Examinations and algorithms to help find a cause of vertigo

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***Abstract*—** Vertigo is very common type of dizziness. There are several sophisticated methods which help to find a cause of vertigo. Many of them were described in the last century or even earlier. These methods still have their place in modern medicine, but the introduction of modern computer technology can make their implementation in many ways to refine and improve. Posturography is one of a non-invasive medical technique used to evaluate vertigo. Traditional static posturography has several results, such as charts describing speed, direction, harmony of patient's tilts, but for the medical studies and formation of norms are more sufficient numerical outputs, which we are going to deal with in this paper. This articles deals with numerical methods of calculation in evaluation of static posturography. Some evaluations have in the past been defined, but still some significant signs remain hidden in charts or worse, in raw data. This paper show traditional numeric approaches and try to point the new one, focused on lateral deviation and refining current options. The proposed algorithms need to be verified by the practical experience now and found the rate of its usability.

***Keywords*—** area, examination, posturography, Romberg, tilt, vertigo, way

I. Introduction

VERTIGO is very common feeling, known more or less to everyone. Vertigo is not a disease, vertigo is symptom. Extensive studies on 30 000 people of all age groups in Germany confirmed that about 20% men and up to 40% of adult women from time to time have feeling of motion when one is stationary. Vertigo may occur in all age groups, although with increasing age, the occurrence increases [1].

Many medical issues can cause problems with balance. Neurological problems in the central or peripheral nervous system may impair a patient's motor control. The vestibular system for balance can be damaged, making it difficult for patients to know where they are relative to other objects and the environment. Muscle weakness may make it harder to stand, or patients can have tremors and other neurological issues that impair the ability to balance and stand safely.

One of the medical techniques, this work deals with most is posturography. Posturography is a non-invasive technique used to quantify the central nervous system adaptive mechanisms involved in the control of posture and balance.

Posturography as an examination method is measuring of postural balance in static or dynamic conditions. Static methods are mostly judging standing balance, dynamic in general focused to walk. This paper entirely deals with static posturography and its numerical evaluations.

II. Types of Balance Problems

There are a number of balance problems that can affect people of all ages. They are broadly broken into causes related to the ears or to the brain, although other medical issues can also be responsible. People with vision impairment, including blindness, can also experience balance problems because their eyes are not providing feedback to the vestibular system, which the body uses to stay in balance. There are treatments available for some disorders involving balance and it is advisable to see a physician if people notice changes in their ability to balance and walk comfortably [8].

Some balance problems are lumped under the category of vertigo, where people have the sensation that they are spinning or in motion. Examples of conditions in this category are benign paroxysmal positional vertigo (BPPV), Meniere's disease, labyrinthine infections of the ear, vestibular migraine, and acoustic neuroma. Vertigo can cause people to fall, and it may also lead to gait abnormalities, such as a rolling gait, to compensate for the dizzy feeling [8].

A. *Benign paroxysmal positional vertigo (BPPV)*

One of the most common peripheral vestibular syndromes is benign paroxysmal positional vertigo (BPPV), which may occur at any age. The characteristic history is brief episodes of positionally induced vertigo, particularly with rapid position changes, such as getting out of bed. The rotational sensation usually lasts less than one minute. However, a nonspecific dizziness or disequilibrium, often described as a swimming sensation, may last hours to days. Although BPPV may remit spontaneously, fully one third of patients have recurrent symptoms over one year. In a review of 240 cases of BPPV, 49% had no identifiable cause established. Eighteen percent occurred following head injury, usually within 3 days. Fifteen percent had a viral illness within the previous two weeks. The remaining 18% had a variety of miscellaneous diagnoses (6% had signs of central nervous system involvement). BPPV symptoms are often reproduced by performing the Hallpike (or Barany's) maneuver wherein the patient is moved from sitting to supine with the neck extended 45 degrees and the head rotated 45 degrees toward the ground. This maneuver may induce rotational nystagmus when the patient looks toward his "down" ear. An upbeating vertical component may develop when he looks towards his "up" ear. The nystagmus appears after a variable period up to 40 seconds. It usually reaches a peak within ten seconds, then slowly decays over 40 seconds. On repeated Hallpike maneuvers, adaptation develops and the nystagmus gradually lessens. This pattern of nystagmus often reverses direction when the patient reassumes the upright position [8, 15].

BPPV is managed with physical therapy. Repeated positional maneuvers promote loosening and dispersion of the fallen otoconia from the hair cells, and permits semicircular canal recalibration by central processing mechanisms. The patient starts in a sitting position and tilts laterally to the lateral decubitus position for at least 30 seconds, or until the vertigo subsides. The patient then sits up for at least 30 seconds, then tilts to the lateral position on the opposite side. This sequence of positional changes is done five times, and is repeated three times a day for at least two to four weeks. This results symptom resolution in a majority of cases. An occasional refractory patient may require surgical resection of the posterior ampullary nerve. Drug therapy for BPPV is generally ineffective, and may delay central recalibration.

B. *Meniere's disease*

Meniere's disease, or endolymphatic hydrops, is a common cause of recurrent vertigo and auditory symptoms. It accounts for approximately 10 percent of vertigo cases. Early in the course of Meniere's disease, there is a fluctuating hearing loss in the low frequencies, a sensation of ear fullness or pressure, and unilateral tinnitus which may persist between episodes.

Vertigo, postural imbalance, and nausea usually reach a peak over several minutes, and resolve over several hours. There is often a reduced tolerance for loud noises. Early in the course of the disease, the hearing loss is reversible. As the disease progresses, the hearing loss becomes permanent, initially affecting the low frequencies. Late in the course of the disease, vestibular drop attacks due to loss of reflex postural tone may cause sudden falls to the ground. During the vertiginous attack, which usually lasts 30 to 60 minutes, a characteristic nystagmus is seen, with the fast phase away from the affected ear. During the recovery phase following the attack, the nystagmus beats towards the side of the lesion.

The pathophysiologic cause of Meniere's disease is distension of the endolymphatic sac, or endolymphatic hydrops. As the membranous labyrinth progressively dilates and increases pressure on adjacent auditory structures. As the disease progresses there is disruption of otolith organs and semicircular canals, resulting in vestibular symptoms. Dilatation of the membranous labyrinth may lead to rupture of the endolymphatic membrane. This rupture allows endolymph to leak into the perilymph, causing immediate damage to the auditory and vestibular hair cells and nerve fibers.

Distension of the endolymphatic sac may be due to either insufficient fluid reabsorption by the endolymphatic sac or blockage of the endolymphatic duct. Several etiologies have been identified in Meniere's disease. Approximately 50 percent of the patients have a positive family history, suggesting a genetic predisposition. Trauma, infection, or inflammation may block the endolymphatic sac, preventing reabsorption, and leading to endolymphatic sac distension. Thirty percent of patients with Meniere's disease will progress to bilateral involvement. Up to 80 percent may have remission of symptoms, sometimes lasting over five years. However, in some patients the progression of symptoms is quite disabling.

The diagnosis of Meniere's disease is based on the characteristic clinical history. A number of clinical tests have been developed. In classic Meniere's disease, the low frequency hearing loss is reversed by administration of a dehydrating agent such as oral glycerol, which can improve the hearing loss by at least 15 to 20 decibels within one to two hours after administration. Medical therapy is the mainstay of treatment for Meniere's disease. A common regimen includes a low salt diet (800 to 1000 mg of sodium a day) and a diuretic, such as hydrochlorothiazide at a dose of 50 mg QD [15].

Other balance problems are related to presyncope, a medical term for "feeling faint." People with presyncope most commonly have a problem with blood pressure, which causes them to feel faint and unsteady. Disequilibrium, balance disorders characterized by lack of balance and the inability to control the body to stay in balance, can be caused by joint and muscle disorders, inner ear problems, nerve damage such as that seen with multiple sclerosis, and some medications [8].

Balance problems can also involve feeling lightheaded. People with anxiety disorders sometimes experience balance problems, and hyperventilation can also lead to a lightheaded feeling because the brain is not getting enough oxygen. Brain tumors and other degenerative diseases that attack areas of the brain like the cerebellum can also lead to balance disorders, as people may have trouble controlling their gait or standing upright [8].

When a balance disorder is identified, a series of diagnostic tests can be used to learn more about why a patient is experiencing problems. These tests can include tilt table tests, stress tests, bloodwork, medical imaging studies of the brain, examination of the ears, and neurological exams. It can be helpful to provide the doctors with as much background information as possible about the patient's history, the onset of the balance problems, and any family history of balance disorders. This information will be considered during the workup of the patient to come up with a list of possible causes and proposed treatments [8].

III. Examination of the Vestibular Apparatus

Special examination provides information about the functional state of the vestibular system, the degree of damage and interaction with other sensory organs, which are also involved in maintaining balance. Before the test should not drink alcohol and should be discontinued drugs which are acting on the central nervous or vestibular system (especially anti-vertigo and motion sickness and also sedatives, antihistamines and tranquilizers.

Clinical tests help establish an etiology in patients with vestibular symptoms. Evaluation of the vestibular system includes a general neurological examination to establish any other nervous system involvement. Routine tests of vestibular function include electronystagmography (ENG) and brain stem auditory evoked response (BSAER). Specific vestibular

tests include evaluation of the vestibular spinal reflex, the vestibular ocular reflex, the optokinetic (visual ocular) reflex, station and gait, and provocative tests (posture, position, and fistula testing). The search for spontaneous or positional induced nystagmus is an essential part of this examination.
Vestibular function tests are important to establish nystagmus as central or peripheral. Central causes of nystagmus imply a more serious prognosis, and usually require referral to a neurological center [11].

The most common tests of vestibular apparatus include:

A. Rotator test

Rotator test consists in recording the eye movements during patient rotation on a special chair. The tests are meant to determine the functional condition of the vestibular apparatus during angular accelerations (sinusoidal rotations, impulse effect) [8, 15, 16]. Necessary tools for this test, rotator seat is shown in Fig. 1.

Fig. 1 Rotating seat [16]

B. Position or situation nystagmus test

Position or situation nystagmus test is used to determine the presence of nystagmus during the examined patient changes position. The test is a basic diagnosis method for the benign paroxysmal vertigo determination [8, 15, 16].

Fig. 2 The seat used for the position test

C. Electronystagmography (ENG)

Electronystagmography (ENG) is one of the most fundamental methods for the most vestibular examinations. It consists from an achieving a nystagmus graphic record during deviation from the lateral axis of the eye. The eye movement is recorded through an electrode attached directly to the patient's skin.

Fig. 3 Electronystagmography [16]

D. Videonystagmography (VNG)

Videonystagmography (VNG) is performed using special glasses with a built-in miniature video system with an infrared source. The glasses record horizontal, vertical and rotational movements of the patient eye and head in the examination moment. Because it requires no electrodes, this method is irreplaceable in the cases where the nystagmus cannot be detected using electronic nystagmography [8, 15, 16].

Fig. 4 Lenses used for videonystagmography with the possibility of viewing the eye into the monitor [16]

E. Posturography (Stabilography)

Posturography (stabilography) is used to determine the vestibular reflexes condition of the patients. The examination is made on a mobile platform that appears after a predetermined schedule (dynamic computer posturography). Through the redistribution of muscle tone, the patient tries to maintain balance (Fig.5). The tests have more degrees of difficulty. This method abilities a person to examine the integration of visual, vestibular and muscle systems, in order to ensure the balance function and make a patient's rehabilitation through some special programs that take into account individual characteristics, the nature and degree of disease development [8, 15, 16].

IV. Vestibular Function Testing

The spectrum of diseases causing vertigo is very broad, hence the first visit a doctor you have to try to provide him as much information as possible. The exact description of the symptoms helps doctors diagnose, determine the strategy of further examination and plays an important a role in treatment.

It is useful to know in particular:

- at which time the dizziness occurs
- what it causes (changes in atmospheric pressure, emotional or physical stress, premenstrual period)
- symptoms, such as (nausea, tinnitus, increase in arterial pressure, sweating, headache, tendency to fall, etc.)
- what medicines you are taking, because dizziness can be caused by the use of certain drugs
- if you have recently suffered a head injury or neck. For example, cervical spine injury in a car accident when the head when braking or crash the car reversed rapidly forward and back

After gathering the data history and measure blood pressure the doctor performed a number of simple tests of balance function testing.

A. *Romberg test*

Romberg's test or the Romberg maneuver is a test used by doctors in a neurological examination, and also as a test for drunken driving. The exam is based on the premise that a person requires at least two of the three following senses to maintain balanced while standing:

- Proprioception (the ability to know one's body in space)
- Vestibular function (the ability to know ones head position in space)
- Vision (which can be used to monitor changes in body position).

A patient who has a problem with proprioception can still maintain balance by using vestibular function and vision. In the Romberg test, the patient is stood up and asked to close his eyes. A loss of balance is interpreted as a positive Romberg sign.

The Romberg test is a test of the body's sense of positioning (proprioception), which requires healthy functioning of the dorsal columns of the spinal cord [12].

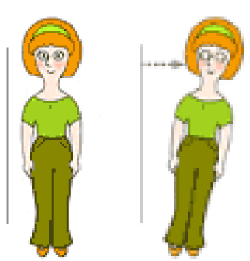

Fig. 5 Romberg test [16]

B. *Unterberg test*

The Unterberger test, also Unterberger's test and Unterberger's stepping test, is a test used in otolaryngology to help assess whether a patient has a vestibular pathology [13]. It is not useful for detecting central (brain) disorders of balance [14].

The patient is asked to walk on the spot with their eyes closed. See Fig. 6. If the patient rotates to one side they may have a labyrinthine lesion on that side, but this test should not be used to diagnose lesions without the support of other tests.

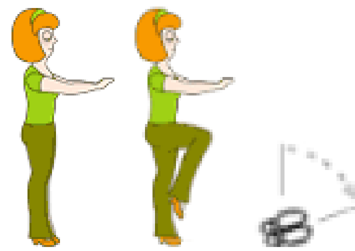

Fig. 6 Unterberg test [16]

C. *Babinski-Weil test*

A test to determine vestibular and cerebellar function, performed by having the patient walk forward or backward 10 or more times with the eyes closed. In cerebellar or vestibular disease, the patient deviates to the side of the lesion.

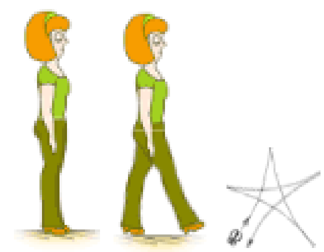

Fig. 7 Babinski-Weil test [16]

D. *Barany test*

T he patient is seated with his back propped and is order to extent the arms before, with the indexes in extension. The examiner marks the position of outstretched fingers with his own fingers, without touching the patient. At the closing eye occurs a tonic deviation in the arms, usually to the injured party. It can be sensitized inviting the patient to swing his arms to vertically [15].

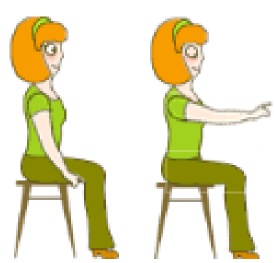

Fig. 8 Barany test [16]

V. Methods of Posturography

Posturography is the clinical study of a patient's ability to remain upright. It involves the use of noninvasive medical testing to quantitatively measure a patient's balance and motor control. Various devices are used for posturography evaluations, including specialized platforms with sensors to provide feedback during the test [8].

In a posturography test, the patient wears a safety harness in case of falls and is positioned on a platform. The most basic test involves asking the patient to stand up and hold the position as long as possible. Sensors in the platform provide information about how the patient's weight is distributed and will update when the patient loses balance and the weight shifts or becomes destabilized. Other tests can involve tilting or moving the platform to see how well a patient adapts to changing conditions [8].

Posturography as an examination method is measuring of postural balance in static or dynamic conditions.

Static methods are mostly judging standing balance, when is the patient placed in a standing posture on a fixed instrumented platform connected to sensitive detectors, which are able to detect the tiny oscillations of the body [7].

Fig. 9 Measuring on the static posturography platform [3]

Dynamic posturography differentiates from static posturography in that it usually involves perturbing the subject’s posture by means of a foam cushion or a special apparatus with a movable horizontal and tilting platform. As the subject makes small movements, the sensitive detectors transmit this time-varying information in real time to a computer. Thus, the dynamic posturography test protocols can quantify the ability of a subject to maintain balance in non-static conditions. Usually coupled with the ability to test the subject either with or without visual references (eyes open or closed) or with a moving environment that gives conflicting visual information, dynamic posturography makes it possible to quantify a subject's vestibular functions. This is because, in certain testing conditions, the visual and proprioceptive systems cannot be used, and the subject must rely only on the vestibular system to maintain balance [7].

Dynamic methods generally used a special apparatus with a movable horizontal platform [7]. See Fig. 10.

Fig. 10 Measuring on the dynamic posturography platform [16]

VI. Process of Examination

Static posturography is carried out by placing the patient in a standing posture on a fixed instrumented platform connected to sensitive detectors (force and movement transducers), which are able to detect the tiny oscillations of the body [2]. See Fig. 11.

The parameters of measurement:
(Based on common options for STP-03 platform)

- Measure period: 40 ms
- Length of measure: 20 s
- Area for calculating weighted area: 5°
- Angle step for display vectors: 15°
- Number of samples for harmonic analysis: 250

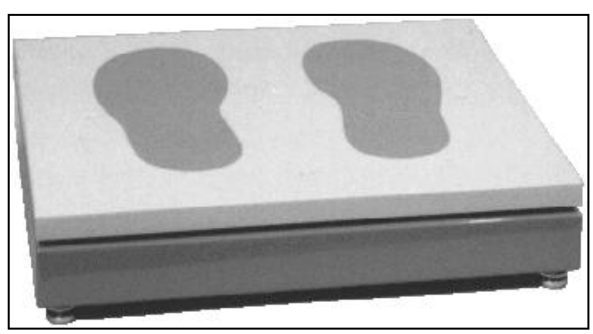

Fig. 11 Static posturography platform

Traditional static posturography is based on Romberg test, which means that two exams are executed - with eyes open and then with eyes closed. The mutual relations between results are track. A normal person is upright, but the patient suffering from vertigo deviates from the vertical position as he (she) tries to compensate for a sense of movement that feels. The patient usually tilts to the side, which has affected labyrinth.

VII. Measurement Results

Posturograph STP-03 software (widely use in Czech Republic) calculates the value of the way (1) and area (2) of the patient center of gravity circumscribed over the posturographic platform. Evaluates the ratio between these values for the examination with open and closed eyes are important parts of vertigo assessment.

Parameter Way, W (cm/s) describes the path of moving center of gravity, but because the examination time given a constant number, Way is characterized as the speed of center of gravity. Parameter Way for open eyes is marked with postfix f; (Wf) - visual fixation. Way for the closed eyes is marked with postfix s; (Ws) – visual suppression [17].

$$M_i = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$
$$W = \frac{T^{-1}}{n} \sum_{i=1}^{n} M_i \; [mm/s] \qquad (1)$$

Where:

M_i	particular element of way calculation
T	measure period [s]
x,y	center of gravity coordinates
n	number of measured samples

Parameter Area, A (cm2/s) indicates the area, which describes variation of center of gravity during the examination. Like the parameter Way, Area for the visual fixation is marked (Af) and for visual suppression (As) [4].

$$N_i = \frac{\left| \begin{matrix} (y_{i+1} - y_0) * (x_i - x_0) \\ -(y_i - y_0) * (x_{i+1} - x_0) \end{matrix} \right|}{2}$$
$$A = \frac{1}{t} \sum_{i=1}^{n-1} N_i \; [mm^2/s] \qquad (2)$$

Where:

N_i	particular element of area calculation
t	length of measure [s]
x_0, y_0	average values of center of gravity coordinate (3)

$$x_0 = \frac{1}{n} \sum_{i=1}^{n} x_i$$
$$y_0 = \frac{1}{n} \sum_{i=1}^{n} y_i \qquad (3)$$

A. Visual presentation of results

As mentioned earlier, the posturograph examination has also visual outputs. This paper is not dealing with those results directly so outputs will be describe shortly, but information covering by them are much more wider than used numerical results.

Fig. 12 shows center of gravity trajectories (patient body motion) focus and direction of motion vector evaluation. The above charts are for open eyes, bottom for closed eyes. On the left is the trajectory of motion, in the middle motion vectors in a bar-shaped view. On the right is shown the envelope vectors.

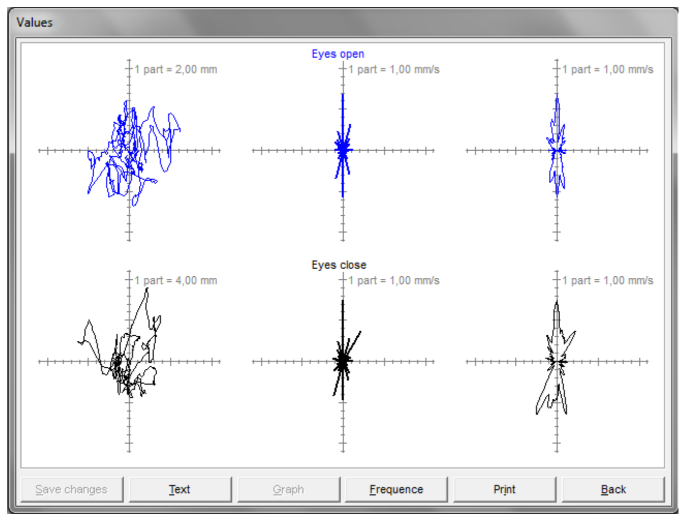

Fig. 12 Results in charts

Fig. 13 shows harmonic analysis of the patient's movements. The above charts are for open eyes bottom for closed eyes. On the left is the lateral component of movement, in the middle anteriopostural component of movement. On the right is the frequency analysis of the above mentioned components is showed. The area for the simulation analysis is highlighted by red line segments.

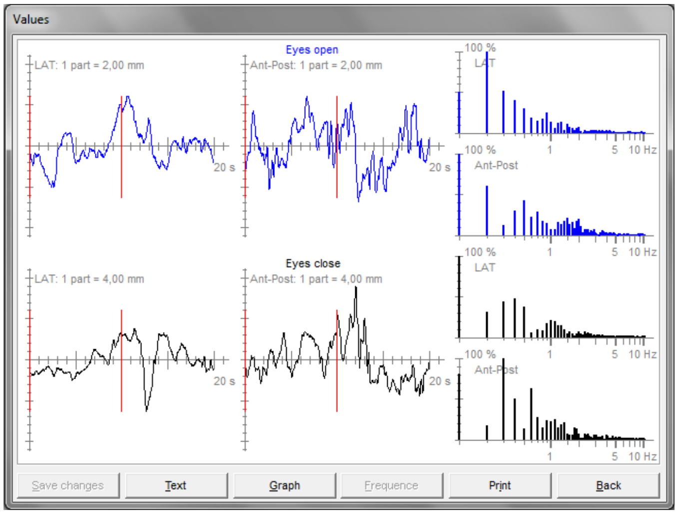

Fig. 13 Frequency analysis in charts

B. Addition of side parameters

For the vertigo evaluation it seems to be important to express the side and harmonic center of gravity move components. There is no direct numerical expression of these motion components, only visual presentation is partly covering it. We try to present simple procedure based on current data and nature of vertigo. Let's suppose, patients who have visual fixation, they have relatively good results but when loosing this fixation, the disturbance become wider. The same presumption can be applied to beginning of the examination and late course.

Modify the equation (3), replacing n with m where m is the number of measured samples in the first second of the examination and retrieve new, average values of center of gravity coordinates xb and yb (4).

$$x_b = \frac{1}{m}\sum_{i=1}^{m} x_i \qquad y_b = \frac{1}{m}\sum_{i=1}^{m} y_i \tag{4}$$

Then the parameter (vector) S can be defined (5).

$$S = \overrightarrow{x_b x_0} \tag{5}$$

For the evaluation of dominant tilts is necessary to calculate orientation and vector size. These values expand current numerical results and improve diagnostics accuracy.

VIII. Practical Example

The example shows part of the practical examination results. To be specific: patient with open eyes were monitored for 20 seconds.

The obtained parameters Way and Area point to abnormal deviation (base on normative values) but proposed parameter „s“ makes result more specific.

Fig. 14 shows track the patient's center of gravity, he has accomplished during the twenty-second test period with open eyes.

Results from the platform:
W = 2.60 cm/s
A = 0.74 cm^2/s

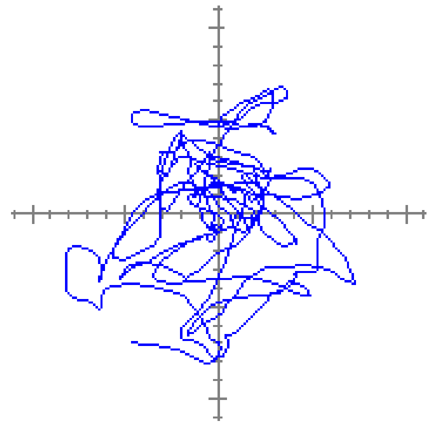

Fig. 14 Track of the center of gravity

Addition parameter „*S*“:
S = ([13.7; -23.4], [7.9; -35.3])
$S_{magnitude}$ = 13.2 mm
$S_{direction}$ = 26°

The additional parameter „*S*“ shows little front-right peripheral deviation of the subject.

IX. Conclusion

This paper describes current methods of vertigo examination focused on posturography evaluation. It shows basic numerical and visual posturography outputs. Also provides new parameter in the form of vector *S* (side). It seems to be important to express the side deviation of the center of gravity and it was a stimulus for expression of the *S* parameter. The proposed evaluation needs to be however verified by the practical experience now and found the rate of its practical usability.

The further research should focus on harmonicity of motion and its easy numerical presentation for standards formulation.

Acknowledgment

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