The Wii Balance Board as a tool for Evaluation of the Static Computed Posturography

L. Pivnickova, V. Dolinay, V. Vasek

Abstract— In this article is presented using the Wii Balance Board in the evaluation of static computed posturography. Posturography is a general term that covers all the techniques used to quantify postural control in upright stance in either static or dynamic conditions. This study focused on static posturography only. Static posturography is carried out by placing the patient in a standing posture on a fixed instrumented platform connected to sensitive detectors, which are able to detect the tiny oscillations of the body. Though the Wii Balance Board was originally designed as a video game controller, obtained results show that Wii Balance Board can become a device useful for assessing center of pressure displacement in medical examinations. The considerable benefits of using the Wii Balance Board are also its portability and low price.

Keywords— posturography, Wii Balance Board, vertigo, balance, Romberg test, medical examinations, Wii Posturografie.

I. Introduction

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 [16].

One of the medical techniques 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 [11, 16].

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 study focused on static posturography only. Static posturography is carried out by placing the patient in a standing posture on a fixed instrumented platform connected to sensitive detectors, which are able to detect the tiny oscillations of the body.

This article introduces the Wii Balance Board in the evaluation of static computed posturography. Though the Wii Balance Board was originally designed as a video game controller, obtained results show that Wii Balance Board can become a device useful for assessing center of pressure displacement in medical examinations. The considerable benefits of using the Wii Balance Board are also its portability and low price.

II. Balance Disorders

A balance disorder is a condition that makes you feel unsteady or dizzy, as if you are moving, spinning, or floating, even though you are standing still or lying down. Balance disorders can be caused by certain health conditions, medications, or a problem in the inner ear or the brain.

Our sense of balance is primarily controlled by a maze-like structure in our inner ear called the labyrinth, which is made of bone and soft tissue. At one end of the labyrinth is an intricate system of loops and pouches called the semicircular canals and the otolithic organs, which help us maintain our balance. At the other end is a snail-shaped organ called the cochlea, which enables us to hear. The medical term for all of the parts of the inner ear involved with balance is the vestibular system (see Fig. 1). [11]

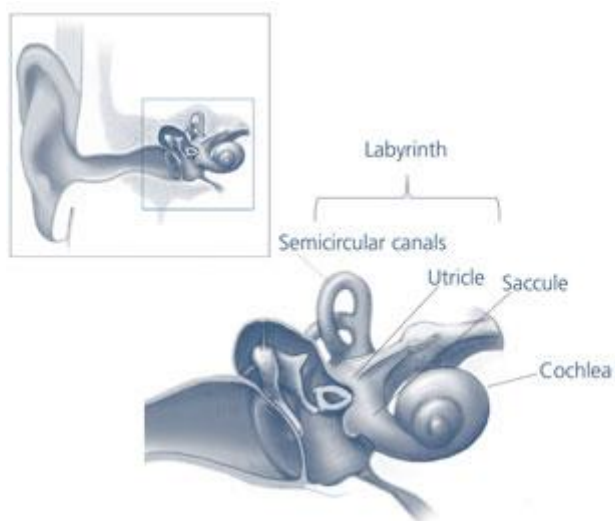

Fig. 1 The vestibular system in relation to the ear [11]

A. *How works the vestibular system*

Our vestibular system works with other sensorimotor systems in the body, such as our visual system (eyes) and skeletal system (bones and joints), to check and maintain the position of our body at rest or in motion. It also helps us maintain a steady focus on objects even though the position of our body changes. The vestibular system does this by detecting mechanical forces, including gravity, that act upon our vestibular organs when we move. Two sections of the labyrinth help us accomplish these tasks: the semicircular canals and the otolithic organs.

The semicircular canals are three fluid-filled loops arranged roughly at right angles to each other. They tell the brain when our head moves in a rotating or circular way, such as when we nod our head up and down or look from right to left.

Each semicircular canal has a plump base, which contains a raindrop-shaped structure filled with a gel-like substance (see Fig. 2). This structure, called the cupula, sits on top of a cluster of sensory cells, called hair cells. The hair cells have long threadlike extensions, called stereocilia, that extend into the gel. When the head moves, fluid inside the semicircular canal moves. This motion causes the cupula to bend and the stereocilia within it to tilt to one side. The tilting action creates a signal that travels to the brain to tell it the movement and position of your head. [11]

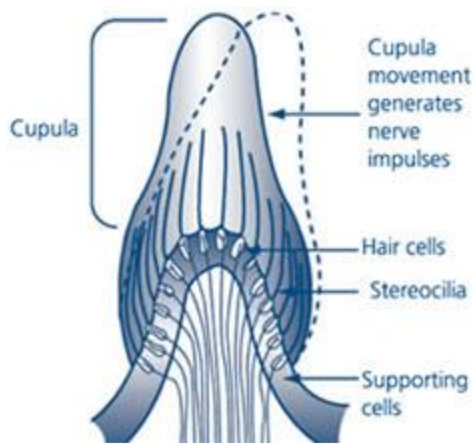

Fig. 2 The role of the cupula in balance [11]

Between the semicircular canals and the cochlea lie the otolithic organs, which are two fluid-filled pouches called the utricle and the saccule. These organs tell the brain when our body is moving in a straight line, such as when we stand up or ride in a car or on a bike. They also tell the brain the position of our head with respect to gravity, such as whether we are sitting up, leaning back, or lying down.

Like the semicircular canals, the utricle and the saccule have sensory hair cells. These hair cells line the bottom of each pouch, and their stereocilia extend into an overlying gel-like layer. On top of the gel are tiny grains made of calcium carbonate called otoconia. When you tilt your head, gravity pulls on the grains, which then move the stereocilia. As with the semicircular canals, this movement creates a signal that tells the brain the head's position.

Our visual system works with our vestibular system to keep objects from blurring when our head moves and to keep us aware of our position when we walk or when we ride in a vehicle. Sensory receptors in our joints and muscles also help us maintain our balance when we stand still or walk. The brain receives, interprets, and processes the information from these systems to control our balance. [11]

B. The symptoms of a balance disorder

If your balance is impaired, you may feel as if the room is spinning. You may stagger when you try to walk or teeter or fall when you try to stand up. Some of the symptoms you might experience are:

- Dizziness or vertigo (a spinning sensation)
- Falling or feeling as if you are going to fall
- Lightheadedness, faintness, or a floating sensation
- Blurred vision
- Confusion or disorientation

Other symptoms are nausea and vomiting, diarrhea, changes in heart rate and blood pressure, and fear, anxiety, or panic. Some people also feel tired, depressed, or unable to concentrate. Symptoms may come and go over short time periods or last for longer periods of time.

C. Causes a balance disorder

A balance disorder may be caused by viral or bacterial infections in the ear, a head injury, or blood circulation disorders that affect the inner ear or brain. Many people experience problems with their sense of balance as they get older. Balance problems and dizziness also can result from taking certain medications.

In addition, problems in the visual and skeletal systems and the nervous and circulatory systems can be the source of some posture and balance problems. A circulatory system disorder, such as low blood pressure, can lead to a feeling of dizziness when we suddenly stand up. Problems in the skeletal or visual systems, such as arthritis or eye muscle imbalance, also may cause balance problems. However, many balance disorders can begin all of a sudden and with no obvious cause. [11]

D. Types of balance disorders

There are more than a dozen different balance disorders. Some of the most common are: [11, 12, 15]

- Benign paroxysmal positional vertigo (BPPV) or positional vertigo is a brief, intense episode of vertigo that occurs because of a specific change in the position of the head. If you have BPPV, you might feel as if you're spinning when you look for an object on a high or low shelf or turn your head to look over your shoulder (such as when you back up your car). You also may experience BPPV when you roll over in bed. BPPV is caused when otoconia tumble from the utricle into one of the semicircular canals and weigh on the cupula. The cupula can't tilt properly and sends conflicting messages to the brain about the position of the head, causing vertigo. BPPV sometimes may result from a head injury or just from getting older.

- Labyrinthitis is an infection or inflammation of the inner ear that causes dizziness and loss of balance. It frequently is associated with an upper respiratory infection such as the flu.

- Ménière's disease is associated with a change in fluid volume within parts of the labyrinth. Ménière's disease causes episodes of vertigo, irregular hearing loss, tinnitus (a ringing or buzzing in the ear), and a feeling of fullness in the ear. The cause of this disease is unknown. For more information, read the NIDCD fact sheet Ménière's Disease.

- Vestibular neuronitis is an inflammation of the vestibular nerve and may be caused by a virus. Its primary symptom is vertigo.

- Perilymph fistula is a leakage of inner ear fluid into the middle ear. It can occur after a head injury, drastic changes in atmospheric pressure (such as when scuba diving), physical exertion, ear surgery, or chronic ear infections. Its most notable symptom, besides dizziness and nausea, is unsteadiness when walking or standing that increases with activity and decreases with rest. Some babies may be born with perilymph fistula, usually in association with hearing loss that is present at birth.

- Mal de debarquement syndrome (MdDS) is a balance disorder in which you feel as if you're continuously rocking or bobbing. It generally happens after an ocean cruise or other sea travel. Usually, the symptoms will go away in a matter of hours or days after you reach land. However, severe cases can last months or even years.

III. 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 [1, 5, 7, 9].

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 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, see Fig. 3.

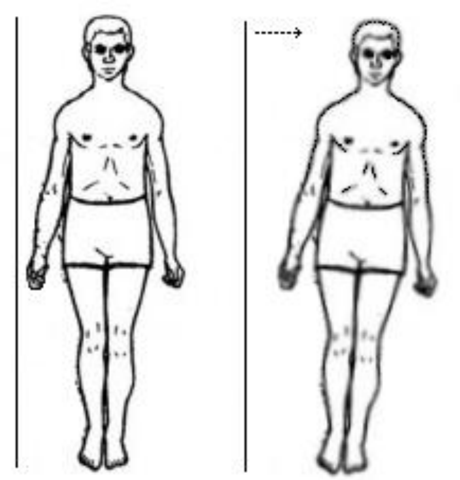

Fig. 3 Romberg test [7]

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 [5, 7, 9].

IV. Wii Balance Board

The Wii Balance Board is a balance board accessory for the Wii and Wii U video game consoles. It runs on four AA batteries as a power source, which can power the board for about 60 hours. The board uses Bluetooth technology and contains four pressure sensors that are used to measure the user's center of balance—the location of the intersection between an imaginary line drawn vertically through the center of mass and the surface of the Balance Board—and weight. Although the Japanese packaging states that it is designed to support people weighing up to 136 kilograms (300 pounds) and the "Western" Balance Board up to 150 kg (330 pounds), they are actually the same board. The packaging differs due to regulatory differences between Japan and the United States. The sensors on the board can accurately measure up to 150 kg (330 pounds). The actual physical structure of the board can withstand much greater force equivalent to around 300 kg (660 pounds) [8, 10].

Fig. 4 The top of a Wii Balance Board [8]

Though originally designed as a video game controller, the Balance Board has become a proven tool for assessing center of pressure displacement. As described Clark [2] it is proven to be both valid and reliable. Was already performed a study to prove the validity and test-retest reliability of the use of a Balance Board. The idea behind using a Balance Board instead of a force platform is the ability to “create a portable, inexpensive balance assessment system that has widespread availability.” Four standing balance tasks were used in this study including a combination of double stance, single stance, eyes open, and eyes closed. Throughout these tests the center of pressure path length was measured and compared these data to an identical study on a laboratory-grade force platform. The study found the Wii Balance Board to be both valid and have high test-retest reliability [2, 8, 10].

V. Process of Measurement

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, see Fig.3.

Conditions of measurement:

- Process of measurement: upright standing posture
- Measurement methods: with eyes open and close
- Measure period: 40 ms
- Length of measure: 20 s

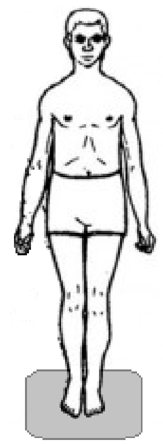

Fig. 5 Process of measurement on the platform [7]

VI. Measurement Diagnostic Values

Wii Posturografie software was special proposed for evaluation of postural stability via Wii Balance Board. This software calculates series of values which are important to determine the correct diagnosis.

Parameter “*Way*” (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 [15].

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

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*” (cm2/s) indicates the area, which describes variation of center of gravity during the examination [2].

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

where:

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

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

Parameter "*Lat*" (cm / s) expressing the resultant vector of the amplitude of the lateral center of gravity (the length of the lateral displacement of center of gravity during the measurement). As in the physical assessment of neurological attitudes, this parameter is to be seen as indicators of the peripheral vestibular lesion.

$$sum = \sum_{i=1} (x_i - x_{i-1})$$
$$Lat = sum/t \qquad (4)$$

where:

t	length of measure [ms]
x	center of gravity coordinates

Parameter "*Ant –Post*" (cm / s) is the anteroposterior amplitude gravity vector (length anteroposterior displacement of center of gravity during the period of measurement). As in the physical assessment of neurological attitudes, mild sagittal vector dominance at the physiological state of equilibrium is considered normal, with balance disorders is to be seen as indicators of central lesions.

$$sum = \sum_{i=1} (y_i - y_{i-1})$$
$$Ant - Post = sum/t \qquad (5)$$

where:

t	length of measure [ms]
y	center of gravity coordinates

Parameter "*AP/Lat*" is the ratio of anterior-posterior and lateral components of the examined balance, which reflects the overall dominance of directional amplitude gravity investigated.

$$\frac{AP_{open}}{Lat_{open}} = \frac{Ant - Post}{Lat}$$
$$\frac{AP_{close}}{Lat_{close}} = \frac{Ant - Post}{Lat} \qquad (6)$$

Parameter "*Romb Way*" is the ratio of way with open and closed eyes. Express the ratio of a visual control of posture to maintain postural balance.

$$Romb\ Way = \frac{Way_{close}}{Way_{open}} \qquad (7)$$

Parameter "*Romb Area*" is the ratio of area with open and closed eyes.

$$Romb\ Area = \frac{Area_{close}}{Area_{open}} \qquad (8)$$

Parameter "*Side*" for the vertigo evaluation it seems to be important to express the side and harmonic center of gravity move components. 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 x_b and y_b (4).

$$x_b = \frac{1}{m}\sum_{i=1}^{m} x_i$$
$$y_b = \frac{1}{m}\sum_{i=1}^{m} y_i \qquad (9)$$

Then the parameter (vector) S can be defined (10).

$$\vec{S} = \overrightarrow{x_b x_0} \qquad (10)$$

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

VII. Proposed Expert System

The proposed expert system using historical data measured on the static posturographic platform. The expert system is based on the combination fuzzy logic and golden ratio. The expert system was based on the differential diagnosis of balance disorders. The data were divided into groups corresponding to individual disorders:

- Benign paroxysmal positional vertigo (BPPV)
- Vestibulopathies
- Meniere's disease
- Neuritis
- Disequilibrium
- Central

Each group contains the measured data way, area, lateral deviation, anteroposterior deviation, Romberg way and Romberg area. For each parameter were calculated median and for the boundary points using the golden section.

A. Median

In case the values are arranged in a non-decreasing sequence,

$$x_1 \le x_2 \le x_3 \le \cdots \le x_n \quad (11)$$

so the median is the value that is in the middle of this sequence. The middle value can vary as a sequence of odd or even number of elements.

- if odd, the median element in position

$$Med(x) = x_{\frac{n+1}{2}} \quad (12)$$

- if a sequence of an even number of elements, then there is no element that was completely surrounded, for which reason it takes the average of the two middle values

$$Med(x) = \frac{x_{n/2} + x_{(n+2)/2}}{2} \quad (13)$$

B. Golden ratio

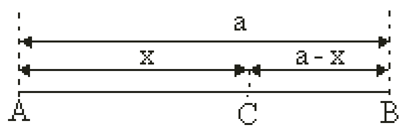

Fig. 4 Distribution segment golden section

If we divide the length of the line AB and the point C into two parts x and (a - x) so that the ratio of lengths greater part x to smaller section (a - x) equals the ratio of the length of the segment a to the greater part of x, thus such that

$$\frac{x}{a-x} = \frac{a}{x}, \quad (14)$$

then we say that we have constructed the golden section of the segment AB and the ratio of a:x, respectively x:(a-x) is called the golden ratio. If we choose the size of the line a = 1 then the equation of the golden section as follows

$$\frac{x}{1-x} = \frac{1}{x} \quad (15)$$

After adjustment we solve a quadratic equation

$$x^2 + x - 1 = 0 \quad (16)$$

whose positive root is

$$x_1 = \frac{-1+\sqrt{5}}{2} = 0{,}61803 \quad (17)$$

and the ratio

$$\varphi = \frac{1}{x_1} = 1{,}61803 \quad (18)$$

C. Example the application of method

The group of the BPPV contains 1896 patients. For illustration was chosen parameter Way from referred group.

Procedure:

- sorting data from smallest to largest
- calculation of the median - 50% of the total number of patients (returns index)

$$median = 1896 * 0{,}5 = 948 \quad (19)$$

- calculation of boundary points HB_{low} and HB_{high}

$$HBlow = 1896 * 0{,}191 = 362 \quad (20)$$

$$HBhigh = 1896 * 0{,}809 = 1534 \quad (21)$$

The median value is placed on the index 948 and values of the boundary points are placed on the index 362 and 1534.

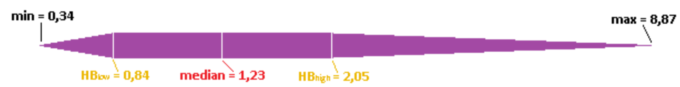

Fig. 6 BPPV group – parameter Way

The level of competence of the patient to the group is evaluated as a percentage. In case that the measured value eg 3.5 then we standardize value by formula (4.21). The result is shown in figure 7.

$$a = 8{,}87 - 2{,}05 = 6{,}82 \quad (22)$$

$$b = 3{,}5 - 2{,}05 = 1{,}45 \quad (23)$$

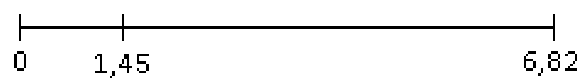

Fig. 7 The line shows the values of the standardized

$$100\% \cdots\cdots\cdots 6{,}82$$

$$1\% \cdots\cdots\cdots 0{,}0682$$

$$x\% \cdots\cdots\cdots 1{,}45$$

$$100 - \frac{1{,}45}{0{,}0682} = 79\% \quad (24)$$

Formula 24 shows the measured value, which belong to the group BPPV from 79%.

VIII. Measurement Results

The Wii Posturography software calculates series of parameters which are used as a support for diagnosis of patients.

A. Program description - data evaluation

1 - Edit box is used for entering the patient's height (before measurement)

2 – Button Calibrate is used to calibrate of the platform (the patient is outside of the platform)

3 – Button Measure is used to run the examination (measurement time is 20 second, the end is indicated by a tone)

4 - Blue arrows are used to change the measurement type (open or closed eyes)

5 - Button Evaluate is used to start the application for analysis of the measurement results

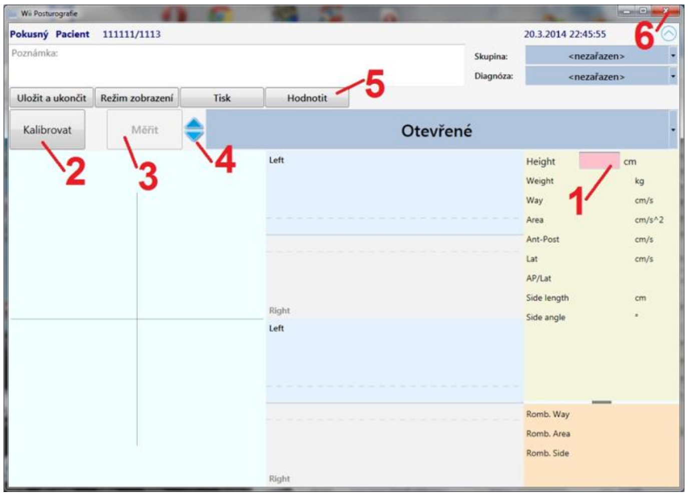

Fig. 8 The software application Wii Posturografie

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

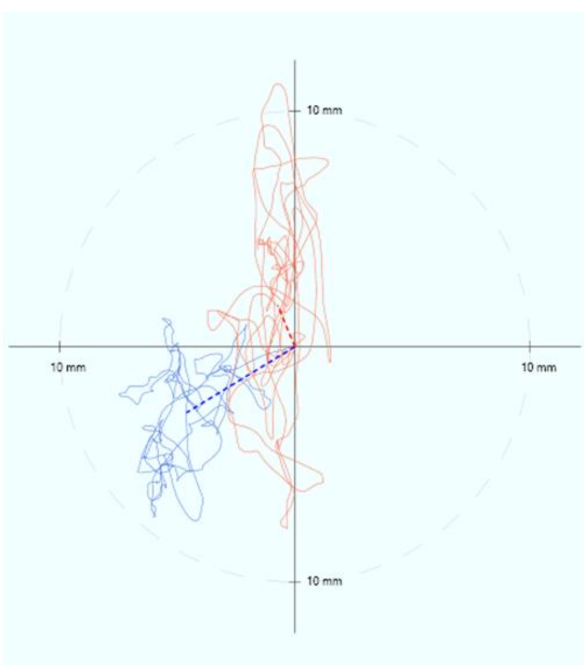

Fig. 9 Image shows the patient´s body motion during measurement with open and closed eyes

Figure 9 shows center of gravity trajectories (patient´s body motion) and direction of motion vector. The chart shows patient´s body motion with eyes open (blue line) and with eyes close (red line).

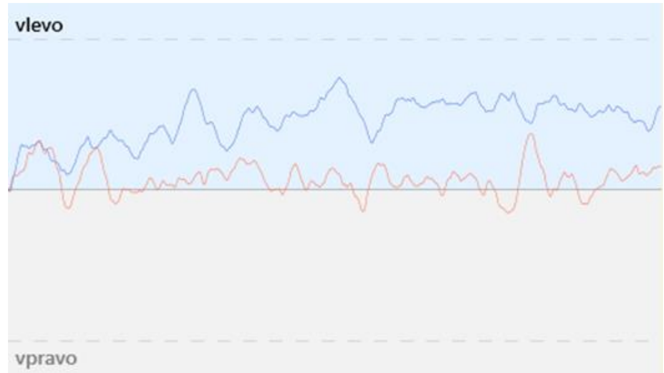

Fig. 10 Shows the X-coordinates in the closed and opened eyes

Figure 10 shows that the patient is tilted to the left side with open eyes (blue line) and with eyes closed (red line) is tilted only slightly to the left side.

Fig. 11 Shows the Y-coordinates in the closed and opened eyes

Figure 11 shows that the patient is tilted to the backward with open eyes (blue line) and with eyes closed (red line) is tilted greatly to the forward.

Fig. 12 Measurement results of the patient

Figure 12 shows the measured values, which are used for the diagnosis of balance disorders. From the diagnostic values and supporting graphical views show that the patient may have a central fault.

IX. Evaluation of the measured values via proposed expert system

For evaluation of the measured data was created the software utilizing already a proposed expert system.

An expert system was developed based on the measured data of patients on the posturography platform. The obtained data were including diagnosis suggested by a doctor. This makes it possible to use fuzzy logic to create an evaluation system that serves as a support for assessment of diagnosis.

Figure 13 shows measurement results as Way, Area, Ant-Post and Lat with opened and closed eyes. This data are copied to the evaluation system, which suggests the diagnosis.

In case the doctor does not agree with the proposed diagnosis has the option to choose a diagnosis and then save it. This makes it possible the expert system repeatedly learns and improves.

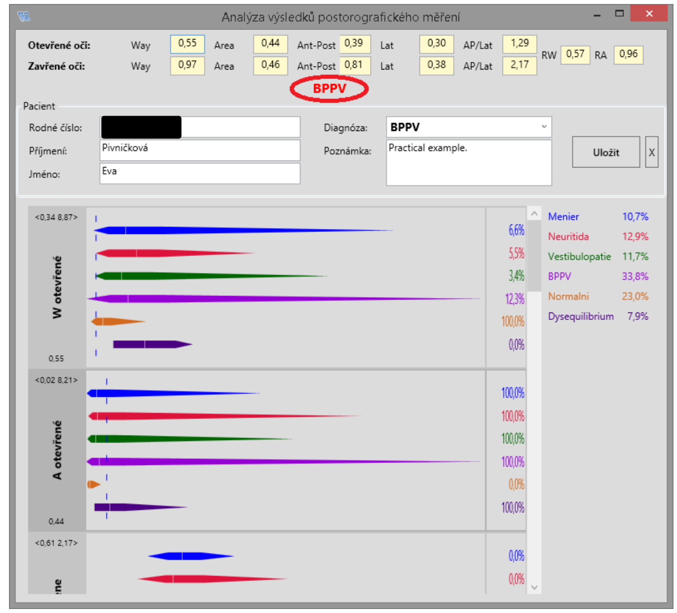

Fig. 13 Software “Analysis of the results of posturography measurement” displaying the proposed diagnosis (in the red frame)

A. *Program description - data evaluation*

The measured values are either automatically inserted into the window form "Analysis of the results of posturography measurement" or can be added manually.

The system suggests the diagnosis - see in **1**, the diagnosis will be pre-filled in menu **2**.

A doctor has the possibility this diagnosis to correct selecting the correct diagnosis from the second list **2**. If the correct diagnosis is not yet included in the list, we can add it to the list.

Button **3** is used to save the patient's diagnosis. After saving, the window automatically closes.

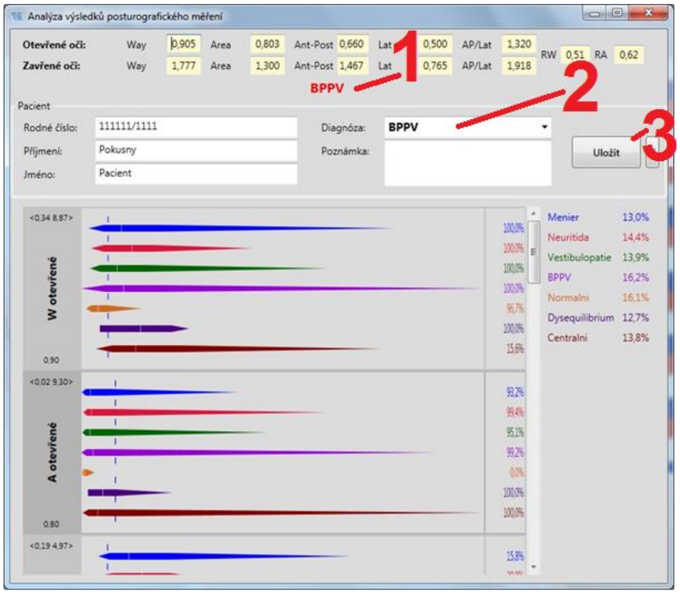

Fig. 14 Software “Analysis of the results of posturography measurement” – program description

X. Conclusion

This article focused on introducing the Wii Balance Board in the evaluation of static computed posturography. For the purposes of measurement was created software "Wii Posturography" that calculates basic numerical values such as the Way, Area, Ant-Post, Lat, but also the "Side" parameter for dominance tilt. The program also displays the measurement results into graphs. Each measurement can be saved for later analysis. This makes it possible to compare individual measurements and track the health status of patients. For determine of diagnosis was created the software Analysis of the results of posturography measurement. The software suggests the diagnosis but the doctor must agree with the proposed result. The Balance Board has become a proven tool for assessing center of pressure displacement. The main advantage using a Wii Balance Board instead of a force platform in evaluation of static posturography is the ability to create a portable, inexpensive balance assessment system that has widespread availability. This would allow the device the Wii Balance Board including created "Wii Posturography" software introduced in GP surgeries. The further research should focus on another measurement of patients and analysis of the obtained data.

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