CONTRIBUTIONS OF THE VECTORIAL ANALYSIS TO THE DIAGNOSIS OF POSTURAL DYSFUNCTIONS

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The postural system and stable equilibrium

The equilibration of the human body depends on the tonic reflexes of posture and positioning, discovered in the early XXth century by Magnus, De Klein, De Bourlé, De Gouvé and other representatives of the Utrecht school (Holland)(R. Magnus, 1962).

On earth, man constantly lives under the influence of gravity. The tonic reflexes of posture give certain rigidity to his body by more or less limiting the degrees of freedom of his joints. In the orthostatic posture, the spine is stiffened by its muscles. The mobility is limited to the coxo-femoral, the knee, the joints of the cervical spine, the skull and corresponding muscles. The tonic postural reflexes also ensure the redistribution of the tonus of the body and of the limbs according to the spatial position of the head and to the reactions of the support basis.

If there were no other reflexes to maintain the body in his standing position, its rigidity would immediately make it fall like an inverted pendulum, set vertically. But it does not happen so because as soon as the body deviates from the vertical, the receptors of the vestibular apparatus and the proprioceptive receptors (mainly articular) operate. The nervous impulses coming from the vestibular apparatus set into motion the muscles of the trunk and of the limbs in order to restore balance. Furthermore, the information coming from the vestibular apparatus and the proprioceptive receptors goes to the cerebellum, which is the center of automatic balance. Its reflex reactions, which have priority, automatically influence trunk and limbs muscles and correct the vestibular reactions, if needed.

Therefore, the information of a deviation of the body from the vertical is absolutely necessary to the restoration of balance. From that perspective, we can characterize the function of balance in a healthy subject as a function of "stabilization of imbalance" within certain limits. That is how the tonic musculature essentially works.

If the postural system does not work well, then a musculature requiring a greater expenditure of energy will have to participate. Those alternative tactics to maintain the orthostatic posture are not economical. In the patient, because of the various dysfunctions of the postural system responsible for the function of balance, the mechanisms of its control are deformed and/or retarded, which often leads to increasing the amplitude of the body's hesitation. Yet sometimes, for instance in the spastic form of cerebral palsy, the spasm of the postural musculature leads to a reduction of the body's hesitation... This gives an idea of how complex the interpretation of stabilometric data is.

The realization of the function of balance is facilitated by the visual information of the environment. Yet proprioceptive and vestibular information are more fundamental. This is proved by the date of apparition of the vestibular and proprioceptive receptors during the phylogenies, which is anterior to that of the retina receptors. Moreover, the subjective visual vertical establishes itself, during the ontogenesis, on the basis of otolithic information. Finally, the proprioceptive data coming from the tendons of the oculomotor muscles is as important for the postural system as it is for vision.

Lastly, the role of the captors of the plantar soles has to be underlined specifically. They are not proprioceptive receptors. Nevertheless, those deep and superficial tactile receptors feel the support basis as if they were our "second pair of eyes".

If, in one way or another, the usual combination of visual, vestibular, proprioceptive and plantar information about the position of the body within its environment is disrupted, then disorders in the regulation of postural tonus appear.

Stabilometry in posturology

Nowadays, to evaluate the function of balance, we use stabilometers that analyze the displacements of the center of pressure of the patient's feet on the platform of the apparatus (Ranquet, 1953; Gagey *et al.*, 1993; Sliva, 1995; Skvortsov, 2000). The first stabilograph recording postural sway in the frontal and sagittal planes was built by E.B. Babsky, V.S. Gurfinkel, E.L. Romel and J.S. Jakobson in 1951 (Babsky *et al.*, 1955).

To underline the dynamic aspect of the equilibration processes, these authors have presented their apparatus not as a means to evaluate the function of balance, but as a means to *study the stability of the standing posture*. It seems to us, nevertheless, that it is possible to say that stabilometry is a means to evaluate the function of body balance, provided we do not forget the dynamic aspect of its physiological mechanisms.

The advantage of stabilometry certainly is its physiological aspect. The physiological mechanisms must not be disrupted by caloric, optokinetic or other unnatural stimulations. We can perfectly do without them in posturology.

We work with the computerized stabilometer "Stabilan-01", produced by the "Rhythm" section of the Radiotechnical University of Taganrog. We are not mere users of that apparatus: during ten years of collaboration with the stabilometry laboratory of the section, directed by Serge Sliva, we have searched for the processing that would rapidly deliver, from the stabilometric signal, complete, clear and accurate information on the postural system - which looks simple at first sight, but is in reality complex and subtle. In other words, we are medical co-producers, with Serge Sliva, and we devote ourselves to the elaboration of medically guaranteed programs and methods.

At the institute of osteopathic medicine, notably, we came to the conclusion that in order to evaluate the postural system, it is not enough to calculate the Romberg coefficient and the plantar coefficient. And, as the apparatus can be programmed by its users, we have built a program for the evaluation of the postural system.

Ten recording situations are used by this program: open and closed eyes, eyes turned by 30°, to the right and to the left, head turned by 60°, to the right and to the left, body turned by 30°, to the right and to the left, in regular occlusion, on a foam mat. The recordings follow one another on the "Return" control of the operator. Each recording lasts 20 s. The total time of the experiment is 3 min. We apply the vectorial analysis of the statokinesigram on the signal, which is digitalized by a 16 bits analogous/digital converter.

After recording, the data is immediately given to the doctor in the form of a printed report (fig. 1 & 2) showing the charts, statokinesigram and stabilograms (frontal and sagittal), the area of the ellipse, the quality of the equilibrium function expressed as a percentage, as well as 9 coefficients of the postural system:

- Romberg coefficient, to evaluate the role of vision;
- plantar coefficient, to evaluate the role of the feet;
- temporo-mandibular coefficient, for the role of TMJ,
- two oculomotor coefficients, of rotation;
- two cervical coefficients, of rotation;
- two thoraco-lumbar coefficients, of rotation

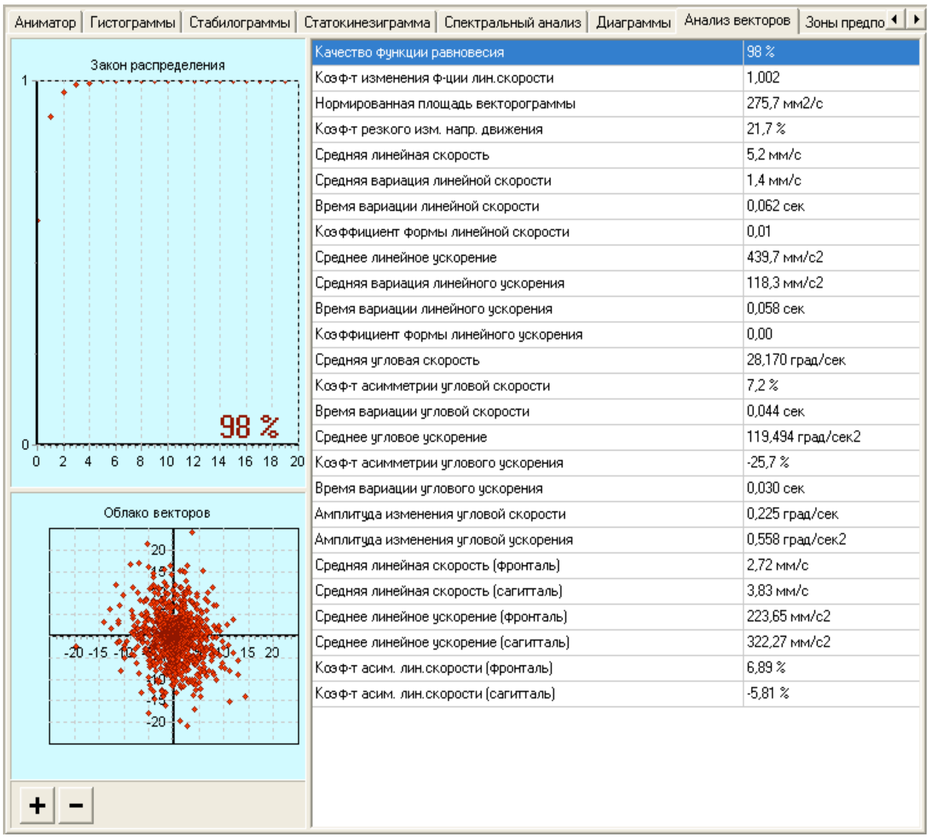

FIG. 1 - Facsimile of an open-eyes recording report

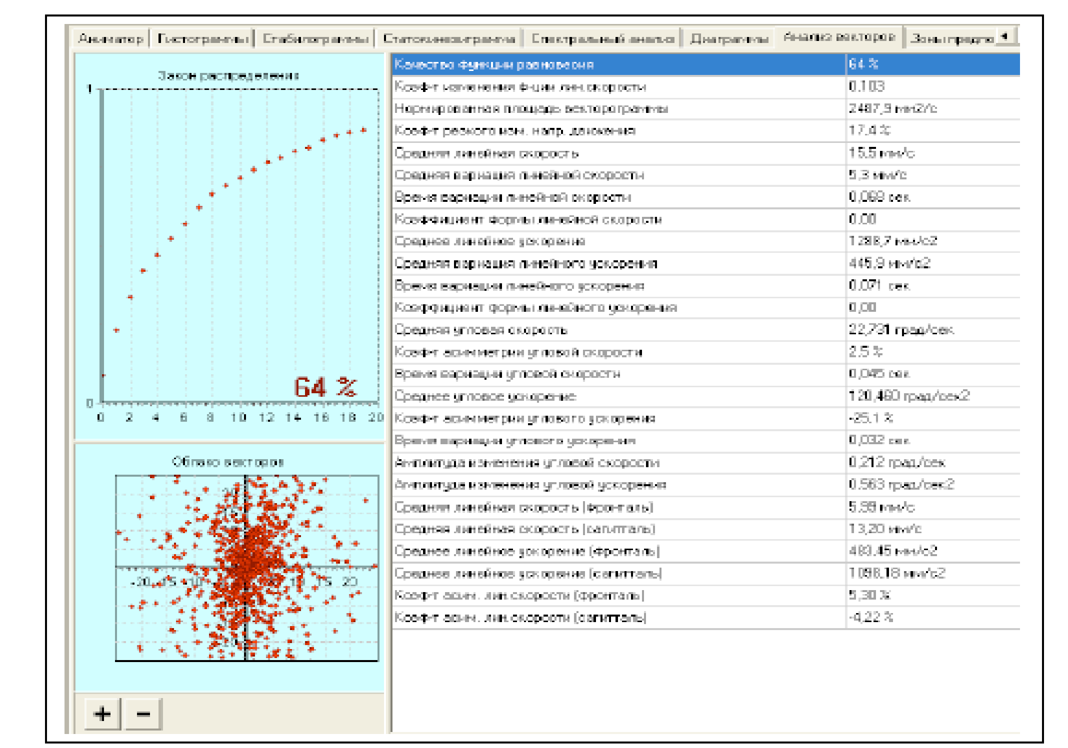

FIG. 2 - Facsimile of a closed-eyes recording report

Those last three pairs of coefficients reflect the proprioceptive functions of the oculomotor muscles and of the cervical and thoraco-lumbar vertebral column.

The coordinates of the center of pressure are also given in that report.

The vectorial analysis of the statokinesigram

The "Stabilan" apparatus can provide all the standard parameters of stabilometry, including the VFY, as well as the spectral analysis of the stabilograms. What led us, then, to search for a new processing of the signal? First, the standard parameters are very dispersed, and then, doctors have difficulties in interpreting the spectral analysis.

If we pay close attention to the way the statokinesigram appears on the computer screen ("Stabilan" offers a dynamic presentation of it, off recording), we are led to believe that the displacements of the center of pressure are not strictly in straight front/back or right/left lines, but in arcs of a circle. Those arcs can have a gentle or a steep slope, sometimes they form a loop or straighten for a while, but they always curve back.

Why has nature chosen such a stabilization mechanism? It certainly is in an ergonomic purpose, as the groups of muscles that participate in the stabilization reactions act in an harmonious way, so that the person does not tire.

In 1983, Okuzono proposed to sample the stabilometric signal at the frequency of 8 Hz. It then appears that the statokinesigram is made of a series of vectors of various lengths and directions (fig.3).

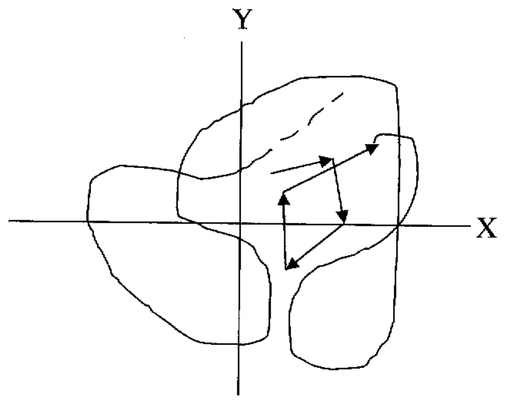

FIG. 3 - The statokinesigram and its constitutional vectors.

Each vector indicates the direction and speed of each elementary displacement of the center of pressure. Then Okuzono proposed to put all the vectors in relation to the origin of the universal set (fig. 4).

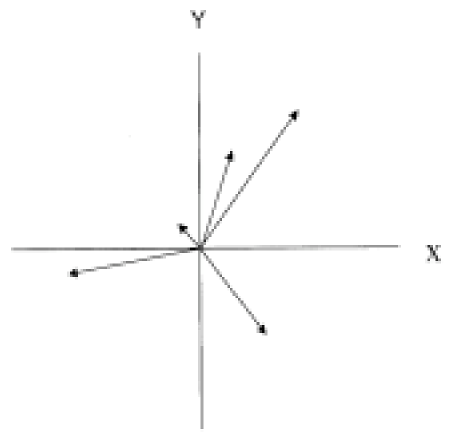

FIG. 4 - The vectors of the statokinesigram in relation to the origin

Then he divided the plane into 16 sectors and after having calculated the means of the vectors in each sector, he drew an histogram of the directions and speeds of the vectors (fig. 5).

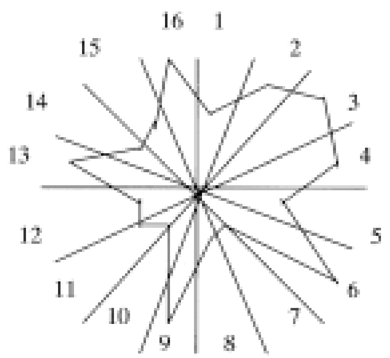

FIG. 5 - Circular histogram of the directions and speeds of the vectors.

The circular histogram of the directions allows to evaluate the amplitude and the speed of the oscillations in any direction, as those magnitudes of the vector are linked to one another for a given sampling frequency. However, that remarkable method of calculation of the means in each sector does not allow to evaluate the characteristics of the movement of the subject's body while maintaining the orthostatic posture.

In our vectorial analysis, the stabilometric signal is sampled at the frequency of 50 Hz.

We think that in the vectors that successively form the statokinesigram, there is some hidden information on the dynamic characteristics of the displacement of the body in space, and we propose to decypher that information through two different vectorial analyses.

As the movement is irregular, we can study the changes, that is to say the speed changes and the acceleration changes in the displacements of the subject's body. Therefore we propose to characterize the distribution of the speed variations by an histogram of the cumulated frequency of the vertices of the speed vectors, adjusted to an exponential function - we call this "the exponential law of distribution of the vectors".

Moreover, the analysis of the temporal series of the successive vectors of the statokinesigram in relation to the origin also gives the possibility to characterize the system from the perspective of its dynamics by a numbered value of the whole set of transitions from one vector to the next - we call this "the phase analysis of the vectors", in reference to the logic of space in phases.

A. The exponential law of distribution of the vectors.

The vertices of all the vectors in relation to the origin are marked by points. Then the cloud of points thus obtained is divided into n zones by concentric circles of equal areas (fig. 6). The area of the first zone, Z_1, at the center, must always be constant, as it represents the conventional unit of zone area. Its optimal value, for our sampling frequency, was experimentally set at 3.18 mm.

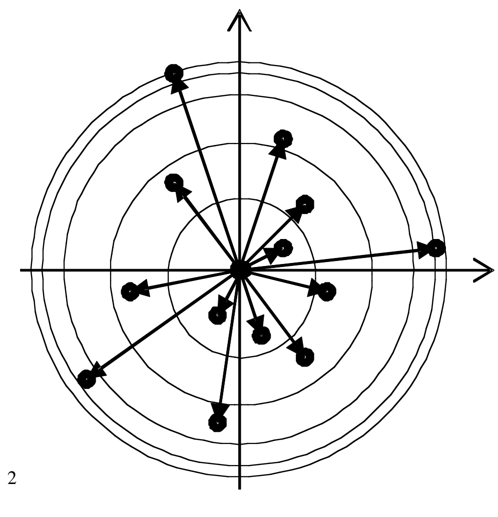

FIG. 6 – Division of the cloud of points into concentric zones of equal areas.

Then, we count the number of vertices of the vectors in each zone, Z_i, of rank i, and we build a histogram of cumulated frequency, $f(k)$ fig. 7), so that

$$f_k = \frac{\sum_{i=1}^{i=k} n_i}{N} \times 100$$

Where:

k is the rank of the most peripherical circle

N is the total number of vectors

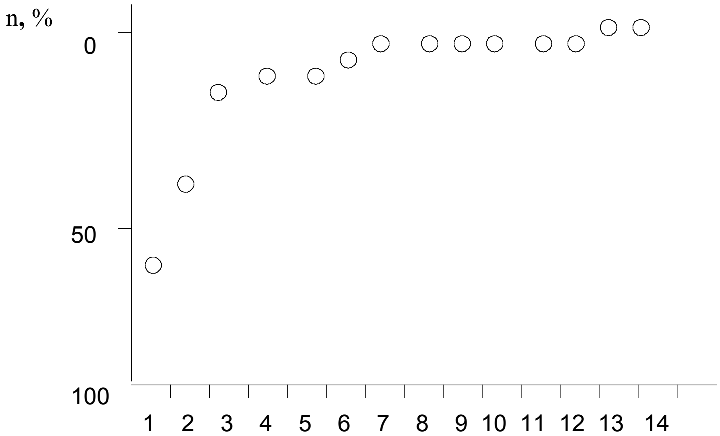

FIG. 7 - Histogram of the cumulated frequencies

The values of that histogram of cumulated frequency are then adjusted to an exponential function (fig. 6) of the form:

$$f(\mathrm{k}) = 1 - \mathrm{e}^{\lambda \mathrm{k}}$$

that gives the value of λ, coefficient of exponential dependence or coefficient of variation of the linear speed of the displacements of the center of pressure, QFLV (Usatchev V.I., 2001).

We then draw the graph of the function, or "graph of exponential dependence of the speed in elementary displacements according to the rank of the zone" (fig. 8).

$F = 1 - e^{\lambda}$

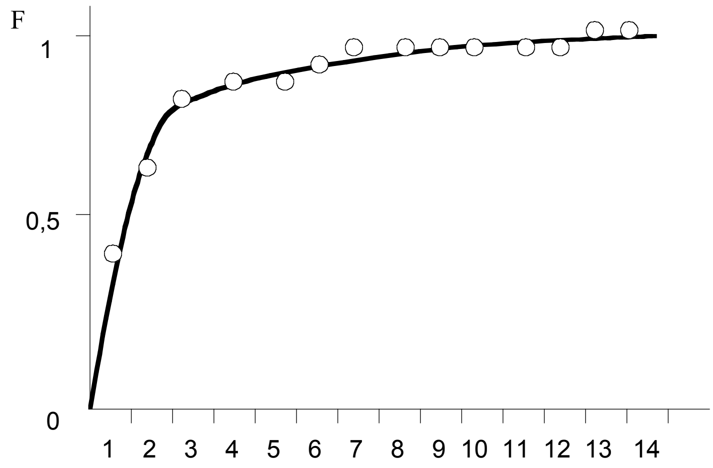

FIG. 8 - Graph of exponential dependence of the density of distribution of the vectors

The more the vertices of the vectors in relation to the origin are close to the origin, the steeper the slope of the exponential and the better the balance of the body. On the contrary, curves with a gentle slope characterize a bad balance of the body.

To better comprehension of the meaning of coefficient λ, we propose a parameter of "quality of the function of equilibrium", QFE (fig.9). We calculate that parameter thanks to an equation of areas:

$$\boxed{QFE = (S_1/S_{totale})\times 100\%}$$

Where :

S_1 represents the area under the exponential curve $f(k) = 1- - e^{\lambda k}$

S_{totale} represents the area limited by the referential axes and the asymptote, $f(k)=1$.

That quotient is expressed as a percentage.

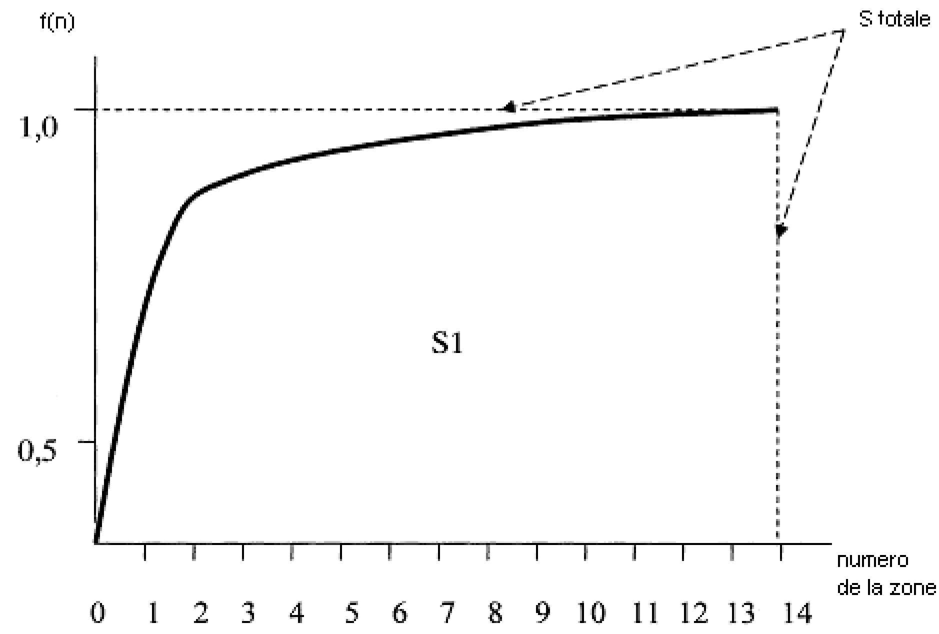

FIG. 9 - QFE parameter of the quality of the equilibrium function

The bigger the QFE, the steeper the slope, and on the contrary, the smaller the QFE, the gentler the slope.

QFE is the most stable stabilometric parameter. It is much less variable than the area of the confidence ellipse. The QFE characterizes the individual properties of the postural system of each genetic individual. In some it is big, in others small. This does not reflect the quality of life, but accounts for the adaptation of people to their various professions, that are more or less demanding with the postural system (for instance workers on skyscrapers, pilots, astronauts, etc.).

Among adults, the QFE nearly does not vary with age. Indeed, it is subjected to certain fluctuation linked to the evolution of the functional state of the organism, but the extent of those changes is not important. If the person is sick, tires or takes too much alcohol or drugs, the QFE will clearly exceed the *individual* functional limits.

B. The phase analysis of the vectors.

The transition from one vector to the next one can be characterized by the area of the triangle defined by the vectors themselves and by the line that joins their vertices (fig. 10).

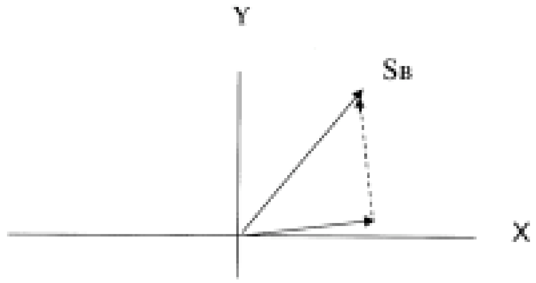

FIG. 10 - Triangle of transition between two successive vectors

The sum of all these triangles of transition, divided by the time of the recording, provides the parameter of "Normalized Area of the Vectogram", NAV in mm^2/s.

As the value of the area of the triangles of transition depends not only on the norm of the vectors but also on the angle between their directions, the NAV parameter bears information on the variation of direction of the vectors. Yet that information is ambiguous. Indeed, a big area of the vectogram indicates frequent changes in the direction of the movement at an angle close to 90° (fig. 11, **A**) but a small area can occur on two occasions: either the movement is better from an ergonomic point of view and in that case an acute angle appears between two successive vectors (fig. 11, **C**), or it is the movement of an unhealthy person making big angular displacements that creates an obtuse angle (fig.11, **B**).

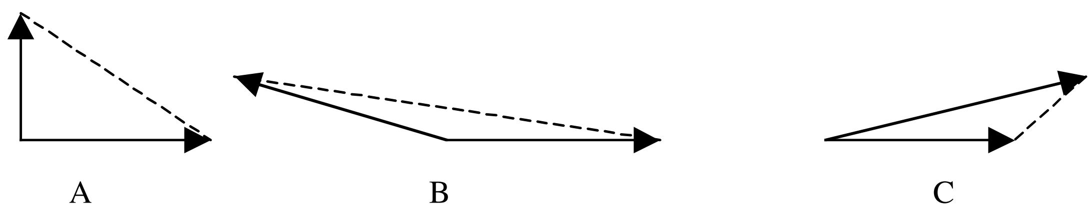

FIG. 11 - Ambiguity of the NAV parameter.

Besides the NAV parameter, we then also have to define a coefficient - the coefficient of the brutal changes in the direction of the movement - QCBM, given by the percentage of pairs of successive vectors that form an angle superior to 45°.

C. Other parameters of the vectorial analysis

- The mean linear speed, in mm/s;
- The amplitude of the variations of the linear speed, in mm/s;
- The mean variation of the linear speed;
- The mean period of the variations of the linear speed, in sec;

- The mean linear acceleration;
- The amplitude of the variations of the linear acceleration, in mm/s_;
- The mean variation of the linear acceleration;
- The mean period of the variations of the linear acceleration, in sec;
- The mean angular speed, in°/s;
- The mean period of the variations of the angular speed, in sec;
- The coefficient of asymetry to the angular speed in %;
- The mean angular acceleration, in °/s_;
- The amplitude of the variations of the angular acceleration, in °/s_;
- The mean variation of the angular acceleration;
- The mean period of the variations of the angular acceleration, in sec;
- The coefficient of asymetry of the angular acceleration, in %.

All these parameters of the vectorial analysis allow a complete presentation of the characteristics of the movements of the center of pressure of the subject in the orthostatic posture. They are put into the complete report (fig. 1 & 2) of the stabilometric study, presented in the form of charts.

Finally, from all those parameters, we can build models of the various disorders of the postural system.

Instead of a conclusion

We must not conclude as it is unlikely that the vectorial analysis provides an exhaustive analysis of the stabilometric signal. And each person practising stabilometry must not only be a user, but a creator, thanks to his new ideas!

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