Application of fuzzy logic in the evaluation of postural stability

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Abstract: - This article describes the experiment focused on balance disorders diagnosis determination.The main idea is based on the measured data, expert diagnosis and the use of fuzzy logic. The data used in this experiment were measured under the static conditions on the posturography platform. The patients were split into three groups: peripheral, central and normal, based on doctor's diagnosis. Membership functionsfor the fuzzy logic were created based on these samples. These functions foundations based on the standards obtained from a set of measurements performed on selected patients and expert base. From the obtained results was found, that for the group of selected patients - without balance disorders, using the proposed methodology, it was found that in 60% of them can be clearly said, that it is a normal patient, without balance disorders and in the remaining 40% of the results was inconclusive, from 85 patients in the group of patients with peripheral balance disorders using the proposed methodology, it was found that in 78% can be clearly argued that these patients are with peripheral balance disorders and in the remaining 22% of the results were inconclusive and from 82 patients in the group of patients with central balance disorders using the proposed methodology, it was found that in 83% can be clearly argued that these patients are with central balance disorders. Remaining 17% of the results were inconclusive.From the performed experiments appears, that proposed methodology has good possibility to distinguish whether patients have impaired balance or not, but ability to distinguish patients with peripheral balance disorders in patients with central disorder seems weak. However, research continues and the application of other modern methods can eliminate this weakness.

Key-Words: -Balance disorders, fuzzy logic, membership function, peripheral vestibular deficits, posturography, vestibular dysfunction.

1 Introduction

Posturography, also known as a test of balance is a general term for methods used to measure postural stability on static or dynamic measuring platforms. The principle of measurement is detection of the center of foot pressure (CFP) during examination on a posturography platform.

The CFP projects the center of gravity of the body to the ground. It must be maintained within the area defined by the feet. Balancing requires information from the vestibular, somatosensory and visual system.

Failure of any of these systems causes specific balance disturbances. Even between the lesions of the central and peripheral vestibular systems are observable clinical differences which may be reflected in the body sway measurement. Posturography is an objective technique, so it is not burdened by subjective interpretation, andthe results can be documented both graphically and numerically. This enables a detailed assessment of postural balance, a comparison of results, and an ability toarchive [2, 4, 11 and 13].

This article is dealt with only static posturography.

Static posturography is based on the principle of measuring the shifts in CFP on a stationary platform [2, 11 and 13]. Opinions on the importance of posturography and its position among other machine-based techniques in vestibulology are divided. Prevailing opinion is that both posturography techniques (SCPG and DCPG) are beneficial especially for the quantitative assessment of postural balance [1, 3, 5, 11 and 13]. Posturography is deemed a suitable complement to standard vestibular examinations, especially in patients with CNS pathology and is useful for evaluating susceptibility to falling [6, 7, 9 and 11].

There are many studies deal with the differential diagnosis of balance disorders of the human but there are not many studies using modern methods. This article deals with thedifferential diagnosis of balance disorders using a fuzzy logic.

2 Fuzzy logic

Fuzzy logic is a form of many-valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values) fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. [8, 10] Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false.

The term "fuzzy logic" was introduced with the 1965 proposal of fuzzy set theory by Lotfi A. Zadeh. [10, 12] Fuzzy logic has been applied to many fields, from control theory to artificial intelligence.

In the past decade, fuzzy logic has proved to be useful for intelligent systems in medicine.

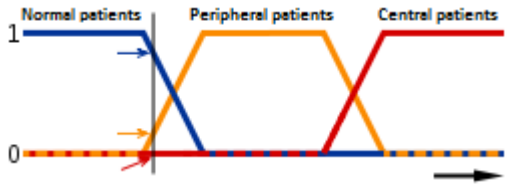

Fig. 1: Schema of the fuzzy logic diagnosis

In this image, the meanings of the expressions normal, peripheral, and central patients are represented by functions mapping a diagnostic scale. A point on that scale has three "truth values"—one for each of the three functions. The vertical line in the image represents a particular value that the three arrows (truth values) gauge. Since the red arrow points to zero, this diagnosis may be interpreted as "not central". The orange arrow (pointing at 0.2) may describe it as "slightly peripheral" and the blue arrow (pointing at 0.8) "fairly normal". It can be concluded that the patient is without balance disorders.

3 Static posturography

All measurements were performed on an STP-03 computerized posturography platform under the standard conditions of measurement in audio-vestibulology laboratory.

Investigations carried out in the sound damping room laboratory under conditions to ensure silence. Basic examination of all patients on the posturography platform is performed in a natural standing position.

3.1 The evaluation parameters of static posturography

Posturograph STP-03 software (widely use in Czech Republic) calculates the value of the way and area of the patient center of gravity circumscribed over the posturographic platform (frequency analysis).

Evaluates the ratio between these values for the examination with open and closed eyes are important parts of vertigo assessment (visual analysis of balance control) shows the direction and magnitude of the vector amplitude of gravity and calculates the resultant vector (vector analysis).

3.1.1 Frequency analysis

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.

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

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, 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).

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

Where:

N_i	particular element of area calculation
t	length of measure [s]

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x_0, y_0 average values of center of gravity coordinates*(3)*

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

3.1.2 Vector analysis

Parameter *LAT (cm / s)* is the resulting lateral vector amplitude of the center of gravity (the length of the lateral deflection of the center of gravity during the period of measurement). It is measured by device a visual fixation Xf and Xs visual suppression. Like the physical assessment of neurological attitudes, this parameter is to be seen as indicators of the peripheral vestibular lesion.

Parameter *Ant-Post (cm / s)* is the vector amplitude of anteroposterior center of gravity (the length anteroposterior displacement during the measurement). It is also measured during visual fixation Yf and Ys visual suppression. Like the physical assessment of neurological attitudes, mild anterior vector dominance in the physiological state of equilibrium is considered normal; the imbalance is to be seen as indicators of central lesions.

The instrument automatically calculates the ratio of anteroposterior and lateral components of the examined balance (AP / LAT) during visual fixation ALf and suppression of ALs, which represents the overall directional preponderance amplitude gravity investigated.

3.1.3 Analysis of visual inspections balance

Derived parameters, known as Romberg Way (RW, Wf / s) is the ratio of the Way with open and closed eyes. It expresses the proportion of visual inspections to maintain postural balance.

RbgArea derived parameters (RA, Af / s) is analogous calculations and interpretations as RbgWay.

4 The using of the fuzzy logic in the differential diagnosis of balance disorders

In this work was used of the range of categories for the evaluation of postural equilibrium SCPG to obtain at the University Hospital in Hradec Kralove with reference to the evaluation range of other physicians. The values used in this work were actually measured on posturographyplatform STP-03 and was diagnosed by doctor.

The aim was to use fuzzy logic to distinguish at first, whether it is a person with the disorder balance or not. It was then ascertained whether the patient has with the disorder balance disorder of the peripheral vestibular syndrome or central vestibular syndrome.[13]

4.1 Preparation of the data

From the data obtained with the posturographicplatform were chosen patients who were initially diagnosed by a doctor. These patients were divided into groups of peripheral and central disorder and patients with normal balance.

4.2 Evaluation of data using fuzzy logic

For each parameter was created the membership function, which had been evaluated measured data from STP-03.

4.2.1 Membership function of the parameters in the visual fixation

Membership functions for parameter Way, W (cm / s) which describes the path of moving circumscribed over theposturography platform during the testing

$$Wf(x) = \begin{Bmatrix} 0, & if\ x < 1{,}7939 \\ 1, & if\ x > 2{,}5798 \\ \frac{x-1{,}7939}{|x-2{,}5798|+(x-1{,}7939)} & if\ 1{,}7939 \le x \le 2{,}5798 \end{Bmatrix} \quad (4)$$

Membership function for the parameter Area, A (cm2 / s) the surface, which describes center of gravity, investigated during the examination

$$Af(x) = \begin{Bmatrix} 0, & if\ x < 0{,}4423 \\ 1, & if\ x > 0{,}7374 \\ \frac{x-0{,}4423}{|x-0{,}7374|+(x-0{,}4423)} & if\ 0{,}4423 \le x \le 0{,}7374 \end{Bmatrix} \quad (5)$$

Membership functions for parameter LAT (cm / s)is the resulting lateral vector amplitude of the center of gravity (the length of the lateral deflection of the center of gravity during the period of measurement)

$$Xf(x) = \begin{Bmatrix} 0, & if\ x < 16{,}3097 \\ 1, & if\ x > 24{,}6109 \\ \frac{x-16{,}3097}{|x-24{,}6109|+(x-16{,}3097)} & if\ 16{,}3097 \le x \le 24{,}6109 \end{Bmatrix} \quad (6)$$

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Membership functions for parameter Ant-Post (cm / s) is the vector amplitude of anteroposterior center of gravity (the length anteroposterior displacement during the measurement)

$$Yf(x) = \begin{Bmatrix} 0, & if\ x < 15{,}2723 \\ 1, & if\ x > 22{,}7030 \\ \frac{x-15{,}2723}{|x-22{,}7030|+(x-15{,}2723)} & if\ 15{,}2723 \le x \le 22{,}7030 \end{Bmatrix} \quad (7)$$

4.2.2 Membership function of the parameters in the visual suppression

Membership functions for parameter Way, W (cm / s) which describes the path of moving circumscribed over the posturography platform during the testing

$$Ws(x) = \begin{Bmatrix} 0, & if\ x < 2{,}0909 \\ 1, & if\ x > 3{,}1489 \\ \frac{x-2{,}0909}{|x-3{,}1489|+(x-2{,}0909)} & if\ 2{,}0909 \le x \le 3{,}1489 \end{Bmatrix} \quad (8)$$

Membership function for the parameter Area, A (cm2 / s) the surface, which describes center of gravity, investigated during the examination

$$As(x) = \begin{Bmatrix} 0, & if\ x < 0{,}6194 \\ 1, & if\ x > 1{,}0934 \\ \frac{x-0{,}6194}{|x-1{,}0934|+(x-0{,}6194)} & if\ 0{,}6194 \le x \le 1{,}0934 \end{Bmatrix} \quad (9)$$

Membership functions for parameter LAT (cm / s) is the resulting lateral vector amplitude of the center of gravity (the length of the lateral deflection of the center of gravity during the period of measurement)

$$Xs(x) = \begin{Bmatrix} 0, & if\ x < 17{,}9141 \\ 1, & if\ x > 26{,}9694 \\ \frac{x-17{,}9141}{|x-26{,}9694|+(x-17{,}9141)} & if\ 17{,}9141 \le x \le 26{,}9694 \end{Bmatrix} \quad (10)$$

Membership functions for parameter Ant-Post (cm / s) is the vector amplitude of anteroposterior center of gravity (the length anteroposterior displacement during the measurement)

$$Ys(x) = \begin{Bmatrix} 0, & if\ x < 17{,}4213 \\ 1, & if\ x > 25{,}9679 \\ \frac{x-17{,}4213}{|x-25{,}9679|+(x-17{,}4213)} & if\ 17{,}4213 \le x \le 25{,}9679 \end{Bmatrix} \quad (11)$$

5 Conclusion

The aim of this study was using fuzzy logic to implement experimental procedures testing failures equilibrium apparatus.

The work dealt specifically with the differential diagnosis of balance disorders, it is essential vestibular question.

Therefore clearly differentiate whether a patient is with balance disorders (peripheral, central) or healthy individuals without balance disorders.

Data utilized in this study were measured at posturography platform STP-03 at the University Hospital in Hradec Kralove and diagnosed by a doctor. This data was divided into three sets according diagnostic split to the group of patients without balance disorders, which were evaluated 50 patients, as well as the group of patients with peripheral vertigo, which were evaluated 85 patients and the group of patients with central disorder where were evaluated total of 82 patients. It was selected for several measuring elements for which the membership functions were created. Specifically, parameters W (path), A(area), X/s (length of lateral deviations) and Y/s (length of anterior deviations).

Of the 50 patients in the group of patients without balance disorders using the selected methodology, it was found that in 60% of them can clearly say that it is a normal patient, without balance disorders and in the remaining 40% of the results was inconclusive, as shown in Fig. 1.

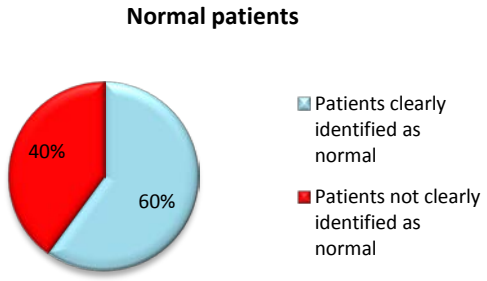

Fig. 2: Result evaluation of normal patients

Of the 85 patients in the group of patients with peripheral balance disorders using the selected methodology, it was found that in 78% can be clearly argued that these patients are with peripheral balance disorders and in the remaining 22% of the results was inconclusive, as shown in Fig. 2.

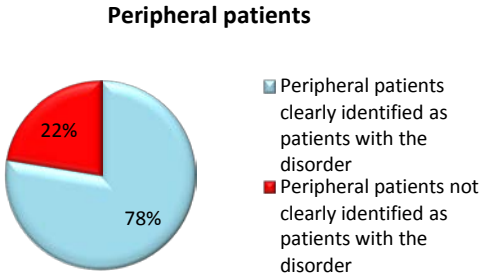

Fig. 3: Result evaluation of peripheral patients

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Of the 82 patients in the group of patients with central balance disorders using the selected methodology, it was found that in 83% can be clearly argued that these patients are with central balance disorders and in the remaining 17% of the results was inconclusive, as shown in Fig. 3.

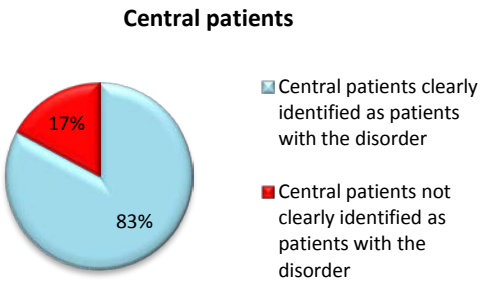

Fig. 4: Result evaluation of central patients

These results show that only 76% of the total numbers of patients corresponding to the diagnostic division a doctor. Due to the solved problem is such a poor result. The work was only possible to distinguish whether patients have impaired balance or not, but cannot be chosen methodology to distinguish patients with peripheral balance disorders in patients with central disorder. For a given problem would perhaps be better to choose another method such as neural networks.

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