

# A Computerized Fuzzy Logic System for Evaluation of the Cardiovascular Autonomic Function Based on Multiple Functional Tests

HS Carvalho, LF Junqueira Jr, J Souza-Neto

University of Brasilia, School of Medicine, Cardiology / Cardiovascular Laboratory  
Brasilia, DF, Brazil

## Abstract

*The interest in the study of the Autonomic Nervous System has grown in the last years, mainly because of its important participation in the cardiovascular regulation and in many pathophysiological processes like heart failure, arrhythmias and sudden death.*

*A great variety of tests have been employed for the functional evaluation of the Cardiovascular Autonomic Nervous System. However, the existence of variables with non-linear characteristics has made difficult the analysis of the responses. Based on this fact and considering that the Fuzzy Logic has been actually used with success in the development of classifier and analysis of control systems, its use in the investigation of the Cardiovascular Autonomic Function seems to be justified and a promise.*

*The present paper describes the development of a system based on fuzzy logic to evaluate simultaneous cardiovascular autonomic tests results.*

## 1. Introduction

The functional evaluation of the Autonomic Nervous System (ANS) has been largely performed. In the last decade, many articles have been published in the Medical Literature trying to clarify the ANS physiology and pathophysiology [1][2][3]. One of the interests in this area is based on the important relationship between the physiologic responses to different kinds of stress and the ANS [4]. Such relationship seems to have a significant influence in the genesis of many cardiovascular diseases [5][6][7] and events, such as the cardiac arrhythmias [8].

Many tests have been used for the ANS evaluation. Some of them are physiological (deep inspiration, baroreflex responses, Valsalva maneuver, postural responses), and others are pharmacological (response to atropine and  $\beta$ -blocker) [9]. Each test has an important role in the ANS evaluation, but for a complete assessment of the autonomic cardiovascular control it would be necessary to employ a combination of some of these invasive and non-invasive tests. Lately, a new method has been utilized to estimate the ANS influence in the cardiac control - the heart rate variability analysis in time

and frequency domain [10]. This method is non-invasive and may quantify the sympathetic and parasympathetic influences on the heart. The development of this new method has brought an expansion in ANS research, since it can be largely used in almost all kinds of patients with sinus rhythm. The results from this test have shown that reduced variability of the RR intervals series is an independent risk factor in prognosis of patients with myocardial infarction and diabetes mellitus [9].

Although there are many methods to study the cardiovascular effects of the ANS, the multivariate analysis using conventional statistics has failed to determine in a simply manner the status of the autonomic control. The artificial intelligence approach has developed and introduced new systems to the management of multivariate processes based on neural networks, belief networks and fuzzy logic. The importance of this new feature can be demonstrated in the increasing number of papers employing artificial intelligence techniques as decision-making aiders in medical practice. The Fuzzy Logic in a non-conventional logic that accepts inputs and outputs inside an interval, in opposition to the formal logic that only accept a binary input or output (yes or no) [11][12]. Many biological variables are characterized by non-linear characteristics that are better represented by an interval than by a binary process [13]. This aspect makes the Fuzzy Logic a potential and useful method to manage biological data.

## 2. Objective

To develop a computerized system based on Fuzzy Logic aiming to perform an innovative integrated evaluation of the Cardiovascular Autonomic Nervous System function.

## 3. Subjects and methods

Thirty-eight normal subjects and fourteen patients with different diseases (Chagas' Disease, Diabetes Mellitus, Arterial Hypertension, Parkinson Disease, Amyloidosis and Neurocardiogenic Syncope) were evaluated with the 80° head-up tilt test, active postural change, cold pressor test, handgrip test, temporal and spectral analysis of the

variability of the R-R intervals and mental stress tests (computer game, arithmetic, error games and memory of names test).

The tests were done in a consecutive manner in the morning, with intervals of 5 to 10 minutes between them, following the international ethical rules for research in human beings. The systolic and diastolic arterial pressure, respiratory frequency and heart rate were evaluated before, during and after the tests.

The Fuzzy System was developed in "C" language and the interface developed in Visual Basic. The system evaluated the variations of activity of the peripheral autonomic system by means the analysis of the diastolic blood pressure. The Cardiac Autonomic System Balance was evaluated estimating the heart rate and the ratio between the absolute spectral areas of low and high frequencies (Figure 1). The evaluation of the normality or abnormality grades of responses were achieved by using the acquired statistic data from the results of the autonomic tests applied to the normal subjects. These results were used to build the fuzzy classes (Figure 2).

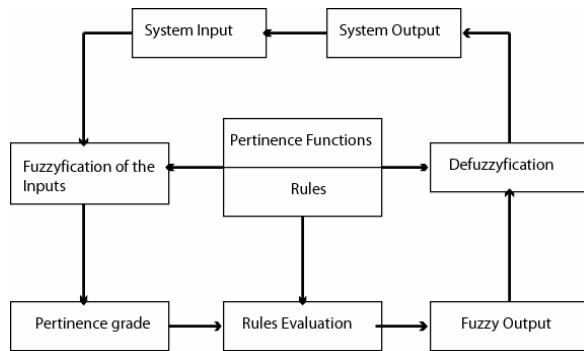


Figure 1: Fuzzy System (adapted from Viot)

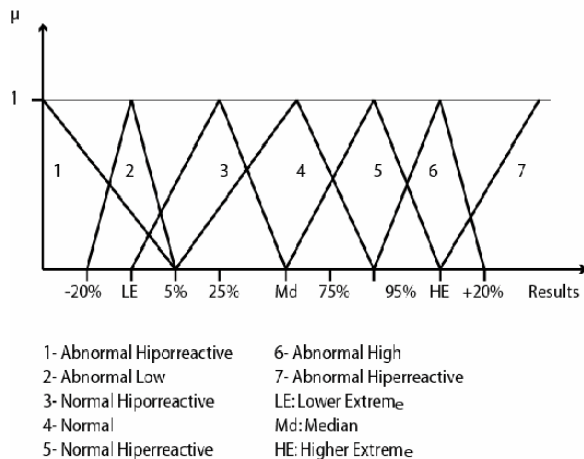


Figure 2: Fuzzy Classes for normal/abnormal patterns

The Fuzzy evaluation of the autonomic tests generated the cardiac and peripheral indexes (evaluation of the normal/abnormal grades), the cardiac autonomic balance and the peripheral autonomic tonus (evaluation of the autonomic activity level) (Figure 3).

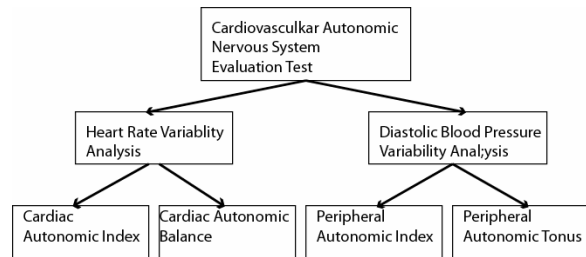


Figure 3: Structure of the Fuzzy Logic – based cardiovascular autonomic tests analysis

#### 4. Results

The application of the autonomic tests in normal subjects demonstrated that with the exception of the mental stress tests, all the others tests resulted in a meaningful statistic raising of the heart rate in comparison with the basal control before the tests. Systolic and diastolic arterial pressures, with exception of the postural tests, showed significant increment in all the others. The respiratory frequency increased significantly in the tests of mental stress, but not showed change in the other tests. The application of the temporal and spectral analysis of the R-R intervals of the electrocardiogram has shown that the postural changes, both passive and active, are related with statistically significant changes of the evaluated variables, occurring reduction of the median R-R intervals and of the low and high quartiles, and increase of the variation coefficient, total spectral area and low frequency area. As a consequence, the analysis of the ratio between the absolute spectral areas of low and high frequency demonstrated enhancement of the sympathetic modulation with the postural change.

The computerized system based on Fuzzy Logic developed has the ability to classify the variations of the peripheral and cardiac autonomic tonus in response to different types of cardiovascular autonomic tests. In addition, it establishes the cardiovascular autonomic index, which represents the result of the grade of normality or abnormality of each test separately and together to represent the cardiovascular autonomic function in an integrated way.

Figures 4 and 5 illustrate the results of the Valsalva maneuver based on Fuzzy evaluation. In both cases the system could discriminate between some patients and normal subjects. Figures 6 and 7 shows the results of the handgrip test Fuzzy evaluation. In the case of cardiac evaluation, the handgrip could discriminate some patients from normal subjects, but the peripheral evaluation was

not able to do that. These results show that the fuzzy classification can be easily understood by a health care professional and that some tests can be better than others to differentiate patients from normal subjects. In this case, the Valsalva maneuver was better than the handgrip test.

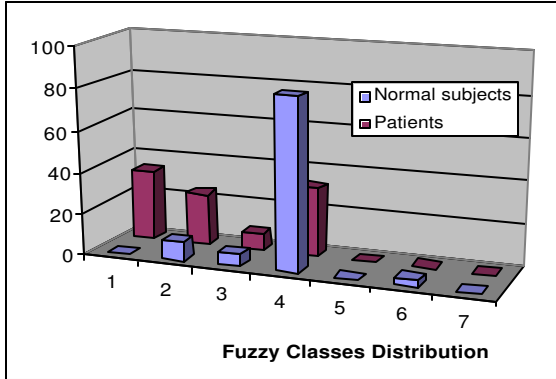


Figure 4: Cardiac Autonomic Index in normal and diseased subjects derived from Valsalva maneuver.

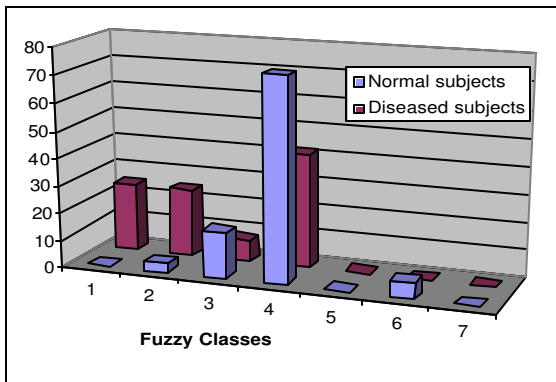


Figure 5: Peripheral Autonomic Index in normal and diseased subjects derived from Valsalva maneuver.

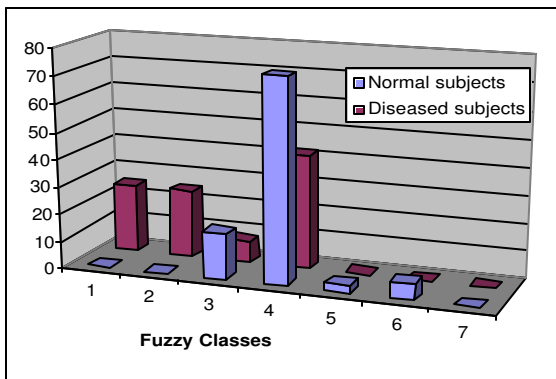


Figure 6: Peripheral Autonomic Index in normal and diseased subjects obtained from handgrip test.

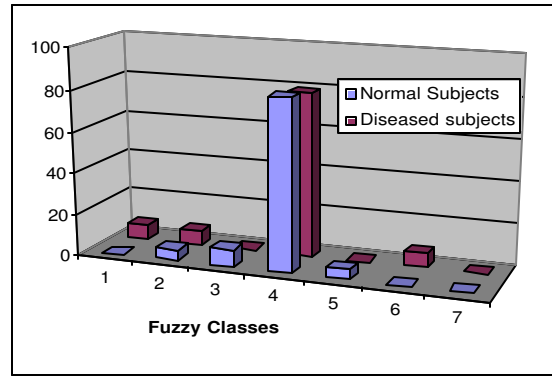


Figure 7: Peripheral Autonomic Index in normal and diseased subjects resulted from handgrip test.

The results obtained with the application of the Fuzzy System has shown that with the exception of the postural tests, all the tests were related with increasing in the peripheral autonomic tonus, and with exception of the mental stress tests, all the others demonstrated increasing in the cardiac autonomic balance in the direction of predominance of cardiac sympathetic activity.

## 5. Discussion and conclusions

The results obtained with the application of the autonomic tests in the normal subjects are compatible with the data found by a variety of authors and published in the literature [14], showing that the database developed was reliable. The tests were related with important variations in heart rate, respiratory frequency and systolic and diastolic arterial pressures. Such variations can be used as a reference to characterize the normal response of the organism to a variety of stimulus affecting the cardiovascular system.

The Fuzzy Logic-based computerized system developed is a new contribution, especially concerned to the area of application of the methodology used. The results obtained reinforce the impression that the system brings the study of the application of Fuzzy Logic to the Medical Decision Making Systems, mainly with respect to the processing of biological data.

The evaluation of the Cardiovascular Autonomic Nervous System based on fuzzy logic brought many contributions to the autonomic nervous system study. The present results have shown that the system can be used to the functional classification of the autonomic status as a result of a variety of autonomic tests. It can evaluate the tonus and normality of response of the peripheral autonomic system, the balance between the parasympathetic and the sympathetic nervous system, the normality of responses of the cardiac autonomic system and the integrated cardiovascular autonomic nervous

system function. The last achievement represent a great contribution provided by the system developed, reinforcing the importance of the continuity of research in this area.

## References

- [1] Iwamoto GA, Botterman BR. Peripheral factors influencing expressions of pressor reflex evoked by muscular contraction. *J. Appl. Physiol.* 1985; 58: 1676-1682.
- [2] Korner PI. Integrative neural cardiovascular control. *Physiol. Rev.* 1971; 51: 312-367.
- [3] Coresh J, Klag MJ, Mead LA, Liang J, Whelton PK. Vascular reactivity in young adults and cardiovascular disease. *Hypertension* 1992; 19:218-223.
- [4] Herd JA. Cardiovascular response to stress. *Physiol. Rev.* 1991; 71: 305-326.
- [5] Junqueira Jr LF, Beraldo PSS, Chapadeiro E, Jesus PC. Cardiac autonomic dysfunction and neuroganglionitis in a rat model of chronic Chagas' disease. *Cardiovasc. Res.* 1992; 26: 324-329.
- [6] Goldstein RE, Beiser GB, Stampfer M, Epstein SE. Impairment of autonomically mediated heart rate control in patients with cardiac dysfunction. *Circ. Res.* 1975; 36: 571-578.
- [7] Bannister R. The Diagnosis and treatment of autonomic failure. *J. Auton. Nervous Syst.* 1990; 30: 19-24.
- [8] Fei L, Keeling PJ, Gill JS, Bashir Y, Statters DJ, Poloniecki J, Mckenna WJ, Camm AJ. Heart rate variability and its relation to ventricular arrhythmias in congestive heart failure. *Br Heart J* 1994; 71: 322-328.
- [9] Ewing DJ, Neilson JMM, Travis P. The value of cardiovascular autonomic functions tests: 10 years experience in diabetes. *Diabetes Care* 1985; 8:491-498.
- [10] Malliani A, Pagani M, Lombardi F, Cerutti S. Cardiovascular neural regulation explored in the frequency domain. *Circulation* 1991; 84: II482-II492.
- [11] Folger TA, Klir GJ. Fuzzy sets, uncertainty, and information. New York: Prentice-Hall, 1988.
- [12] Viot G. Fuzzy Logic: concepts to constructs. *AI Experts* 1993.
- [13] Baxt WG. Complexity, chaos and human physiology: the justification for non-linear neural computational analysis. *Cancer Letters* 1994; 77: 85-93.
- [14] Piha SJ. Cardiovascular autonomic reflex tests: normal responses and age-related references values. *Clinical Physiol.* 1991; 11: 277-290.

Address for correspondence.

Dr. Hervaldo Sampaio Carvalho.  
Cardiovascular Laboratory, School of Medicine, University of Brasilia, Brasilia, DF, Brazil – 70910-900.  
carvalho@unb.br