reduction of a spontaneous nystagmus is often used as an important measure for the compensation following a unilateral loss of vestibular function. The reduction of the spontaneous nystagmus does not always run parallel with the patients' complaints and the outcome of the tilting room examination. Regarding the uni- and bilateral loss of vestibular function, the tilting room is an accurate tool to assess the level of compensation. In these patients the temporary increased sensory weight of the visual input is clearly demonstrated.

In case of an acoustic neurinoma the ongoing loss of vestibular function leads to a situation in which a state of complete compensation is never achieved. Therefore, these patients persist in exhibiting an increased left-right body sway at all frequencies in the tilting room in combination with an incorrect perception of the test situation. This outcome demonstrates the permanent change in the sensory weighing in favour of vision.

Another reason to shift the sensory weight in favour of the visual input is a whiplash trauma of the cervical spine. In most patients who suffered a whiplash injury, no abnormalities could be found at routine equilibrium examination. In the tilting room, however, they tend to show an increased left-right body sway in combination with an incorrect perception of the test situation. Since many patients were examined up to years after their accident, the change of the relative weight towards the visual information is permanent. After adequate therapy was applied, both a subjective and an objective improvement could be demonstrated with the use of the tilting room.

An interesting finding in all patient groups is a deviation of the subjective horizontal (SH). This deviation is not in all patients related to a malfunction of the vestibular apparatus, especially the otoliths. On the other hand, a deviation of the SH is a clear reason for all patients to increase the relative weight of the visual information and, at least partly, deny the vestibular input. In this situation the visual information is used as a reference and not the otolith information as with healthy subjects. As long as the deviation of the SH is present, an increased left-right body sway in the tillting room will be notable.

The over all conclusion is that dynamic equilibrium examination in the tilting room gives relevant information about posture and gait disorders. For certain diagnoses the tilting room is not mandatory. On the other hand, examination in the tilting room is a very accurate method to assess the level of compensation for a sensory deficit. The fact that in all patient groups -and also in healthy subjects in certain situations- a permanent or temporary increased left-right body sway in the tilting room could be demonstrated, implies that in every condition the relative weight of the sensory information has changed in favour of vision. These findings demonstrate that the tilting room is not specific but very sensitive in establishing disorders of the equilibrium system.

SUMMARY

In this thesis the tilting room is used for dynamic equilibrium examination of both patients and healthy controls. Aim of the study is to evaluate and review these examinations with the purpose to identify similarities in postural behaviour. The main advantage of dynamic examination of posture and gait disorders is that the equilibrium system is tested as a whole and not just one part of it as is normally done in the routine equilibrium examination with the use of a rotating chair and electro-nystagmography. With this routine examination most attention is being paid to the functioning of the horizontal semi-circular canals. With the tilting room the CNS responses, resulting from the integration and weighing of the sensory information, are measured. Chapter I contains this general introduction to the study as well as the history and development of the tilting room is presented.

In Chapter II the anatomy and physiology of upright stance is dealt with. Attention is focused on the close interactions between the sense organs involved and the CNS. It is important to note that the plasticity of the CNS may camouflage a sensory deficit. Dynamic examination may reveal such a malfunction. Although nowadays the fore-aft body sway is used in most studies because this sway is less complicated to describe, the tilt of the visual surrounding in the tilting room used in this study is in the lateral direction. The left-right body sway is further described with the use of a model designed by Kapteyn.

Chapter III deals with the equipment used in this study which is the stabilometer, the tilting room and a tilting chair. The stabilometer consists of two plates connected with a bar and a person standing on the top plate will cause a bending of the bar. With this system the torques exerted by the moving body on the stabilometer are resolved in the anterior-posterior and the left-right directions and recorded as a function of time: The stabilogram. The tilting room is a closed cabin which tilts from the base laterally about a front-back axis. A hole in the floor admits a horizontally fixed stabilometer platform on which the subject stands. Tilting of the room does not affect the position of the stabilometer. Although different stimulation patterns are possible, routinely a sinusoidal stimulus is used at frequencies of 0.025, 0.05, 0.1 and 0.2 Hz, resulting in periods of resp. 40, 20, 10 and 5 seconds. The amplitude of these stimuli is 5 degrees to the left and to the right for all frequencies. As soon as the room tilts lateral a sensory conflict arises between the otolithic and visual information. In this situation two extreme options are possible: An otolithic or visual option. In case of a pure otolithic option, no change in the direction of the gravity vector during room tilt is registered and thus no postural adjustments are needed. Furthermore the room will be perceived

as tilting and the stabilometer platform as stable. On the other hand, the visual option will lead to the perception of a stationary room and in this situation postural adjustments are required to align the body with the vertical structures of the room. The perception in this situation is a stable visual surrounding in combination with a tilting stabilometer platform. Analysis of both the visually induced left-right body sway and the perception of the test situation will reveal which sensory system, the otoliths or vision, is relative dominant at that moment.

In Chapter IV pilot experiments in the tilting room are described. Since routinely a sinusiodal lateral tilt of the room is used, the effect of a non-sinusoidal complex movement is examined which proves to have the same effects on posture. This outcome enables us to continue with the sinusoidal stimulus. The next section consists of training experiments with different time intervals up to one year. The results show that a once obtained postural stability in the tilting room is lasting even if re-examination takes place after one year. This outcome is in contrast to other studies on effect of training. Subjective horizontal (SH) and ocular counterrotation (OCR) measurements with the use of the tilting chair placed in the tilting room are carried out in order to establish their effect on the perception of the test situation in the tilting room. The influence of the visual, otolith and neckproprioceptive input, separate and combined, on both the SH and OCR is measured. A deviation of the SH may be due not only to a vestibular dysfunction but a neckproprioceptive or other sensory cue as well. It also appears that all three sensory systems have their effect on the OCR.

Chapter V deals with the examination of a group of healthy subjects on the stabilometer and in the tilting room. The SH of the controls was measured as well. The stabilometric results reveal a slide increase of postural instability after closure of the eyes. So the visual information is responsible for a stabilization of posture in the presence of an adequate visual frame. The tilting room hardly affects the postural stability. At increasing frequencies of room tilt, the left-right body sway even diminishes. Furthermore is the perception of the situation in the tilting room correct. The SH is indicated very accurately in the dark also at repeated examinations.

In Chapter VI the first group of patients with a uni- and bilateral loss of vestibular function are examined. The patients with a bilateral loss of vestibular function indicate on average their SH in line with the controls. At repeated examinations, however, the range increases up to 12 degr. which is in contrast to the range of less than one degr. in the control group. On the stabilometer the postural sway enlarges after closing the eyes. The patients exhibit in the tilting room a large left-right body sway, especially at the higher frequencies. In accordance the perception is a stable visual surrounding in combination with a tilting stabilometer platform. The level of compensation for the vestibular deficit can easily be determined with the use of the tilting room. In the end, all patients compensate completely for the low frequencies of room stimulation but at the highest frequency, they persistently show an increased body sway.

In case of a unilateral loss of vestibular function the results of the tilting room examination are more or less similar to the findings in the patients with a bilateral loss of vestibular function although the postural stability on the stabilometer is less affected after closing the eyes. The SH is in the acute stage on the unilateral loss deviated to the ipsilateral side. In many studies the normalization of the SH is regarded as a measurement for the compensation process. On the other hand, many patients still have complaints about posture and gait disorders. The SH by itself is not in all cases an accurate indicator for the compensation process. In the tilting room again at all frequencies the left-right body sway is enlarged, especially at the high frequencies of room tilt. In the end, all patients show an normal body sway well in range with the control group, also at the highest frequency. A unilateral loss of vestibular function, just as a bilateral deficit, leads temporarily to a relative dominance of the visual information over the hampered vestibular input. This shifting of the relative weight of the involved sensory information can easily be demonstrated in the tilting room.

Chapter VII concerns the examination of patients with an acoustic neurinoma in the tilting room. Registration of the SH shows a deviation in most patients to the ipsilateral side. Some patients indicate a SH deviated to the contralateral side despite their tumour is not so big that an increased pressure on the pons and cerebellum is likely to occur. Again, postural stability on the stabilometer is seriously affected after closing the eyes. In the tilting room all patients show an increased left-right body sway which indicates a relative dominance of the visual information. Not only acute vestibular pathology leads to this strategy, also a creeping loss of vestibular function has the same impact. Although patients with an acoustic neurinoma seldom complain about posture and gait disorders, a seriously affected postural control could be demonstrated.

In Chapter VIII patients with cervical ataxia resulting from a whiplash trauma are examined in the tilting room. Since their complaints are often head position dependent, stabilometric measurements were also executed in different head positions. Extension of the neck proved to have a serious negative effect on posture. The SH estimates with the head in the upright position are not disturbed. With the head tilted towards the left and right shoulder, asymmetries were found in many patients. On examination in the tilting room a damage of the afferent neck proprioceptors also leads to an increased left-right body sway, especially at the higher frequencies. In accordance is the incorrect perception of the test situation in the tilting room. Also in this patient group leads a damage of the afferent neck proprioceptors to a relatively increased weight imparted to the visual information.

Chapter IX contains the general conclusion and discussion of this study and a proposal for a model which may explain tilting room behaviour of both healthy subjects and patients. The incorrect perception of the testsituation in the tilting room appears to be linked with a deviation of the SH. Since the tilting room has so little effect on healthy subjects, an increased postural sway in the tilting room must be a reason for further examinations. The outcome of the tilting room examination itself is not specific but very sensitive in establising equlibrium disorders.

SAMENVATTING

In dit proefschrift wordt de kantelkamer gebruikt voor het dynamisch evenwichtsonderzoek van zowel patienten als een gezonde controle groep. Doel van deze studie is een evaluatie en herbeoordeling van deze onderzoeken om overeenkomsten in het houdingsevenwicht te identificeren. Het grote voordeel van het dynamisch onderzoek van een verstoord houdingsevenwicht is dat het evenwichtssysteem als een geheel beoordeeld wordt en niet slechts een facet er van, zoals het geval is bij het routine evenwichtsonderzoek met de draaistoel en de electro-nystagmografie. Bij het routine evenwichtsonderzoek ligt het accent van het onderzoek op het functioneren van de horizontale half-cirkelvormige kanalen. Bij het kantelkameronderzoek worden uiteindelijk de responsies van het centrale zenuwstelsel (CZS), als resultaat van de centrale integratie en weging van de zintuiginformatie, geregistreerd. Hoofdstuk I bevat deze algemene introductie evenals de geschiedenis en ontwikkeling van de kantelkamer.

Hoofdstuk II beschrijft de anatomie en fysiologie van het rechtop staan. De aandacht richt zich met name op de intensieve wisselwerking tussen de betrokken zintuigsystemen en het CZS. Juist de plasticiteit van het CZS maakt het mogelijk dat een disfunctie van een zintuigsysteem gemaskeerd wordt. Dynamisch evenwichtsonderzoek kan dit aan het licht brengen. In de meeste studies wordt vandaag de dag gebruik gemaakt van de voor-achterwaartse lichaamszwaai aangezien de beschrijving hiervan minder gecompliceerd is dan de links-rechts zwaai. Echter, in de kantelkamer wordt gebruik gemaakt van de symmetrische lichaamszwaai in links-rechts richting. Voor de beschrijving van de links-rechts lichaamszwaai wordt gebruik gemaakt van een model zoals ontworpen door Kapteyn.

Hoofdstuk III beschrijft de apparatuur, bestaande uit de stabilometer, de kantelkamer en de kantelstoel, waarvan in deze studie gebruik is gemaakt. De stabilometer is opgebouwd uit twee cirkelvormige platen welke centraal door een staaf verbonden zijn. Wanneer een persoon, staande op de bovenste plaat, zijn zwaartepunt verplaatst zal dit een verbuigen ven de staaf tot gevolg hebben. Het koppel dat zo door de bewegende proefpersoon op de staaf wordt uitgeoefend wordt ontbonden in voor-achterwaartse en laterale componenten en als functie van tijd weergegeven: het stabilogram. De kantelkamer is een gesloten ruimte die vanuit een voor-achterwaartse as door de bodem van de kamer in het laterale vlak kantelt. De proefpersoon staat op een stabilometer gemonteerd in een opening in de bodem van de kamer. Kanteling van de kamer heeft geen invloed op de positie van de stabilometer. Hoewel verschillende stimulatie vormen mogelijk zijn, wordt routinematig gebruik gemaakt van een sinusvormige stimulus met verschillende frequenties: 0.025, 0.05, 0.1 en 0.2 Hz. hetgeen leidt tot perioden van respectievelijk 40, 20, 10 en 5 seconden. De stimulus amplitude is voor alle frequencies 5 graden naar links en naar rechts. Zodra de kamer begint te bewegen, ontstaat een sensorisch conflict tussen de otolieten informatie enerzijds en de visuele informatie anderzijds. In extremo zijn er in deze situatie twee mogelijkheden: een otolieten of een visuele optie. In het geval van een zuivere otolieten optie zal de proefpersoon geen verandering in de richting van de zwaartekracht registreren en er zijn dan ook geen houdingscorrecties noodzakelijk. De kamer zal dan ook als bewegend worden ervaren en de stabilometer als stabiel. In het geval van een zuivere visuele optie zal de perceptie een stabiele visuele omgeving zijn met een bewegend stabilometer platform: nu zijn wel houdingscorrecties nodig om het lichaam evenwijdig te houden aan de verticale structuren van de kantelkamer met als gevolg een grote laterale lichaamszwaai. Analyse van zowel de amplitude van de geïnduceerde links-rechts lichaamszwaai en de perceptie van de testsituatie zal duidelijk maken welk zintuig systeem, de visus of de otolieten, op dat moment het zwaarst gewogen wordt.

In hoofdstuk IV worden aanvullende experimenten met de kantelkamer beschreven. Aangezien bij het routine onderzoek gebruik wordt gemaakt van een sinusvormige beweging van de kamer, wordt hier het effect van een complexe, niet-sinusvormige stimulus onderzocht. Beide stimulus vormen blijken eenzelfde effect op het houdingsevenwicht te hebben zodat bij het patienten onderzoek volstaan kan worden met de sinusvormige stimulatie van de kantelkamer. Het volgende onderdeel betreft habituatie experimenten met verschillende tijdsintervallen, van een uur tot een jaar. De resultaten laten zien dat eens verkregen stabiliteit in de kantelkamer behouden blijft zelfs als het herhalingsonderzoek een jaar later plaatsvindt. Deze bevinding is in tegenspraak met de resultaten van andere onderzoeken naar het effect van training. Zowel de geïsoleerde als de onderling gecombineerde invloed van de visuele, de otolieten en afferente nekproprioceptieve informatie op de subjectieve horizon (SH) en de ocular counterrotation (OCR) worden bepaald door de kantelstoel in de kantelkamer te plaatsen. Meting van de SH en de OCR wordt verricht zodat de invloed van de SH en de OCR op de perceptie van de testsituatie in de kantelkamer bepaald kan worden. Uit de resultaten blijkt dat een deviatie van de SH niet alleen door een vestibulaire aandoening maar ook door een laesie van de afferente nekproprioceptoren of een ander betrokken zintuig systeem veroorzaakt kan worden. Verder hebben alle drie de betrokken zintuigen hun effect op de OCR.

Hoofdstuk V behandelt het onderzoek van een groep gezonde proefpersonen op de stabilometer en in de kantelkamer. Ook de SH van deze personen wordt gemeten. De resultaten van de stabilometrie metingen laten een geringe toename zien van de houdingsinstabiliteit na het sluiten van de ogen. Hieruit blijkt dat de aanwezigheid van adequate visuele informatie een stabiliserend effect heeft op het houdingsevenwicht. De kantelkamer heeft slechts een beperkt effect op het houdingsevenwicht. Bij de hogere frequenties wordt de invloed op de links-rechts lichaamszwaai zelfs nog minder.

De perceptie van de testsituatie is dan ook correct in de vorm van een bewegende visuele omgeving en een stabiel stabilometer platform. De SH wordt in het donker zowel intra- als interindividueel zeer nauwkeurig aangegeven.

In hoofdstuk VI wordt de eerste groep patienten behandeld met een enkel- of dubbelzijdige labyrinth uitval. De patienten met een dubbelzijdige labyrinth uitval laten gemiddeld een SH zien vergelijkbaar met de controle groep. Bij herhaalde meting echter is er sprake van een zeer grote spreiding tot 12 graden in tegenstelling tot de spreiding van minder dan een graad bij de controle groep. Bij de stabilometrie is er sprake van een aanzienlijke toename van de beweeglijkheid na het sluiten van de ogen. In de kantelkamer neemt bij alle frequencies, maar juist bij de hoogste, de links-rechts beweeglijkheid sterk toe. In overeenstemming hiermee is de perceptie verstoord: de meeste patienten ervaren stabilometer beweeglijkheid in combinatie met een stabiele visuele omgeving. Met het gebruik van de kantelkamer is verder de mate van compensatie na een geheel verlies van de vestibulaire functie eenvoudig vast te stellen. Uiteindelijk compenseren de patienten volledig voor de lage frequenties. Voor de hoogste frequentie echter blijft er sprake van een vergrote lichaamszwaai.

In het geval van een enkelzijdige labyrinth uitval zijn de resultaten van het onderzoek min of meer gelijk aan de uitkomst van de onderzoeken van patienten met een dubbelzijdige labyrinth uitval. De toename van de beweeglijkheid op de stabilometer is na het sluiten van de ogen minder uitgesproken. In de acute fase is de SH gedevieerd naar de aangedane zijde. Door verschillende onderzoekers wordt het normaliseren van de SH gebruikt als een maat voor de compensatie. Het blijkt echter dat veel patienten nog klagen over een verstoord houdingsevenwicht terwijl hun SH alweer normaal is. De SH is dus niet in alle gevallen een juiste maat voor de compensatie van een enkelzijdige labyrinth uitval. In de kantelkamer is ook nu bij alle frequenties, vooral bij de hoge, de lichaamszwaai vergroot.

Uiteindelijk normaliseert voor deze patienten groep de lichaamszwaai bij alle kantelkamer frequenties tot binnen de spreiding van de controle groep. Net als bij een enkelzijdige labyrinth uitval is er ook in het geval van een dubbelzijdig verlies van vestibulaire functie sprake van een tijdelijke relatieve dominantie van de visuele informatie over de verstoorde vestibulaire informatie. In de kantelkamer kan deze verschuiving van het relatieve gewicht van de betrokken sensorische informatie eenvoudig worden aangetoond.

Hoofdstuk VII bevat de resultaten van het kantelkamer onderzoek van patienten met een acousticus neurinoom. Meting van de SH laat bij de meeste patienten een deviatie naar de aangedane zijde zien. In een enkel geval is de SH gedevieerd naar de gezonde zijde zonder dat het neurinoom een afmeting heeft dat compressie van de pons en de hersenstam te verwachten is. Ook nu blijkt weer dat het sluiten van de ogen een aanzienlijke toename van de beweeglijkheid veroorzaakt op het stabilogram. In de kantelkamer is de lichaamszwaai bij alle frequenties sterk toegenomen zodat er weer sprake is van een relatieve dominantie van de visuele informatie. Zowel in het geval van een acuut verlies van vestibulaire functie als bij een geleidelijke afname is de uiteindelijke strategie identiek. Hoewel patienten met een acousticus neurinoom zelden klagen over een verstoord houdingsevenwicht worden bij heronderzoek evidente afwijkingen gevonden.

In Hoofdstuk VIII worden resultaten gepresenteerd van het onderzoek van patienten met een cervicale ataxie veroorzaakt door een whiplash-verwonding. Aangezien de klachten voornamelijk geluxeerd worden door bepaalde hoofdposities, wordt de stabilometrie uitgebreid met een aantal metingen met verschillende hoofdposities. Extensie van de nek blijkt een uitgesproken negatief effect op het houdingsevenwicht te hebben. Meting van de SH met het hoofd rechtop laat geen afwijkingen zien. Wanneer nu het hoofd op de linker of de rechter schouder gebracht wordt, blijkt bij een groot aantal patienten een asymmetrie van de SH op te treden. Bij het kantelkamer onderzoek wordt ook bij een beschadiging van de afferente nekproprioceptoren een visuele dominantie gevonden hetgeen blijkt uit de foutieve perceptie en de toegenomen lichaamszwaai tijdens beweging van de kamer.

Hoofdstuk IX tenslotte bevat de uiteindelijke conclusies van deze studie en een voorstel voor een model dat mogelijk het gedrag in de kantelkamer verklaart van zowel de gezonde proefpersonen als de verschillende patienten groepen.

De incorrecte perceptie van de testsituatie in de kantelkamer lijkt gerelateerd aan een afwijking van de SH. Aangezien de kantelkamer slechts een gering effect heeft op het houdingsevenwicht van gezonde personen, moet in het geval van een te grote beweeglijkheid in de kantelkamer verder onderzoek verricht worden naar de mogelijke oorzaak. De uitkomst van het kantelkamer onderzoek op zich is niet specifiek voor een bepaalde afwijking maar wel zeer sensitief in het vaststellen van evenwichtsstoornissen.

LITERATURE

[1] Handbook of Sensory Physiology, Kornhuber, H.H. (ed), Section I, Vol. III, part 2, 1984, Springer Verslag, Berlin.

[2] Handbook of Sensory Physiology, Kornhuber, H.H. (ed), Vol. VI, part 2, 1984, Springer Verslag, Berlin.

[3] Handbook of Sensory Physiology, Kornhuber, H.H. (ed), Vol. VIII, 1978, Springer Verslag, Berlin.

[4] Atlas of Human Anatomy, Sobotta and Bechner, Vol. III, 1975.

[5] Abrahams, V.C., Richmond, F.J.R. and Rose, P.K. (1975) Absence of monosynaptic reflex in dorsal neck muscles of the cat. Brain Res. 92, 130-131.

[6] Allum, J.H.J. and Kesher, E.A. (1986) Vestibular and proprioceptive control of sway stabilization. In: Bles, W. and Brandt, Th. (eds.) Disorders of posture and gait. Elsevier sience publishers B.V., Amsterdam.

[7] Aubert, H. (1861) Eine scheinbare bedeutende Drehung von Objecten bei Neigung des Kopfes von rechts nach links. Virchows Arch. path Anat., 20, 381-393.

[8] Babinski, J. and Weill, G.A. (1913) Desorientation et desequilibration spontanee et provoquee. La deviation angulaire. C.R. Soc. Biol. Paris, 74, I, 852-855.

[9] Baloh, R.W., Konrad, H.R., Dirks, D. and Honrubia, V. (1976) Cerebellar pontine angle tumors. Results of quantitative vestibulo-occular testing. Arch. Neurol. 33, 507-512.

[10] Baloh, R.W. and Honrubia, V. (1979) Clinical neurophysiology of the vestibular system. Davis, Philidelphia.

[11] Barany, R. (1906) Untersuchungen uber den vom Vestibularapparat des Ohres reflektorisch ausgelösten Rhithmischen Nystagmus und seine Begleiterscheinungen. Monatschr. Ohrenheilk. 40, 193-297.

[12] Barany, R. (1906) Uber die vom Orhlabyrinth ausgelöste Gegenrolling der Augen bei Normalhorenden, Ohrenkranken und taubstummen. Arch. Ohrenheilkd., 68, 1.

[13] Barlow, D. and Freedman, W. (1980) Cervico-ocular reflex in the normal adult. Acta Otolaryngol.(Stockh.) 88, 487-496.

[14] Bender, M. and Jung, R. (1948) Abweichungen der subjektiven optischen Vertikalen und Horizontalen bei Gesunden und Hirnverletzten. Archiv. f. Psychiatrie, Bd. 181, 193-212.

[15] Bernard, Cl. (1858) Cours de Medecine du College de France. Lecon sur la physiologie et la pathologie du systeme nerveux. 25 mars 1857.

[16] Berthoz, A., Pavard, B. and Young, L.R. (1975) Perception of linear horizontal selfmotion induced by peripheral vision (Linear vection). Basic characteristics and visual-vestibular interactions. Exp. Brain Res. 23, 471-47.

[17] Bles, W. and de Wit, G. (1976) Study of the effect of optic stimuli on standing. Agressologie 17C, 1.

[18] Bles, W., Kapteyn, T.S. and de Wit, G. (1977) Effects of visual-vestibular interaction on human posture. Adv. Oto-Rhino-Laryngol. 22, 111-118.

[19] Bles, W. (1979) Thesis: Sensory interactions and human posture. Free University, Amsterdam, Holland.

[20] Bles, W. Kapteyn, T.S., Brandt, Th. and Arnold, F. (1980) The mechanism of physiological height vertigo, II, Posturografy. Acta Otolaryngol. 89, 534-540.

[21] Bles, W., de Jong, J.M.B.V. and de Wit, G. (1983) Compensation for labyrinthine defects examined by use of a tilting room. Acta Oto-laryngol. (Stockh.) 95, 576-579.

[22] Bles, W., de Jong, J.M.B.V. and de Wit, G. (1984) Somatosensory compensation for loss of labyrinthine function. Acta Otolaryngol. (Stockh.) 97, 213-221.

[23] Bles, W. and de Jong, J.M.B.V. (1986) Uni- and bilateral loss of vestibular function. In: Bles, W. and Brandt, Th. (eds.) Disorders of posture and gait.Elsevier sience publishers B.V., Amsterdam.

[24] Bles, W. (1988) TNO Institute for Perception, Soesterberg, report 1988 C 9.

[25] Bles, W. and van Raaij, J.L. (1988) The tilting room and the D1 spacelab mission. Adv. ORL, Vol. 42, 132-17.

[26] Brandt, Th., Dichgans, J. and Koenig, E. (1973) Differential effects of central versus periferal vision on egocentric and exocentric motion perception. Exp. Brain Res. 16, 476-491.

[27] Brandt, Th. and Daroff, R.B. (1980) The multisensory physiological and pathological vertigo syndromes. Ann. Neurol. 7, 195-203.

[28] Brandt, Th., Arnold, F., Bles, W. and Kapteyn, T.S. (1980) The mechanism of physiological height vertigo. I. Theoretical approach and psychophysics. Acta Otolaryngol. 89, 513-523.

[29] Brandt, Th., Krafczyk, S. and Malsbenden,I. (1981) Postural imbalance with head extension: Improvement by training as a model for ataxia therapy. Ann. NY Acad. Sci. 374, 636-649.

[30] Brandt, Th. (1984) Episodic vertigo. In: R.E. Rakel (ed), Conn' current therapy. Saunders Co., Philadelphia, 741-746.

[31] Brandt, Th., Paulus, W and Straube, A. (1986 a) Vision and posture. In: Bles, W. and Brandt, Th. (eds) Disorders of posture and gait. Elsevier sience publishers B.V. Amsterdam.

[32] Brandt, Th., Dieterich, M. and Büchele, W. (1986 b) Posturalabnormalities in central vestibular brain stem lesions. In: Bles, W. and Brandt, Th. (eds) Disorders of posture and gait. Elsevier science publishers B.V., Amsterdam.

[33] Brandt, Th., Buchele, W. and Krafczyk, S. (1986 c) Training effects on experimental postural instability: A model for clinical ataxia therapy. In: Bles, W. and Brandt, Th. (eds.) Disorders of posture and gait. Elsevier sience publishers B.V., Amsterdam.

[34] Clark, B. and Graybiel, A. (1963) Perception of the postural vertical in normals and subjects with labyrinthine defects. J. of Exp. Psychol. 5, 490-494.

[35] Cohen, L.A. (1961) Role of eye and neck proprioceptive mechanisms in body orientation and motor coordination. J. of Neurophysiol. 24, 1-11.

[36] Cooper, S. and Daniel, P.M. (1963) Muscle spindles in man, there morphology in the lumbricals and the deep muscles of the neck. Brain 86, 563-594.

[37] Courjon, J.H. and Jeannerod, M. (1979) Visual substitution of labyrinthine defect. In: R. Granit and O. Pompeiano (eds.) Progress in brain research, Vol. 50. Reflex control of posture and locomotion. Elsevier, Amsterdam, 783-792.

[38] Diamond, S.G., Markham, C.H. (1983) Ocular counterrolling as an indicator of vestibular otolith function. Neurology, 33, 1460-1469.

[39] Dichgans, J., Brandt, Th. and Held, R. (1975) The role of vision in gravitational orientation. Fortschr. d. Zool., 23, I, 255-264.

[40] Dichgans, J., Mauritz, K.H., Allum, J.H.J. and Brandt, Th. (1976) Postural sway in normals and atactic patients: Analysis of the stabilizing and destabilizing effects of vision. Agressologie 17C, 15.

[41] Dichgans, J. and Diener, H.C. (1986) Different forms of postural ataxia in patients with cerebellar diseases. In: Bles, W. and Brandt, Th. (eds) Disorders of posture and gait. Elsevier science publishers B.V., Amsterdam.

[42] Dix, M.R. and Hallpike, C.S. (1952) The pathology, symptomatology and diagnosis of certain common disorders of the vestibular system. Ann. Otol. (St. Louis) 61, 987-1016.

[43] Duchenne, G.B.A. (1958) De L'ataxie locomotrice progressive. Recherches sur une maladie caracterisee specialement par des troubles genereaux de la coordination des movements. Arch. Gen. Med. 641.

[44] Ebenholtz, S.M. (1977) Determants of the rod and frame effect: The role of retinal size. Percept. Psychophys., 22, 531-538.

[45] Ebenholtz, S.M. and Benzschawel, T.L. (1977) The rod and frame effect and induced head tilt as a function of observation distance. Percept. Psychophys., 22, 491-496.

[46] Edwards, A.S. (1946) Body sway and vision. J. Exp. Psychol. 36, 526.
[47] Fisch, U. (1973) The vestibular response following unilateral vestibular neurectomy. Acta Otolaryngol. (Stockh.) 73, 229
[48] Fischer, M.H. (1927) Messende Untersuchungen uber die Gegenrollung der Augen und die Lokalisation der Scheinbaren Vertikalen bei seitlicher Neigung. Albrechts v. Graefes Arch. Ophtal., 118, 663-680.
[49] Fischer, M.H. (1930) Messende Untersuchung uber die Gegenrollung der Augen und die Lokalisation der scheinbaren Vertikalen bei seitlicher Neigung des Gesamtkorpers bis 360 Grd. II. Albrechts v Graefes Arch Ophtal, 123, 476-508.
[50] Fisher, C.M. (1967) Vertigo in cerebrovascular disease. Arch. Otolaryngol. 85, 529-534.
[51] Fleishman, M.H. (1953) Perception of body position in the absence of visual cues. J. Exp. Psychol., 46, 261-270.
[52] Fluur, E. (1975) A comparison between subjective and objective recording of ocular counter-rolling as a result of tilting. Acta Otolaryngol (Stockh), 79, 111-114.
[53] Fregly, A.R. (1974) Vestibular ataxia and its measurement in man. In: H.H. Kornhuber (ed.) Handbook of Sensory Physiology, Vol. VI(2), 321-360. Springer-Verslag, Berlin.
[54] Frenzel, H. (1928) Rucknystagmus als Halsreflex Und Slagfeldverlagerung des Labyrinthaeren Drehnystagmus durch Halsreflexe. Z. Hals-, Nase Ohrenheilk. 21, 177-187.
[55] Friedman, G. (1970) The judgement of the visual vertical and horizontal with peripheral and central vestibular lesions. Brain, 93, 313-328.
[56] Fukuda, T. (1983) Statokinetic reflexes in equilibrium and movement. Tokyo University Press, Tokyo.
[57] Gibson, J.J. and Mowrer, O.H. (1938) Determinants of the perceived vertical and horizontal. Psychol. Rev., 45, 301- 323.
[58] Gollas, E. (1936) Untersuchungen der Raddrehung der Augen bei einseitigem Labyrinthausfall. Arch Orhen Nasen Kehlkopfheilkd, 140, 340-354.
[59] de Graaf, B. (1990) Thesis: Influence of eye movements on visual perception. Utrecht, Holland.
[60] Graybiel, A. and Patterson, J.L. (1955) Threshold of stimulation of the otolith organs as indicated by the oculogravic illusion. J. Appl. Physiol., 666.
[61] Graybiel, A. and Clark, B. (1962) Perception of the horizontal or vertical with head upright, on the side, and inverted under static conditions, and during exposure to centripetal force. Aerospace Med., 33, 147-155.
[62] Graybiel, A. and Fregly, A.R. (1966) A new quantitative ataxia test battery. Acta Otolaryngol. (Stockh.) 61, 292-312.

[63] Gupta, G.C. (1973) Effects of lateral body tilts and visual frames on perception of the apperent vertical. J. of Experimental Psychology, 100, 162-167.
[64] Haines, R.F. (1974) Effect of bedrest and exercise on body balance. J. Appl. Physiol. 36, 323-327.
[65] Hellebrandt, F.A., Franseen, E.B. (1943) Physiological study of the vertical stance of man. Physiol. Reviews, 23, 220-255.
[66] Howard, I.P. and Evans, J.A. (1963) The measurement of eye torsion. Vision Res, 3, 447.
[67] Howard, I.P. (1982) Human visual orientation. Wiley & Sons, Toronto.
[68] Igarashi, M., Levy, J.K., O-Uchi, T. and Reschke, M.F. (1981) Further study of physical excercise and locomotor balance modification after peripheral vestibular lesions (unilateral utricular neurotomy) in squirrel monkeys. Acta Otolaryngol. (Stockh.) 92, 101-105.
[69] Igarashi, M. (1986) Compensation for peripheral vestibular disturbances - animal studies. In: Bles, W. and Brandt, Th. (eds.) Disorders of posture and gait. Elsevier sience publishers B.V., Amsterdam.
[70] Janecke, J.J., Sommerville, S., Maddox, H.E. and Battin, R.R. (1972) Importance of vestibulography in the acoustic neurinoma test battery. Laryngoscope 82, 1035-1039.
[71] de Jong, J.M.B.V., Bles, W. and Bovenkerk, G. (1981) Nystagmus, gaze shift and selfmotion perception during sinusoidal head and neck rotation. Ann. NY Acad. Sci. 374-599.
[72] de Jong, J.M.B.V. and Bles, W. (1986) Cervical dizziness and ataxia. In: Bles, W. and Brandt, Th. (eds) Disorders of posture and gait. Elsevier science publishers B.V., Amsterdam.
[73] Jongkees, L.B.W. (1974) Pathology of vestibular sensation. In: Handbook of sensory physiology. Kornhuber, H.H. (ed), Vol. VI(2), 413-450, Springer Verslag, Berlin.
[74] Kanzaki, J. and Ouchi, T. (1978) Measurements of counter-torsion reflex with fundoscopic camera in normal subjects and in patients with inner ear lesions. Arch Oto-Rhino-Laryngol., 218, 191-197.
[75] Kapteyn, T.S. and de Wit, G. (1972) Posturography as an auxiliary in vestibular investi-gation. Acta Otolaryngol. 73, 101-111.
[76] Kapteyn, T.S. (1973) Thesis: Het staan van de mens. Free University, Amsterdam, Holland.
[77] Kapteyn, T.S. and Bles, W. (1976) Effects of optic and vestibular stimuli on stabilograms of patients with dizziness complaints. Agressologie 17D, 25-29.
[78] Kapteyn, T.S. and Bles, W. (1977) Circular vection and human posture. Relation between the reactions to various stimuli. Agressologie 18, 335-339.

[79] Katsarkas, A. and Outerbridge, J.S. (1981) Compensation of unilateral vestibular loss in vestibular neuronitis. In: Cohen, B. (ed) Vestibular and oculomotor physiology. New York academy of siences, Vol. 374, 784-793.

[80] Kim, J.H. and Partridge, L.D. (1969) Observations on types of response to combinations of neck, vestibular and muscle stretch signals. J. Neurophysiol. 32, 239-250.

[81] Krejcova, H., Highstein S. and Cohen B. (1971) Labyrinthine and extralabyranthine effects on counterrolling. Acta Otolaryngol. (Stockh), 72, 165-171.

[82] Lechner-Steinleiter, S. (1978) Interaction of labyrinthine and somatoreceptor inputs as determinants of the subjective vertical. Psychol. Res., 40, 65-76.

[83] Lechner-Steinleiter, S., Schone, H. and Wade, N.J. (1979) Perception of the visual vertical: Utricular and somatosensory contributions. Psychol. Res., 40, 407-414.

[84] Lechner-Steinleiter, S. and Schone, H. (1980) The subjective vertical under dry and wet conditions at clockwise and counterclockwise changed positions and the effect of parallel-lined background field. Psychol. Res., 41, 305-317.

[85] Leroux, J., Baron, J.B., Bizzo, G., Bessineton,J.C., Gueguen, C., Noto, R. and Pacifini, M. (1973) Etude spectrale des deplacements spontanes antero-posterieurs et lateraux de centre de gravitee de l'homme en orthostatisme. Agressologie 14C, 57.

[86] Leopold, H.C., Doerr M. and Thoden U. (1983) Cervico-ocular responses (COR) during slow sinusoidal head movements in subjects with bilateral labyrinthine lesions. Arch. Psychiat. Nervenkr. 233, 439-447.

[87] Mann, C.W. (1952) Visual factors in the perception of verticality. J. of Exp. Psychol., 44, 460-465.

[88] Mauritz, K.H. and Dietz, V. (1980) Characteristics of postural instability induced by ischaemic blocking of leg afferents. Exp. Brain Res. 38, 117-119.

[89] McCabe, B.F., Ryu, I.H. and Sekitani, T. (1972) Further experiments on vestibular compensation. Laryngoscope, 82, 381

[90] Miller, E.F. (1962) Couterrolling of the human eyes produced by head tilt with respect to gravity. Acta Otolaryngol. (Stockh), 54, 479-501.

[91] Miller, E.F. and Graybiel, A. (1966) Role of the otolith organs in the perception of horizontality. Am. J. Psychol., 79, 24-37.

[92] Miller, E.F., Fregly, A.R. and Graybiel, A. (1968) Visual horizontal perception in relation to otolith function. Amer. J. Psychol. 81, 488-496.

[93] Müller, G.E. (1916) Uber das Aubertsche Phenomenon. Z. Psychol. Physiol. Sinnesorg., 49, 109-246.

[94] Nashner, L.M. (1970) Thesis. Sensory feedback in human posture control. M.I.T. MVT-70-3.

[95] Nashner, L.M., Black, F.O. and Wall, C. (1982) Adaptation to altered support surface and visual conditions during stance. Patients with vestibular deficits. J. Neurosci. 2, 536-544.

[96] Nelson J.R., Cope, D. (1971) The otoliths and the ocular counter torsion reflex. Arch Otolaryngol, 94, 40-50.

[97] Njiokiktjien, C.J. and Van Parijs, J.A.P. (1976) Romberg's sign expressed in a quotient. II. Pathology. Agressologie 17, 19-24.

[98] Norré, M.E. and Forrez, G. (1983) New perspectives in otoneurology. Evaluations of the vestibulospinal reflex by posturography. Acta ORL belg., 19, 15-23.

[99] Olsen, J.E. and Wolfe, J.W. (1984) Responses to rotational stimulation of the horizontal canals from patients with acoustic neurinomas. Acta Otolaryngol. (Stockh.), suppl. 406, 203-208.

[100] Olsen, J.E., Wolfe, J.W. and Engelken, E.J. (1981) Responses to low frequency harmonic acceleration in patients with acoustic neurinomas. Laryngoscope 91, 1270-1276.

[101] Oosterveld, W.J. (1972) Duizeligheid. Leiden, Stafleu

[102] Parker, D.E. (1980) The vestibular apparatus. Scientific American, 243, 118.

[103] Peitersen, E. (1974) Measurement of vestibulo-spinal responses in man. In: Handbook of sensory physiology. Kornhuber, H.H. (ed), Vol. VI(2), 267-280, Springer Verslag, Berlin.

[104] Precht, W. (1979) Vestibular mechanisms. Ann. review Neurosciense, 2, 265-289.

[105] Purdon Martin, J. (1967) The basal ganglia and posture. Pitman medical publishing company, London, England.

[106] Richmond, F.J.R. and Abrahams, V.C. (1979) What are the proprioceptors of the neck? In: Granit, R. and Pompeiano, O. (eds), Progress in brain research, Vol. 50, Reflex control of posture and movement. Elsevier sience publishers B.V., Amsterdam.

[107] Romberg, M.H. (1846) Lehrbuch der Nervenkrankenheiten des Menschen. Duncker, Berlin.

[108] Roos, J.W.P., Bles, W. and Bos, J.E. (1988) Postural control after repeated exposure to a tilting room. In: Amblard, B., Berthoz, A. and Clarac, F. (eds) Posture and gait. Elsevier sience publishers B.V., Amsterdam.

[109] Rubin, W. (1973) Whiplash with vestibular involvement. Arch. Otolaryngol. 97, 85-87.

[110] Schaefer, K.P. and Meyer, D.L. (1974) Compensation of vestibular lesions. In: H.H. Kornhuber (ed.) Handbook of Sensory Physiology, Vol. VI(2), 463-492. Springer-Verslag, Berlin.

[111] Schöne, H. (1962) Uber den Einfluss der Schwerkraft auf die Augenrollung und auf die Wahrnehmung der Lage im Raum. Zeitschrift vergl. Physiologie, 46, 57-87.

[112] Schöne, H. (1964) On the role of gravity in human spatial orientation. Aerospace Med., 35, 764-772.

[113] Schöne, H., Parker, D.E. and Mortag, H.G. (1967) Subjective vertical as a function of body position and gravity magnitude. Naturwissenschaften, 54, 288.

[114] Schöne, H. and Udo de Haes, H. (1968) Perception of the gravity vertical as a function of head and trunk position. Zeitschr Vgl Physiol 60, 440-444.

[115] Schöne, H. and Udo de Haes, H.A. (1969) Space orientation in humans with special reference to the interaction of vestibular, so maesthetic and visual inputs. Biokybernetik, band III Materialen des II. internationalen Symposiums "Biokybernetik", Leipzig, Sept. 1969.

[116] Schöne, H. (1975) The weight of gravity organ's signal in the control of perceptual and reflex type orientation at different body positions. Fortschr. d. Zool., 23, 1, 274-283.

[117] Schöne, H. and Lechner, S. (1978) The effect of preceding tilt on the perceived vertical. Acta Otolaryngol. (Stockh), 85, 68-73.

[118] Smith, J.W. (1957) The forces operating at the human ankle joint during standing. J. Anat. london. 91, 545-564.

[119] Solley, C.M. (1956) Reduction of error with practice in perception of the postural vertical. J. of Exp. Psychol., 52, 329-333.

[120] Steinleiter, S. (1975) Thesis. Untersuchungen zum Einfluss der Somatorezeptoren auf die Wahrnemung der Vertikalen im Dunkelraum.

[121] Stenvers, H.W.(1918) Un "stellreflex" du bassin chez l'homme. Arch. Neerl. Physiol. 2, 669-673.

[122] Toglia, J.U.(1976) Acute flexion-extention injury of the neck. Neurology (Minneap.) 26, 808-814.

[123] Torres, F. and Shapiro, S.K. (1976) Electroencephalograms in whiplash injuries. Arch. Neurol. (Chic.) 5, 28-35.

[124] Udo de Haes, H. (1970) Stability of apparent vertical and ocular countertorsion as a function of lateral tilt. Percept. Psychophys, 8, 137-142.

[125] Unterberger, S. (1938) Neue objective registrierbare Vestibularis-Korper drehreaction, erhalten durch Treten auf der Stelle: Der Tretversuch. Arch. Ohr-, Nas.-, Kehlk. Heilk. 145, 478-492.

[126] Vieville, T. and Masse, D. (1987) Ocular counter-rolling during active head tilting in humans. Acta Otolaryngol. (Stockh), 103, 280-290.

[127] Vogel, H., Thumler, R. and von Baumgarten, R.J. (1986) Ocular counterrolling. Some practical considerations for a new evaluation method for diagnostic purposes. Acta Otolaryngol. (Stockh), 102, 457-462.

[128] de Vries, N., Bles, W. and Feenstra, L. (1985) Patients with an acoustic neurinoma examined with a tilting room. Clin. Otolaryngol. 10, 103-108.

[129] Wade, N.J. (1968) Visual orientation during and after lateral head, body and trunk tilt. Percept. Psychophisics, 3, 215-219.

[130] Waespe, W. and Henn, V. (1977) Neuronal activity in the vestibular nuclei of the alert monkey during vestibular and optokinetic stimulation. Exp. Brain Res. 27, 523.

[131] Wagenaar, W.A. (1969) Note on the construction of diagram balanced latin squares. Psych. Bull., 72, 384-386.

[132] van Waveren, A.H. (1978) Rapport Stabilometrie. ENT-Department, Free University, Amsterdam, Holland.

[133] Werner, H., Wapner S. and Chandler, K.A. (1951) Experiments on sensorytonic field theory of perception: II+III. Effect of supported and unsupported tilt of the body on the visual perception of verticality. J. Exp. Psychol., 42, 346-357.

[134] de Wit, G. (1973 a) The stabilometry as an auxillary in investigation of patients with vestibular disturbances. Agressologie 14, 27.

[135] de Wit, G. (1973 b) The flying enterprise symptom. O.R.L. 35, 248-251.

[136] Witkin, H.A. and Asch, S.E. (1948) Studies in space orientation. III. Perception of the upright in the absence of a visual field. J. Exp. Psychol., 38, 603-614.

[137] Witkin, H.A. and Asch, S.E. (1948) Studies in space orientation. IV. Furtherexperiments on perception of the upright with displaced visual fields. J. Exp. Psychol. 38, 762-782.

[138] Woellner, R.C. and Graybiel, A. (1960) The loss of counterrolling of the eyes in three persons presumably without otolith organs. Ann Otol., 69, 1006-1012.

Stellingen

behorende bij het proefschrift
Posturography in the tilting room

1. Het afwijkend kantelkamer onderzoek heeft een lage specificiteit maar een hoge sensitiviteit.

2. Compensatie voor een geheel of gedeeltelijk verlies van vestibulaire functie kan met kantelkamer onderzoek geobjectiveerd worden.

3. Een evenwichtsonderzoek zonder aandacht voor de otolieten functie, waarbij geen afwijkingen gevonden worden, is niet alleen onvolledig maar kan ook niet als normaal worden afgegeven zonder de toevoeging 'voor zover onderzocht'.

4. De invloed van de afferente nek proprioceptieve informatie op de subjectieve horizon en de ocular counterrotation is nog onvoldoende onderzocht.

5. Ook bij gezonde personen kan tijdelijk een afwijkend kantelkamer gedrag geinduceerd worden onder andere door veranderingen in de grootte van de zwaartekracht.

6. Bij de indicatiestelling tot een gehoor verbeterende ingreep dient de gehoorfunctie van het niet te opereren oor betrokken te worden.

7. De keuze voor een 'mini in het oor' hoorapparaat dient op audiologische gronden gemaakt te worden en niet door cosmetische overwegingen bepaald te worden.

8. Bij chemopreventie trials dient meer aandacht te worden besteed aan bio-markers als 'intermediate endpoints'.

9. De 'external approach' voor de uitwendige correctieve neuschirurgie vertegenwoordigt geen nieuwe stroming maar slechts de keuze voor een incisie.

10. Het toenemend gebruik van aspirine in het kader van de primaire en secundaire preventie van hart- en vaatziekten is, gelet op de verhoogde bloedingsneiging, een vergroot risico voor niet-electieve ingrepen.

11. Cholesterol verlaging werkt stress verhogend.

12. Ter bevordering van de doorstroming op de Nederlandse snelwegen verdient het aanbeveling een minimum snelheid gelijk aan de maximum snelheid in te voeren.

13. Een evenwichtig mens is niet per definitie in staat in alle situaties zijn evenwicht te bewaren.

J.W.P. Roos, 11 januari 1991