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Analysis of Postural Sway in Patients with Normal Pressure Hydrocephalus: Effects of Shunt Implantation

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Abstract

Poor postural balance is one of the major risk factors for falling in normal pressure hydrocephalus (NPH). Postural instability in the clinic is commonly assessed based upon force platform posturography. In this study we focused on the identification of changes in sway characteristics while standing quiet in patients with NPH before and after shunt implantation. Postural sway area and sway radius were analyzed in a group of 9 patients and 46 controls of both genders. Subject's spontaneous sway was recorded while standing quiet on a force platform for 30-60 s, with eyes open and then closed. Both analyzed sway descriptors identified between-group differences and also an effect of shunt implantation in the NPH group. Sway radius and sway area in patients exhibited very high values compared with those in the control group. Importantly, the effect of eyesight in patients was not observed before shunt implantation and reappeared after the surgical treatment. The study documents that static force platform posturography may be a reliable measure of postural control improvement due to shunt surgery.

Key words: posture, sway, normal pressure hydrocephalus

Introduction

Postural stability is a fundamental part of the entire motor activity [1]. Decline in the postural stability may result from impairment of the central or peripheral postural control efficiency as well as abnormalities in function of motor executive systems.

Postural stability control involves the generation of appropriate stabilizing responses. This is done either by triggering and scaling preprogramed reactions or by continuous updating the center of gravity (COG) position in a feedback mode. The COG deviates from equilibrium and usually enlarges velocity, which is being detected and signaled by sensation receptors and muscle tension receptors, receptors of angle and linear accelerations – by a peripheral part of the system of balance and by the vision system that provides data related to the body shifts when the field of vision changes. The restoration process starts when the deflection of the equilibrium state exceeds some threshold level which can be different for everyone. The main factor which influences the threshold level is the actual state of the postural system. This state permanently changes in years but it can also change within days and even hours and minutes in among others due to fatigue.

During quiet stance stabilizing torques generated at different levels of the body's kinematic chain are transmitted mainly down to the base of support. They are observed as a compound center of foot pressure (COP) signal. These stabilizing processes shape COP characteristics [2]. Since COP is a measure of whole-body dynamics, it represents the summed up effect of a number of different neuromuscular components. These components are acting at different joints [3, 4] and their characteristics are strongly dependent on the main inputs that control postural stability. These inputs include visual, proprioceptive and vestibular systems. The effectors are muscles of the torso and limbs [5]. Locomotion control system consists of locomotion centres in the cortex, brain stem, and spinal cord (medulla). These regions obtain information (signals) from other areas of the brain, namely from the cerebellum and basal ganglia. Impairments of a central processing of input signals, e.g., due to ageing or resulting from pathology, also affect the COP characteristics.

Normal pressure hydrocephalus (NPH) is a pathological process caused by excessive accumulation of cerebrospinal fluid in the intracranial space related to unbalanced production and absorption of the fluid. The syndrome of normal pressure hydrocephalus is usually characterized by a triad of symptoms: complaints of gait disturbance, mild dementia and impaired bladder control [6]. Gait and balance disturbances are often the most pronounced symptom and the first to become apparent. The disturbances range in severity from mild imbalance to the inability to stand or walk at all. Gait is often wide-based, short-stepped, slow and shuffling, and with the whole body leaning posture. Patients with NPH may have trouble picking up their feet, making stairs and curbs difficult, which frequently results in falls. Normal pressure hydrocephalus is one of the few reversible causes of hypokinetic gait disorder in which the older adult's feet look as though they are glued to the floor [7]. The gait also has been described as magnetic.

Disturbances in gait and balance are real clinical problems which in many cases lead to handicapped movement and considerably increase risk of falls. There is also present a substantial deficit in upper limbs locomotor coactivity that helps maintain dynamic balance in the normal gait. A deficit in postural balance is even observed during quiet stance due to postural stability decline.

Postural instability is a commonly accepted risk factor which contributes to falls. By definition, a person irrevocably loses balance during quiet stance when his center of mass falls outside of the base of support [8]. Generally, the upright posture is stable if, when perturbed, it returns to its original state; the more quickly it returns, the more stable it is [9]. Efficiency of the central processing is the main physiological determinant of postural stability that is being affected by NPH.

The described pathology of gait does not result from any impairment of perception within the vestibular systems. Functions of proprioceptive receptors and the labyrinth remain unchanged. Nor are the causes for gait abnormalities related to the effector systems, that is, to bones, joints, and muscles. The observed pathologies, localized inside the brain are, however, not fully explained. These pathologies can be related to changes caused by dysfunctions of many tracts conducting stimuli of deep and surface sensibility, correcting tracks, leading to or from the cerebellum, regulating functions of oculomotor muscle, pyramidal tracts. These dysfunctions can be developed by tensions related to the sheer tensile stress of the lateral ventricles.

The purpose of the research presented here was to quantify the characteristics of the postural sway in patients with normal pressure hydrocephalus before and after shunt implantation, in order to establish its relevance to the stability of the upright posture. In this study we evaluated the postural sway control. We assumed that due to the pathology all the postural programs requiring on line feedback control have to be reorganized adequately to the quality of a control input. Thus, results of this study should elucidate the manner in which postural stability control is altered to compensate for the central processing deficits clearly pronounced in the hydrocephalic patients.

Material and Methods

Subjects

After ethical approval by a local Ethics Committee, posturographic recording were taken from NPH patients. The NPH group was composed of 9 diagnosed patients who were qualified for shunt implantation. Spontaneous postural sways were studied in 6 women and 3 men, 50-84 years old, the mean age of 65.

NPH diagnosis was based on the presence of the classical triad of symptoms confirmed by dilated ventricular system in CT imaging, neuropsychological examination, and an infusion test. Resistance outflow was increased in all patients qualified for the shunt implant, where R was >11 mmHg/ml/min. Before surgery, all patients had the characteristic gate and balance disturbances. The control group consisted of 47 healthy subjects aged 50-69.

Measurements

During the experiment, the patients were secured from a fall by close assistance of the experimenter. It was, however, not allowed to support or even touch the patient, who had to stand independently on the platform during the whole measurement time. That was sometimes too difficult for an NPH patient and, therefore, in many cases it was impossible to perform a full and correct measurement.

During the experiment, subjects were instructed to stand on a force plate (Pro-Med, Poland) in a comfortable stance. All subjects chose an open stance with the feet apart, slightly turned out. The examination was composed of two tests: with eyes opened (EO) and eyes closed (EC). Typical posturographic measurements last for 30 s, but recordings in the NPH patients were often confounded by artefacts resulting from uncontrolled movements: rapid swinging of the arms, turning the head, speech and attempts to get off the platform. For these reasons it was necessary to lengthen the recording time for up to 60 s. Posturographic examinations were performed twice for the same NPH patient: before and after the shunt implantation.

Force plate data were low-pass filtered (15 Hz cutoff frequency), sampled at 100 Hz and stored on a hard disk for off-line analysis. The collected data were used to calculate:

- Average radius of sway (Radius) in millimetres;
- Area of posturogram expanded surface (Area) in square millimetres.

Statistical Analysis

The Wilcoxon matched pairs test was used for intragroup comparison during EO and EC conditions, while the Mann-Whitney U test was performed for between-group comparisons. The tests are nonparametric alternatives to the t-test for dependent (Wilcoxon) and correlated (Mann-Whitney) samples. All the nonparametric analyses were conducted using Origin software (OriginLab Corporation, USA, v. 8.0 Pro).

Results

The results indicate that shunt implantation had a positive influence on the postural stability in the NPH patients. The sway range showed a substantial expansion before shunt implantation, with both eyes open and closed (Fig. 1) and it significantly decreased after the shunt treatment in both eye conditions (Fig. 2).

Comparison of NPH Patients before and after Shunt Implantation

Comparison of the mean values of the sway Radius in the NPH patients before and after shunt implantation

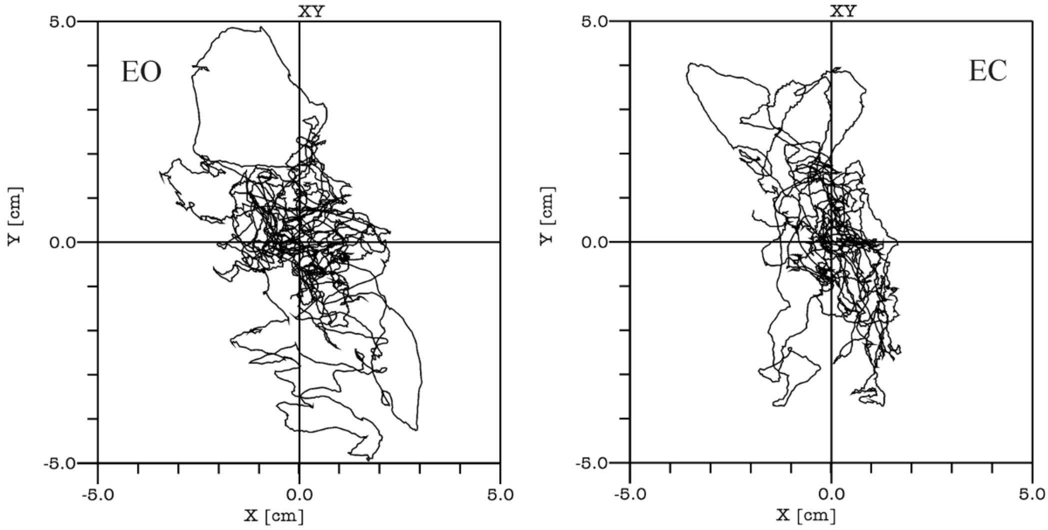

Fig. 1. Posturogram measured before shunt implantation with eyes open (EO) and closed (EC) in a normal pressure hydrocephalus (NPH) patient.

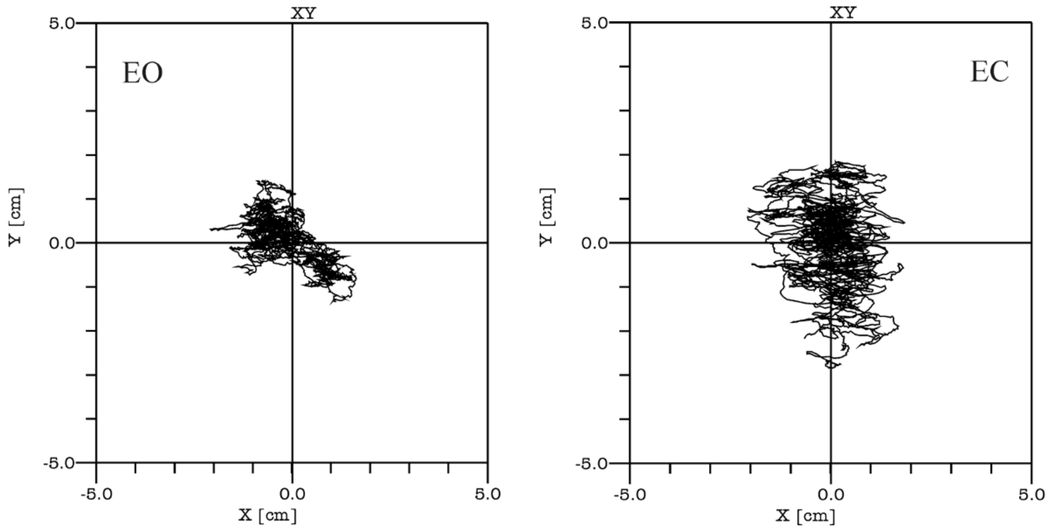

Fig. 2. Posturogram recorded in the NPH patient shown in Fig. 1 after shunt implantation. EO – eyes open, EC – eyes closed.

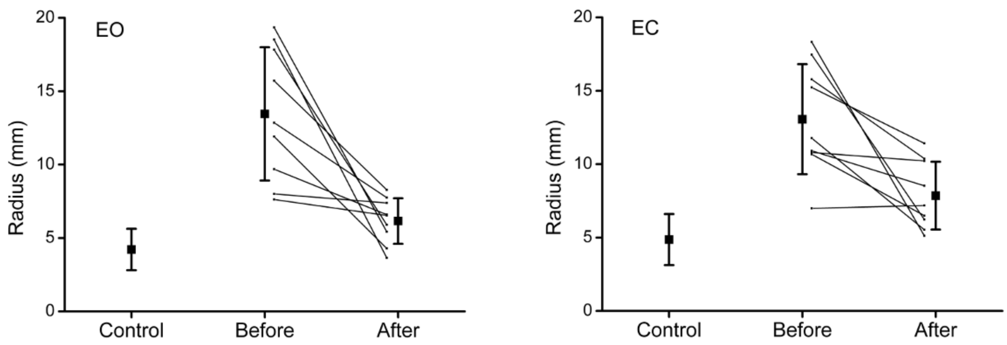

Fig. 3. Individual and mean values of the sway Radius measured with eyes open (EO) and closed (EC) in NPH patients before and after operation.

showed substantial reductions, from 13.5 to 6.2 mm while measured with the eyes open and from 13.1 to 7.9 mm with eyes closed ($P<0.01$ for both) (Fig. 3). The Area measurement also showed reductions of the sway; it decreased 4-fold for the eyes open condition, from 44.7 in the pre-treatment state to 10.8 cm^2 after the shunt treatment and 2-fold for the eyes closed, from 44.6 to 20.7 cm^2, respectively ($P<0.01$ for both) (Fig. 4).

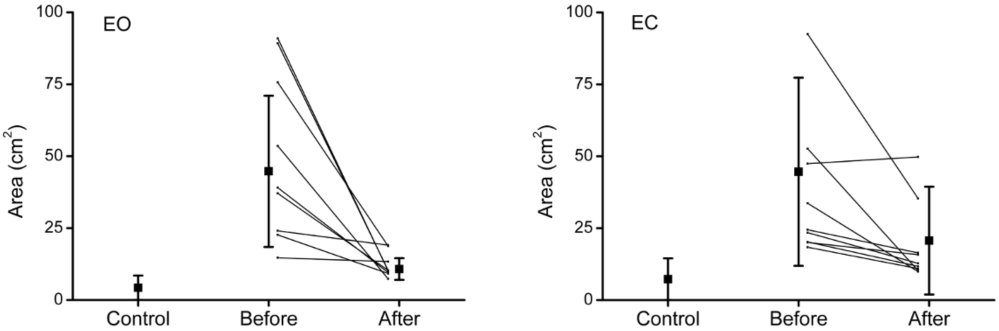

Fig. 4. Individual and mean values of the sway Area with eyes open (EO) and closed (EC) in NPH patients before and after operation.

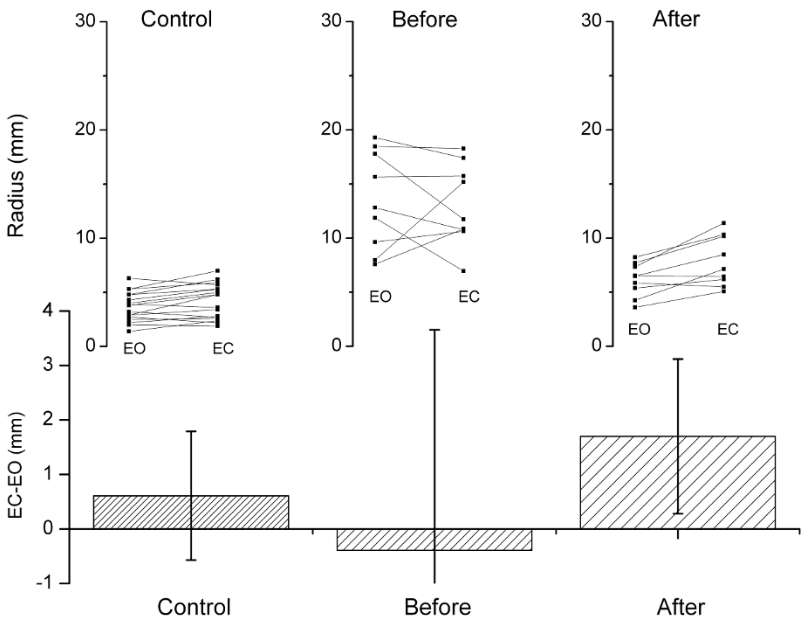

Fig. 5. Effects of visual conditions on the sway Radius in control and NPH patient groups before and after operation. The upper panels show individual values of the Radius for each subject in either group measured with eyes open (EO) and closed (EC). The bottom columns express differences between the respective EC-EO values.

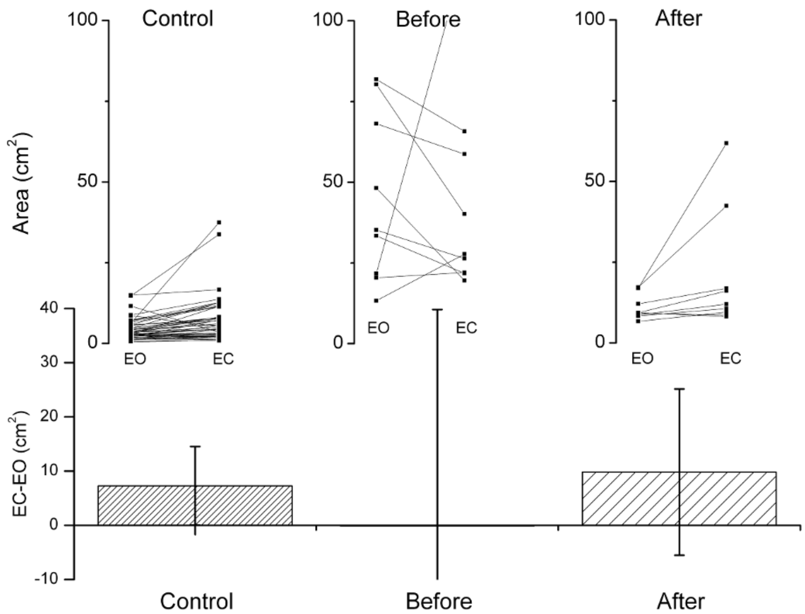

Fig. 6. Effects of visual stimulus on Area values in control and NPH patient group before operation and after operation. The upper panels shows individual values of Area for each subject in either group measured with eyes open (EO) and closed (EC). The bottom columns express differences between the respective EC-EO values.

Comparison with the Control Group

The mean values of the Radius and Area, measured with both eyes open and closed in the NPH group before shunt implantation significantly exceeded the corresponding values in healthy subjects. The results of statistical analyses were summarized in Table 1. Differences between the NPH patients after shunt implantation and the control subjects were meager, in view of a considerable reduction of the mean posturografic values after operation, making them approach those present in healthy subjects. With eyes open, the mean

Table 1. Average values of the sway Radius and the Area measured before and after shunt implantation in NPH patients and in the control group in two conditions: eyes open (EO) and eyes closed (EC).

		Control (n = 46)	Before Shunt (n = 9)	After Shunt (n = 9)	P		
					B vs. A	B vs. C	A vs. C
Radius (mm)	EO	4.2 ± 1.4	13.5 ± 4.5	6.2 ± 1.5	0.0039	2.6e-09	0.009
	EC	4.9 ± 1.7	13.1 ± 3.8	7.9 ± 2.3	0.0078	5.2e-07	0.015
p (EO vs. EC)		2.1e-04	n.s	0.019			
Area (cm²)	EO	4.3 ± 3.3	44.7 ± 26.3	10.8 ± 3.8	0.0039	1.5e-08	6.9e-06
	EC	7.3 ± 7.2	44.6 ± 32.7	20.7 ± 18.7	0.0078	1.5e-08	0.00019
P (EO vs. EC)		2.0e-07	n.s.	0.019			

B vs. A - the NPH group before vs. after operation; B vs. C and A vs. C – the NPH group before and after operation vs. the control group, respectively; The rows depicted as EO vs. EC show statistical significance for comparisons of the measurements with eyes open vs. eyes closed in each group.

Radius in the NPH patients after operation was 6.2 mm compared with the 4.2 mm in the control group (Fig. 3). With eyes closed, the respective Radius values were 7.9 and 4.9 mm. Despite relatively small differences, the mean values differed significantly ($p<0.01$ for EO and $p<0.05$ for EC). Similarly, statistical analysis for the sway Area (Fig. 4) revealed statistically significant difference for both eyes open and closed conditions ($p<0.001$).

Influence of Vision on Postural Sway Characteristics

The mean values of the Radius measured with eyes opened and closed in the NPH patients before shunt implantation were 13.5 and 13.1 mm, respectively; the difference was insignificant (Table 1, column B, row 4). This small difference is shown on a column chart in Fig. 5–middle panel, which also shows that differences in individual patients were rather random. The Radius values measured with eyes open and closed in the same NPH group after the shunt implantation treatment differed significantly ($p<0.01$, Table 1). The respective mean values were 6.2 and 7.9 mm for EO and EC condition. The mean difference achieved approximately 25% of the mean value (Fig. 5 – right hand panel). Here, differences in individual patients were similar, showing a growth in the Radius in each subject after closing the eyes. In the control group, eye closure resulted in lengthening of the mean Radius from 4.2 to 4.9 mm, i.e., by 15%, depicted in the left hand panel of Fig. 5. Therefore, the effect of visual stimulus in the NPH patients after shunt implantation was stronger than that in healthy subjects.

An analysis of the Area calculations gives similar results to that of the Radius ones. In the NPH patients before shunt implantation a paired statistical test did not show any significant differences between the values of 44.7 and 44.6 cm² for the eyes open and closed condition, respectively (Table 1, column B, row 7 and Fig. 6 - bottom middle chart). Differences in individual patients also were random. After the shunt implantation treatment, the Area values measured with eyes open – 10.8 cm² and closed – 20.7 cm² differed significantly ($p<0.01$). A coherent growth in individual Area values was also observed in patients after closing the eyes.

Discussion

The cause of balance disturbances being a frequent symptom in NPH is an abnormal cerebellum control over various groups of muscles and over correct flow of neural stimuli to these muscles. The cerebellum acts by coordinating and modifying when defining the body position and sensing its movements during voluntary and automatic movements, which allows maintaining balance during standing or walking. Afferent stimuli regarding the body, limbs, and head position and about the direction of eyeball position are transmitted to the cerebellum mainly through:

1. Spinocerebellar, vestibulospinal, and rubrospinal tracts and proprioceptive stimuli;
2. Deiters's nucleus which is directly connected with both the cerebellum and the vestibulum.

Cerebellofugal stimuli traverse the whole chain of neurones and pass the red nucleus and Deiters's nucleus. In this way the cerebellum regulates the innervation of the torso, limb, and eye muscles. Damage of the rear region of the cerebellar vermis and connected flocculuses, named archicerebellum, causes ataxia of body movements and disturbances of the balance, which do not aggravate with the eyes closed.

Force platform posturography is commonly used in the contemporary clinic for the evaluation of postural balance and indirectly for motor control. The present study confirmed that spontaneous body sway indices may be used in the evaluation of NPH patients. Such patients are often treated by surgical shunt placement, directing away the excess of cerebrospinal fluid. However, the degree of clinical improvement is variable and the dynamics of cerebrospinal fluid pressure in shunted hydrocephalus is poorly understood. Static posturography provides an objective assessment of patients' motor performance.

The main objective of this study was to determine the effect on postural sway characteristics of a ventriculoperitoneal shunt. Performance of a patient with NPH in specific postural tests was analyzed during two successive experimental sessions: before and shunt implantation. Subjects were tested with full vision control (eyes open) and without vision (eyes closed). The results showed a substantial increase in the static sway indices in NPH patients compared with the control group, which documents postural stability deficit. This finding is in accordance with a number of cross-sectional studies which reported a significantly greater sway in subjects with a history of falling compared with non-fallers [10]. The most puzzling result of the present study was, however, the lack of the 'eyes closure' effect on both sway measures in the patients. In normal older adults, eye closure results in a significant increase of postural sways (see [10] for review); a feature also observed in our control group. In contrast, NPH patients did not show the 'eyes closure' phenomenon, which may suggest that sway measures may have reached their maximum values (ceiling effect). Noteworthy, relief of the hydrocephalic pressure due to shunt operation resulted in both the decrease of sway and the reappearance of the vision effect, pointing to motor function improvement.

There are a limited number of reports in the literature that document stability improvement in NPH patients after shunt placement. Mesure et al [11] showed a beneficial effect of shunt implantation on patients' locomotor performance. The authors showed that gait disorders, except dynamic balance, may normalize as soon as one week after surgery. In their NPH patients, there was a significant improvement in gait performance including mean velocity of locomotion, stride length, and step cadency. Blomsterwall et al [12] studied postural sways in balance in NPH patients. The postural function was better in the position with eyes open, but significantly worse in NPH than control subjects. NPH patients had a larger sway area and a higher backward directed velocity of the pressure center and they improved more in the postural than motor functions after shunt surgery. The authors concluded that a misinterpretation of afferent visual stimuli in the brainstem postural center is the most likely cause of postural deficits in hydrocephalus. This notion also was supported by the results of the present study which indicates impaired visual deficit in NPH before surgery. It seems, therefore, that in NPH patients vision is not an essential source of information related to body stabilization or that these patients cannot take any advantage of this information channel to maintain the balance.

In conclusion, the results presented herein suggest that static posturography may provide verifiable indices of balance improvement in NPH patients after shunt implantation. Both measures employed in the present study, the sway radius and the sway area, document beneficial effects on the posture balance and on the visual control of balance recovery of surgery aimed at relieving hydrocephalic pressure.

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