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Sensory interaction testing in platform posturography

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Abstract

Mostly techniques measuring the vestibulo-ocular reflex (VOR) have been used for the evaluation of patients with dizziness problems. Some investigators, however, have also tried to take into account the vestibulospinal reflex (VSR). So recording techniques for the Romberg-test have been proposed and called posturography (PG). By interfering with the visual and proprioceptive sensory inputs during this PG-testing one tries to find out how 'sensory interaction' is organized in the balance performance of the patient examined. To interfere with vision, closure of the eyes has been commonly used and to interfere with proprioception, the patient can be put on foam-rubber, which makes the contribution of the foot–ankle proprioception less adequate. These interferences are applied once separately and once combined. The degree of 'abnormality' is assessed by a score-system for parameters surface (S) and velocity (V), which measure the postural sway. A comparison of tests with and without influence on the sensory inputs gives an idea of the sensory interaction. Patients with peripheral vestibular disorders were examined: patients with BPPV, with spontaneous vertigo attacks and with a sudden vestibular deficit.

When applying this evaluation technique different formulae or patterns can be found. Firstly complete normal evaluation, which means that there is no influence of the vestibular disturbance upon the PG results. Secondly a normal balance when using all available sensory information, but disturbed balance as soon as one of the sensory inputs is influenced by the test conditions. Thirdly striking destabilization when closing the eyes. Fourthly striking destabilization when misleading the ankle and foot proprioceptor. Fifthly a combined effect, when the vestibular input is the only one not influenced by the test conditions and sixthly no specific effect, no complementary compensatory effect of this sensory interaction.

In the group of patients with peripheral vestibular disorders, no special pattern linked to a peripheral syndrome could be found. Not only in the acute stage could abnormal PG be found: in fact, PG provides 'functional' data, which are complementary to the 'classical' evaluation and subdivide the patients into other sub-categories. The sensory interaction testing points to some conditions where balance will be more inclined to be troubled.

Key words: Vestibular function tests, posturography

Introduction

Though examination techniques using the vestibulo-ocular reflex (VOR) have been the only methods applied for evaluation of patients with dizziness problems (Baloh and Honrubia, 1979), some investigators have also tried to take into account the vestibulospinal reflex (VSR). 'Latero-torsion'-recording during caloric testing (in fact the recording of the vestibulo-collic reflex after caloric stimulation) (Henriksson *et al.*, 1962) and recording techniques for the Romberg-test, called posturography (PG) (Henriksson *et al.*, 1967; Taguchi, 1977; Black, 1985; Norré, 1992) have been proposed and represent the most significant landmarks in the history of otoneurology in the context of VSR in examination techniques. In the most recent PG-techniques, interfering with the visual and proprioceptive sensory inputs during PG-testing has been applied (Black and Nashner, 1984; Booth and Stockwell, 1986) in order to find out how 'sensory interaction' (i.e. the relative contribution of each sensory input to the achievement of a stable standing position) is organized in the balance performance by the patient examined. To this goal a very sophisticated and rather expensive engine is propagated, called Equi-test (Black, 1985; Black and Nashner, 1984). A more simplified device is proposed for routine clinical use (Norré, 1990 and 1992).

The rationale of sensory interaction (or sensory organization)

Posturography (PG) is based upon the recording of the postural sway (Roberts, 1978), which is an expression of the postural muscle activity during standing and which induces a continuous to-and-fro movement of the projection of the point of gravity (Black, 1985; Norré, 1990 and 1992). Recording with open eyes, the patient standing upon a stable support, constitutes a basic condition, corre-

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sponding with what happens in most of the 'normal' conditions of daily life. In these conditions the sensory input available (of the visual, vestibular and proprioceptive systems) can be used optimally. As far as these inputs are normal and sufficient, a normal behaviour of standing is expected. If from information by other functional tests an insufficiency or a disturbance of one sensory input is known (e.g. by caloric examination for the vestibular input), the PG-test is expected to show abnormality, which is measured by increased values of the parameters of the postural sway. It is very well known that compensatory mechanisms are put into action in case of vestibular sensory insufficiency (Putkonen *et al.*, 1977; Llinas and Walton, 1979; Flohr *et al.*, 1981; Precht and Dieringer, 1985). In these mechanisms the substituting action of the other non-involved sensory sources—in case of vestibular deficit, vision and proprioception—provides an important contribution (Putkonen *et al.*, 1977; Flohr *et al.*, 1981). This compensation makes it possible that notwithstanding a disturbed vestibular input, normal PG-performance is recorded. This means that this patient with a vestibular deficiency, has a perfect stability at least when using his total sensory input of the three sensory functions, unimpeded in their working (Norré *et al.*, 1987b; Norré, 1990).

If now, in a test-condition the 'other' sensory inputs are not allowed to contribute or if their contribution is reduced or misled, it may be possible that the effect of the initially disturbed input is not sufficiently cancelled (compensated): then PG will show abnormal values. In this way the influence of the initially disturbed sensory organ becomes manifest, whereas the difference between the test condition where the other sensory inputs contribute normally and the test condition where one or both of them are excluded or reduced, will give an idea of the complementary compensation by the sensory input in consideration. This is the basic rationale of such sensory interaction (Norré, 1990 and 1992) or sensory organization (Black and Nashner, 1984; Black, 1985).

In this study, during PG-testing on the platform two sensory inputs are artificially impeded, i.e. vision and proprioception in patients where a vestibular deficiency is known from other test results.

Posturography with sensory interaction

By closing the eyes the visual contribution is abolished or one can mislead the visual input by making it sway-referenced (also called 'stabilized vision') (Black and Nashner, 1984; Black, 1985; Booth and Stockwell, 1986). In the latter condition the patient looks at surroundings which move synchronically with the patient's sway. In this way the sway is not visually perceived. To interfere with proprioception, the ankle-proprioception can be reduced by inducing a sway-referenced movement to the support, as is done in the Equi-test (Black and Nashner, 1984; Black, 1985). As a simplified technique the patient can be put on foam-rubber (Shumway-Cook and Horak, 1986), which makes the contribution of the foot–ankle proprioception less adequate (Norré, 1990 and 1992). The foam rubber used meets the requirements suggested by Brandt *et al.* (1981), i.e. a slab of 10 cm height and a specific weight of 40 g/dm^3.

In the technique we propose, closure of the eyes and standing on foam rubber are used, once separately (t2 and t4) and once combined (t5) (Table I). For this study we left out t3 and t6, which are recordings with eyes closed, head in retroflexion.

TABLE I
SCHEME OF THE STATIC POSTUROGRAPHY TYPE III (SPGIII)

	Eyes open (EO)	Eyes closed (ECl)	Eyes closed/ head in retroflexion (retro)
Stable platform	Test 1 – t1	Test 2 – t2	Test 3 – t3
Foam-rubber	EO Test 4 – t4	ECl Test 5 – t5	retro Test 6 – t6

Recording time: 42 seconds.

Test procedure applied

The test procedure, which we call static posturography—type III (SPGIII), is composed as shown in Table I.

Technique of evaluation

Measurement of the postural sway

In contra-distinction with the Equi-test (Black and Nashner, 1984; Black, 1985), where only the forwards–backwards movements (y) are measured, in SPGIII x (left–right) and y (forwards–backwards) movements are evaluated. Two parameters are used: surface (S) of the area within which the projection of the point of gravity is moving (postural sway), evaluated according to Takagi *et al.* (1985) and velocity (V) which is the total distance covered by the moving point (L = length) pro time-unit (sec) (L/t) (Norré *et al.*, 1987a; Norré, 1990 and 1992).

Evaluation of the normality of the obtained results

The parameters surface (S) and velocity (V) are computed and the values obtained are compared with normal values. For the patients, the value of S or V, obtained in each test, is compared to its limit of normality (x+2 SD). The degree of 'abnormality' is assessed by a score system and related to the standard deviation e.g. score 1 = values between x+2 SD and x+3 SD; score 2 = between x+3 SD and x+5 SD etc. (*cf.* Table II). Score 10 = falling; the test is repeated and the second trial is recorded. In this way a rough estimation of the degree of abnormality can be obtained for clinical use.

Evaluation of the sensory interaction

The comparison of the result of respectively t2, t4 and t5 with that of t1 gives an idea of the sensory interaction. So can be computed:

1/the visual effect: t2–t1.
2/the proprioceptive effect: t4–t1.
3/the combined effect: t5–t1.

The dominant effect determines the 'pattern' (Table II).

Patients examined

Three classical groups of patients were studied (Table III): (a) BPPV (benign paroxysmal positioning vertigo), which signifies a typical provoked, positioning vertigo, where the Dix-Hallpike manoeuvre (Dix and Hallpike,

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TABLE II
SENSORY INTERACTION EVALUATION IN STATIC POSTUROGRAPHY TYPE III

Related to average (x) and standard deviation (SD)	Score	Sensory interaction t1 Visual vis (t2–t1)	Proprioceptive p (t4–t1)	Combined v+p (t5–t1)
<x+2SD	0			
<x+2SD–x+3SD	1			
> x 3SD – x+5SD	2	Pattern		
> x+5SD – x+10SD	4			
> x+10SD	6			
Fall	10			

1952) is positive and further examination only may show a caloric asymmetry, which occurs in less than 20 per cent of the cases (n = 116); (b) Ménière's disease, which indicates a syndrome with typical recurrent attacks of rotatory vertigo and with a typical unilateral (or bilateral) perceptive deafness of labyrinthine origin (Alford, 1972) (n = 91); (c) sudden unilateral vestibular loss (USL), also called neuronitis (Dix and Hallpike, 1952), which consists of a sudden attack of vertigo, followed by a period of recovery with positioning vertigo and/or instability. Caloric testing shows a unilateral hypo- or areflexia (n = 41).

Results

SPGIII applied in peripheral vestibular disorders

When applying this evaluation technique in patients with well-defined peripheral vestibular disorders, different formulae or patterns can be found:

(a) All tests are normal.

This formula indicates that there is no influence of the vestibular disturbance upon the PG results, only the normal influence of the sensory interaction is shown. Even when both vision and proprioception are impeded to deliver their normal contribution (t5), there is normal performance on the platform. This can be considered as a 'complete' compensation.

(b) Test 1 is normal, abnormal results in other tests.

This is seen in examples of Fig. 1 and 3. When in test 1 the patient performs as does a normal person, this means that he has a normal balance when using all available sensory information. This test-1-condition corresponds with normal life conditions, when a person is standing on a stable support and uses his visual input. However, he needs all available sensory information uninfluenced for a normal performance in t1. The abnormal values in the other tests point to a 'substituting' compensation by these other sensory inputs for obtaining normal performance in t1.

(c) Visual effect is dominant.

In this example (Fig. 1), we see normal performance in test 1, (*cf.* supra) but a striking destabilization in t2, i.e. when closing the eyes. This effect is dominant in the testing results and indicates a visual pattern. This may suggest instability, especially in conditions where vision is impaired as in darkness.

(d) Proprioceptive effect is dominant.

Here the patient destabilizes in t4, when his proprioception is disturbed (Fig. 2). This effect is dominant and defines a proprioceptive pattern. This pattern suggests a risk of falling, especially when this person has to stand on an unstable support.

(e) The combined effect is dominant (so-called 'vestibular formula').

In some cases this t5-effect is dominant as is seen in Fig. 3 and defines a combined pattern. As in t5 the vestibular input is the only one not influenced by the test-conditions, the non-compensated vestibular deficiency will become manifest. So this pattern can be called 'vestibular formula'.

(f) Absence of sensory interaction (no effect or equal effect).

In some cases there is no specific effect, no complementary compensatory effect of this sensory interaction (Fig. 4). As the results are compared to normal limits, only the 'normal' effect is present. In Fig. 4 there is no effect, the recording in t2, t4 and t5 showing an equal degree of abnormality as t1. The differences (vis-pr-v+p) are zero.

Occurrence in peripheral vestibular disorders

When comparing these groups of patients with peripheral vestibular disorders there is no significant difference between BPPV and Ménière's disease, except for the combined effect, which is more pronounced in the Ménière-group. The 'test 1 being normal' has also a higher frequency in this latter group (Table III). The patients with unilateral loss show less normal results and the visual effect is strikingly dominant.

Comments

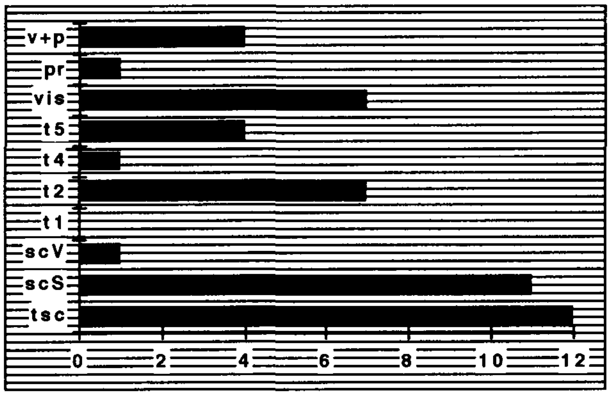
Applying PG in patients with a peripheral vestibular

TABLE III
RESULTS IN PATIENTS WITH PERIPHERAL VESTIBULAR DISORDERS

	t1 normal	percentage	PGnl	Percentage	vis	pr	comb	eq-no effect
BPPV(n = 116)	46	37	29	25	37	34	7	9
Ménière (n = 91)	42	46	21	23	26	20	15	9
USL (n = 41)	13	31	5	12	20	7	9	6
Total (= 248)	101	41	55	33	83	61	31	24

t1normal = normal value in t1, PG nl = all four tests with normal values; vis = visual effect dominating, pr and comb = proprioceptive and combined effect dominating; eq-no effect = equal effect or no effect.
BPPV = benign paroxysmal positioning vertigo; USL = unilateral sudden loss (neuronitis–neuritis).

Example of 'visual pattern'.
Female (42 years)



Score

	t1	t2	t4	t5	Total
S	0	**6**	1	4	11
V	0	**1**	0	0	1
Total	0	**7**	1	4	**12 = tsc**

FIG. 1

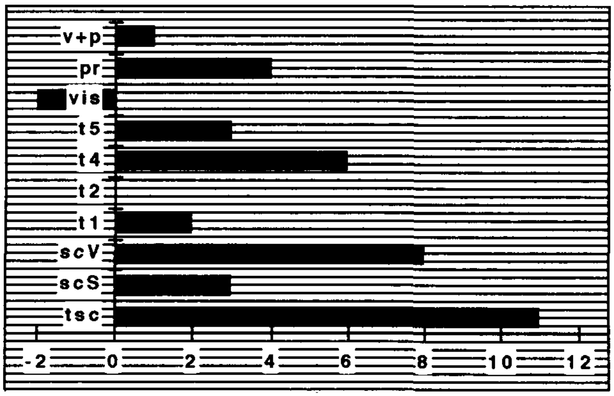
Graphical presentation (from bottom to top).
Global results.
tsc indicates the total score for the whole testing and gives an idea of the degree of abnormality of the posturographic testing (in this case tsc = 12). scS and scV indicate the score for surface (S) and velocity (V), respectively 11 and 1.
Results for each test.
t1 shows the score obtained by test 1 (this test gives normal results: score = 0).
t2 shows the score for test 2 (eyes closed). The score of 7 reveals a striking destabilization by eye closure and evaluates the visual effect.
t4 gives a score of only 1, in this way the proprioceptive interference appears to be poor.
t5 indicates the effect of the combined interference (vision and proprioception) and has here a score of 4.
The sensory interaction evaluation.
vis = difference t2–t1, which is the quantification of the visual effect: 7.
pr = difference t4–t1, which is the quantification of the proprioceptive effect: 1.
v+p = difference t5–t1, which is the quantification of the combined effect: 4.
Pattern of the whole testing.
The dominant difference or effect is the visual one = *visual pattern*.

disorder affords information about the vestibulo spinal aspect. When the vestibular input is disturbed, this becomes manifest by some kind of vertigo (or instability) and by abnormal findings in the VOR-testing (e.g. positional nystagmus, asymmetrical reactions in caloric and rotation testing) (Baloh and Honrubia, 1979; Norré, 1990). But also in the vestibulospinal reflex an influence may be expected (Igarashi and Kato, 1975). In PG the global balance performance of the standing position is recorded. This means that the recording on the force-plate is not only dependent on the vestibular input, but also the other sensory contributions as well as the central processing play their role. In this way it is the total result of this whole processing which is observed in PG (Norré, 1990).

When looking at the results of patients with peripheral vestibular disorders, obtained in PG , a first category is obvious: a number of patients perform on the platform as if there was no trouble. This means that either the vestibular disorder is too weak to disturb the VSR, or that the disturbing influence has been cancelled by 'compensatory' mechanisms. Such mechanisms have been examined clinically (Mittermaier, 1950) and experimentally for the VOR (Precht and Dieringer, 1985), but also for the VSR (Igarashi and Kato, 1975; Putkonen *et al.*, 1977; Flohr *et al.*, 1981). Not only clinical observations but also experimental work have stressed the indispensable contribution of the 'other' sensory inputs, vision and proprioception in the elaboration of this compensation. The rebuilding of a sufficient vestibular nuclear tonus at the affected side is stimulated by this complementary sensory input, but also a 'substituting' function is provided by these sensory functions (Putkonen *et al.*, 1977; Flohr *et al.*, 1981; Precht and Dieringer, 1985).

One can suppose that, if in t5 normal values are found, the compensation at the vestibular level is very satisfying. Indeed, in this test condition, where visual input is abolished and proprioceptive input is disturbed, a normal performance is obtained, the vestibular input being the only one not influenced. If only or mainly t5 gives abnormal values and especially if t1 is normal, a perfect 'substituting' compensation is supposed for t1. A visual pattern indicates that vision provides the major contribution to the compensation process, whereas the proprioceptive pattern suggests that it is the proprioception.

Example of 'proprioceptive pattern'
Male (56 years)



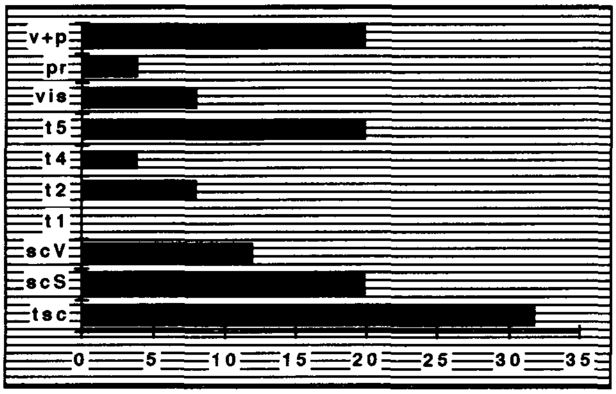
Score

	t1	t2	t4	t5	Total
S	0	0	**2**	1	3
V	2	0	**4**	2	8
Total	2	0	**6**	3	**11 = tsc**

FIG. 2

Graphical representation (from bottom to top).
Global results.
tsc indicates the total score for the whole testing = 11.
scS and scV indicate the score for surface (S) and velocity (V), respectively 3 and 8.
Results for each test.
t1 shows the score obtained by test 1 (this test gives score = 2).
t2 shows the score for test 2 (eyes closed). The score is 0.
t4 gives a score of 6, in this way the proprioceptive interference appears to be dominant.
t5 indicates the effect of the combined interference (vision and proprioception) and has here a score of 3.
The sensory interaction evaluation
vis = difference t2–t1, which is the quantification of the visual effect: 2 (no visual effect).
pr = difference t4–t1, which is the quantification of the proprioceptive effect: 4.
v+p = difference t5–t1, which is the quantification of the combined effect: 1.
Pattern of the whole testing.
The dominant difference or effect is the proprioceptive one = *proprioceptive pattern*.

Example of 'vestibular formula'
Female (49 years)



Score

	t1	t2	t4	t5	Total
S	0	6	4	**10**	20
V	0	2	0	**10**	12
Total	0	8	4	**20**	**32 = tsc**

FIG. 3

Graphical representation (from bottom to top).
Global results.
tsc indicates the total score for the whole testing = 32.
scS and scV indicate the score for surface (S) and velocity (V), respectively 20 and 12.
Results for each test.
t1 shows the score obtained by test 1 (this test gives normal results, score = 0).
t2 shows the score for test 2 (eyes closed). The score is 8.
t4 gives a score of 4.
t5 indicates the effect of combined interference (vision and proprioception) and has here a score of 20 (falls in t5).
The sensory interaction evaluation
vis = difference t2–t1, which is the quantification of the visual effect: 8.
pr = difference t4–t1, which is the quantification of the proprioceptive effect: 4.
v+p = difference t5–t1, which is the quantification of the combined effect: 20.
Pattern of the whole testing.
The dominant difference or effect is the combined one = *combined pattern or vestibular formula.*

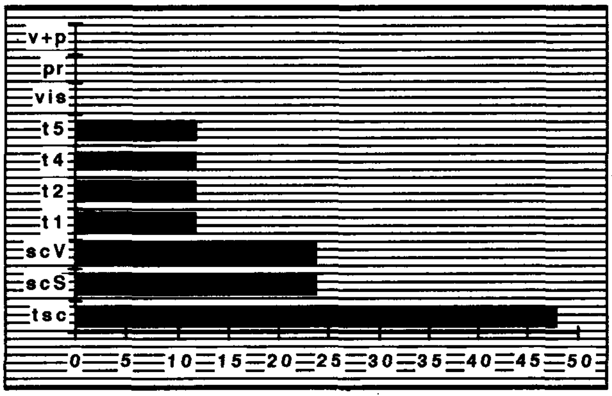
In the Equi-test special patterns were described as 'sensorineural loss', which corresponds with the 'vestibular formula' in cases with unilateral or bilateral deficit and a special visual pattern (distorted function with stabilized vision) in cases with BPPV (Black and Nashner, 1984). However, it was admitted that 60 per cent showed a 'mixed' pattern. Otherwise, only in the acute phase of unilateral vestibular lesion PG can be found abnormal in Equi-test (Fetter *et al.*, 1991).

Concerning the differences from our findings, one has to take into consideration that beside the differences in technique, mainly two points, related to the evaluation, are different. In Equi-test only the y-axis is evaluated and this only related to the falling-condition, where as in SPG III x-axis as well as y-axis are evaluated and this by two parameters S and V, which express two different aspects of the postural sway. S is an indicator of 'precision' of the postural mechanism and V is an expression of the postural activity or energy. In this way SPGIII is likely to be more sensitive and to show abnormality.

We could not find a special pattern linked to a peripheral syndrome and abnormal PG was found not only in the acute stage. Patients with unilateral vestibular loss show more abnormal patterns and the visual pattern is dominating. In the Ménière patients there is no difference between the stabilized and the non-stabilized cases. As in former studies (Norré, 1990 and 1992; Norré *et al.*, 1987), the main conclusion is that PG does not provide a diagnosis by a special PG pattern in the sense of defining a patient as having BPPV or Ménière's disease, these diagnoses were already defined by other data of the examination. On the contrary, PG provides 'functional' data, which furnishes another subdivision of the patients, characterizing their balance in standing. The sensory interaction testing points to some conditions where balance will be more inclined to be troubled. Advice can help the patient in his daily life or directed exercises may be suggested.

In patients with complaints about stability (e.g. in cases with unilateral loss (UL) or after treatment of BPPV by exercises) PG suggests where the exercises (BCT–balance coordination training) should be based (Norré, 1990). Accordingly, when visual compensation appears to be insufficient, the visual cues should be stimulated. This is not indicated when the visual compensation seems to be sufficient. The same is valuable for the findings concerning proprioceptive interference. A special test-battery has been used for practical determination of suitable BCT exercises.

Example of 'no effect'
Female (24 years)



Score

	t1	t2	t4	t5	Total
S	6	6	6	6	24
V	6	6	6	6	24
Total	12	12	12	12	**48 = tsc**

FIG. 4

Graphical representation (from bottom to top).
Global results.
tsc indiates the total score for the whole testing = 48.
scS and scV indicate the score for surface (S) and velocity (V) = 24.
Results for each test.
t1 shows the score obtained by test 1 (this test gives score = 12).
t4 gives a score of 12.
t5 indicates the effect of the combined interference score = 12.
The sensory interaction evaluation.
vis = difference t2–t1, which is the quantification of the visual effect: 0.
pr = difference t4–t1, which is the quantification of the proprioceptive effect : 0.
v+p = difference t5–t1, which is the quantification of the combined effect: 0.
Pattern of the whole testing.
There is no dominant difference or effect = *'no effect pattern'.*

Conclusion

Posturography with sensory interaction testing (SPGIII) provides information about the sensory mechanisms acting in the standing position in patients with peripheral vestibular disorders. The role of vision, proprioception and of the combined interference can be defined by the comparative study of the test results, which show several patterns of sensory organization of the compensatory process. No typical pattern could be found related to any vestibular dysfunction.

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