RORSCHACH INK-BLOTS ARE MULTIFRACTALS AND A CORRESPONDING MULTIFRACTAL STRUCURE IS REALIZED IN HUMANS DURING THEIR PERCEPTION AS MEASURED BY THE GSR (GALVANIC SKIN RESPONSE) NEUROLOGICAL AND PSYCHO-PYSIOLOGICAL SIGNAL

Leonardo Mendolicchio[1,2] , Ferda Kaleagasioglu[1,3], Fang Wang[4] ,Rich Norman[1], Francesco Casciaro Losito[1,5], Anna Maria Losito[1,6], Elio Conte[1],
and
Franco Orsucci[7]

[1] School of Advanced International Studies on Applied Theoretical and non Linear Methodologies of Physics, Bari, Italy
[2] Clinic Villa Miralago, ASL Varese, Italy
[3] Faculty of Medicine , Yeditepe University, İstanbul , Turkey .
[4] Hunan Agricultural University · Computing & information science and statistics China · Changsha
[5] Department of Basic Sciences and Human Oncology, University of Bari, Bari, Italy
[6] Clinic Santa Maria, G.V.M. Hospital, Bari, Italy
[7] Psychoanalysis Unit, University College, London, England

ABSTRACT: We demonstrate that the Rorschach ink-blots are multifractals. Normal subjects submitted to their perception for two minutes have been studied recording their GSR neurological and psychophysiological signal during the observation of the ink blots. It has resulted that also the induced perceptive dynamics in the subject is a multifractal. In the framework of the theory of complexity we elaborate that the intrinsic complexity of the ink-blots induces in the subjects an emotive and cognitive condition of profound inner conflict that may be estimated by the generalized Hurst exponent of the subject as arising from the GSR recording. We expect that the results are important not only in the theory of complexity but also in the clinical study of cases of neurological, psychological and psychiatric interest.

KEY WORDS: Theory of complexity, multifractals, computational neuroscience, Rorschach ink-blots, Galvanic Skin Response (GSR).

1. INTRODUCTION

In recent years the science of the complexity and, in particular, the connected application of the fractal analysis has been extensively used to investigate phenomena that result relevant to neuroscience (Smith Jr et al., 1996; Fernández and Jelinek, 2001; Jelinek et al., 2004a, 2004b; Cornforth and Jelinek, 2005; Losa, 2014, 2015; Mattei, 2014; Di Leva et al., 2015). This kind of analysis has proven especially valuable for investigating various cell types of interest in neuroscience (Jelinek and Steinke, 1996; Nonnenmacher et al., 1994; Ristanović et al., 2002, Ristanović and Losa, 2013; Smith Jr et al., 1996). In essence, fractal analysis examines the scaling inherent in a pattern or dataset and assigns a number to the scaling (Karperien A, 2013; Gisiger, 2001). The estimated number is a fractal dimension (FD), a statistical index of complexity (Mandelbrot, 1983; Schroeder, 1991; Iannaccone and Khokha, 1995; Fu-Zen Shaw, 1999; Nazahah et al., 2012). Authors have focused their activity on FDs obtained from patterns extracted from digital images using a fractal analysis approach known as box-counting, in which the derived FD is called the box-counting dimension (BD) (Block et al., 1990; Jian et al., 2009). A single, global FD or BD index describes a pattern that is consistently self-similar or scale-invariant everywhere (i.e., monofractal), but neither uniquely nor completely describes the pattern. Indeed, sometimes the scaling within a dataset may itself vary (Wang et al., 2014a, 2014b, 2015). In essence, we have a non-uniform scaling determining a multifractal that may be quantified accordingly by measuring multiple dimensions (Mandelbrot, 1983; Voss and Wyatt, 1991; Stanley et al., 1999). The theoretical basis of multifractality has been reviewed in depth by several authors and will not considered here in detail (Chhabra and Jensen, 1989; Block et al., 1990; Vicsek, 1992; Jestczemski and Sernetz, 1996). Multifractal analysis has been applied in neuroscience also, even if analysis of multifractality of biological images remains a rather difficult matter often marked by some limitations (Nonnenmacher et al. 1994; Jelinek and Fernández, 1998; Fernández et al., 1999; Jelinek et al., 2004a; Bullmore et al., 2009). In order to allow chaos and fractal analysis of images, one of us, in collaboration with other authors (Conte et al., 2006; Conte et al., 2008a; Conte et al., 2012; Conte et al., 2009; Conte et al., 2008b) started studies years ago in which we realized for the first time a new method of elaboration where images were selected and converted into the three basic colors Red/Green/Blue (RGB) (or, perhaps, gray scale) for each pixel, thereby obtaining a pixel-space series, suitable for fractal and chaos analysis. Following the advent of the Detrended Fluctuation Analysis (DFA) (Peng et al., 1994) for time series, multifractal detrended fluctuation analysis (1D-MF- DFA) was introduced in 2002 (Kantelhardt et al., 2002) and the method was extended also to the two-dimensional case (2D MF- DFA) (Gu and Zhou, 2006). A 2D MF-DFA was elaborated by one of us and his coauthors (Wang et al., 2014a; Wang et al., 2014b; Wang et al., 2015).

The inner structural characteristics of biomedical electrophysiological signals are often interpreted and analyzed by traditional methods but it has become progressively more clear in the studies of the last ten years that the basic inner structure cannot be captured by such conventional measures since biomedical signals arising from a wide range of physiological phenomena possess a scale invariant structure. Generally speaking, a biomedical signal has a scale invariant structure when the structure repeats itself on subintervals of the signal. Formally, the biomedical signal $X(t)$ is scale invariant when $X(ct)=c^H X(t)$. Consequently it has become of basic interest to examine such scale invariant behavior by using the Fractal Analysis that in fact arrives to estimate the power law exponent, H, that defines the particular kind of scale invariant structure of a specific biomedical signal. Consequently, fractal analyses are presently employed in biomedical signal processing to define the scale invariant structure in ECG, EEG, MR, and X-ray pictures (Lopes and Betrouni, 2009). Considerable interest has been demonstrated in the analysis of the scale invariant structures of the inter-spike-interval of neuron firing, inter-stride-interval of human walking, inter-breath-interval of human respiration, and inter-beat intervals of the human heart deriving important contributions in differentiating between healthy and pathological conditions (e.g., Ivanov et al., 1999; Peng et al., 2002; Zheng et al., 2005; Hausdorff, 2007), and between different types of pathological conditions (e.g., Wang et al., 2007). Scale invariant structures have also been found in spatial phenomena like the branching of the nervous system, lungs (e.g., Bassingthwaighte et al., 1990; Abbound et al., 1991; Weibel, 1991; Krenz et al., 1992), and bone structure (Parkinson and Fazzalari, 1994). The results differentiate between healthy and cancerous tissues (Atupelage et al., 2012). Recently we have also conducted studies on neuron locations, neural netwok, calcium activity and connectomics in the C-Elegans (Conte 2016a and Conte 2016b) as further neurological confirmation that brain functions respond to the basic requirement of scale invariant structure starting also with the most elementary neural network as represented in a small creature such as the C-elegans that is structured by a very restricted number of neurons. Several results in the last decade have suggested that changes in the scale invariant structure of biomedical signals reflect changes in the adaptability of physiological processes implying successful treatment of pathological conditions might change fractal structure and improve health (Goldberger, 1996; Goldberger et al., 2002). Fractal analyses are therefore promising prognostic and diagnostic tools in biomedical signal processing.

It is not surprising that in this framework, fractal and multifractal analysis of images relating the individual neuron, groups of neurons and their interconnections assume a particularly valuable interest in neuroscience.

In front of such new and advanced methods of investigations, it must be outlined on the other hand that unfortunately this kind of analysis is not exempt from difficulties, particularly when the aim of the investigation has the scope to more deeply understand the inner mechanisms and the temporal dynamics of these types of cells.

The present paper represents subsequent work following the publication [Conte et al., 2008a] in which we introduced a new methodology, the variogram, aimed at calculating the Generalized Fractal Dimension, the Fractal Measure, the Fractal Variance Function, and the Marginal Density functions of a given spatial (time) series in the sphere of biological dynamics with particular interest in the analysis of images of biomedical or psychological interest. For details regarding this methodology and for detailed previous studies on the general formulation of the method, here including also Rorschach ink-blot fractal structure , see the references [Conte et al 2008a, 2008b, 2009a, 2012a].

It is well known that the Rorschach inkblots Test is a projective psychological test of personality in which a subject's interpretations of ten standard, abstract, and ambiguous designs (ink-blots), given in sequential order, are than analyzed giving information about the emotional state of the subject and his intellectual functioning , and integration . Rather recently [Conte 2016c, 2015a, 2015b, 2015c, 2011a, 2011b, 2011c, 2013a, 2013b, 2011d, 2009b, 2012b, 2007, 2010, 2009c, 2008c], we performed theoretical studies and experimentation also on Gestalt and ambiguous figures, and the results enabled us to introduce a quantum like model of the perceptual mechanism with relation also to the dynamics of how the human visual system resolves perceptual ambiguity in stimuli that contextually may induce multiple potential interpretations.
The aim of our studies is to investigate the possible implications of existing time or space scale invariant structure at the level of perception, cognition and structure of our mental states. It is well known that E.H. Weber and G.T. Fechner, researchers that were active about 1885-1887, were the first to introduce physical methods in psychology since they analyzed in detail the mechanism of perception, and attempted to find a relationship between the physical magnitudes of the given stimuli and the perceived intensity of these stimuli during the perception of the subject. In brief, they were the first to consider the possibility of linking a stimulus of physical nature with the corresponding human-subjective response to it. Their results may be expressed by the following equation

$$p = kLnS + C$$

where p relates perception whose stimulus is given by S. C and k are constants to be determined by the experimental framework.
We recently located another important result. O.V. Mitina and F.D. Abraham [http://www.blueberry-brain.org/dynamics/mitina-fractal-perception.htm] who studied the use of fractals in perception. In this case fractals were chosen as stimuli, and they were submitted to an observer's perception at increasing levels of complexity . Some stimuli evoked subjective sensations including the subjective perception of the time during fractal observation, the subjective assessment of complexity and the aesthetic attractiveness of the visual objects were measured. It was demonstrated that the evoked subjective sensations were strongly determined by the fractal dimension of the submitted fractal objects.
In the field of perception research , it has been found that many of our sensory systems follow psychophysical (psycho-physiological) power laws, that are self-similar because the same relationship holds between the variables independent of how they are scaled or rescaled. Note that in every case we have always a relation mediating an internal subjective quality that defines our conscious experience through an external physical quantity of physical intensity. This result seems to open some perspective of innovative investigation not only in the general field of perception and cognitive science but also in the most general tentative attempt to ward a further understanding of the dynamics of our mental entities. As an example, an interesting result established the fact that (Conte et al.1991) a power law still relates word rank and word frequency in many natural languages .If we list the words of a book by rank order of word popularity with respect to the number of times each word appears, we still find a power law relationship. Analysis of the language under different experimental conditions, also including the relationship between subject and interaction of the subject and the therapist was recently studied by us (Orsucci et al.2013) demonstrating still finding encouraging results under such new direct line of investigation. Under the psychological and psychiatric profile, it seems that the arising important feature relates to the fact that fractals delineate systemic dynamics since lower dimensional objects strive towards higher dimensions by recursively adding structure, or instead they start as higher dimensional objects that retreat progressively into lower dimensions by recursively removal of the structure. Also according to Terry Marks-Tarlow

(http://goertzel.org/dynapsyc/2002/ObserverObserved.htm), in psychological dynamics of our mental entities, we may observe a distinction between progressing towards higher versus regressing towards lower dimensionality as a model depending upon whether a subject's psyche is better characterized by structure building evolution of consciousness or structure eroding involution. Along with such important new intuitions we have to link the fact that, as previously stated, fractal structures have been found to be ubiquitous in the brain, and, in particular, fractal behaviors have been found also related to specific mental entities e.g., in our mood shifts. One of the most important results is that a fractal dynamics have been identified (Delignières et al.,2004) also in tests of self-esteem and self. Following such a line of analysis, one is tempted to retain that consequently fractals and multifractals should also exist within the inner structure of our personality since it organizes itself in self-similar patterns of behavior at different scales of observations. It has been also suggested that the tiniest fragment of a dream has the capacity to reflect the whole of the psyche so that every dream carries out a fractal structure. Still from the microlevel of speech patterns, through a medium scale event of a chance encounter on the highway, to a large scale level of ongoing business relations, people generally demonstrate self-similar behavior across multiple scales of observation. When this gets rigidly stereotyped, one may think in terms of Freud's notion of repetition compulsion.

In conclusion we retain that a new perspective within studies is emerging that may be of interest in neurology, in psychology and psycho-physiology as well as in psychiatry. The general reason is that it seems that the concept of self and of identity could be re-conceptualized in multivalent terms, that is to say, in terms of self-similar processes repeating on multiple size and event scales. As it has been demonstrated, different studies seem to evidence that fractal structures enter in psychology and, in particular, enforce the position that self- perception is an emergent product of a dynamical system based on fractal processes and composed of multiple interacting components. Another reason is also that, according to the studies of M. Schroeder in 1991 (Schroeder 1991), fractals exist symbolically, and this definitively opens a new way to investigation of the nature of the mind since, consequently, fractals should exist in the psyche at symbolic, invisible realms (Norman, 2016).

These results give support to our present paper. As said, fractals exist symbolically and thus fractals could exist in the psyche in symbolic, invisible (unconscious) realms, and since, as discussed in particular in (http://goertzel.org/dynapsyc/2002/ObserverObserved.htm), the fractal dimension should result in being a determinant of the characterization of the kind of subjective evoked sensation or emotions during image perception. Rorschach's ink blots were extensively used in years in psychological and psychiatric studies but in the last years their use has progressively decreased and often dismissed from scholars . The initial assumption was that they were able to induce responses in a subject in correspondence with his projected story, indicating his emotional state, his intellectual functioning ,integration and revealing vital data on this basis its use became of basic importance in psychological and psychiatric analysis. However, a basic limit was revealed in the absence of a firm , standardized interpretative basis of test results .

Of course some points remain clear. Rorschach ink blots do not have a defined meaning and identification when submitted to the perception and interpretation of the subject. At the same time, as previously studied by us (Conte 2008a)) they have on us a large attractiveness mixed to a large measure of complexity. In research the term complexity should not be considered as a generic or philosophical term. To day we have the science of complexity arising from the intrinsic inner non linear structure of natural processes, and it may be quantified as well as any other physical or physiological variable. Of course often complexity results strongly related to the fractal or multifractal structure of the investigated process. The presence of high complexity in the Rorschach ink-blots determines in the perceptive and cognitive phases of the subject observing the images a situation involving many coexisting interpretive alternatives in a kind of quantum model such as demonstrated in (Conte 2011a, 2011b, 2011c, 2013a, 2013b; Conte et al.2016c, 2015a, 2015b, 2011d, 2009b, 2012b, 2007, 2010, 2009c, 2008c). This situation involving very complex coexisting multiple alternative of interpretations, induces in the subject a substantial condition of conflict. To explain such situation of conflict by our inner quantum model let us use an example. Consider a task posed to a subject: "do you like this picture?" During the actions of perception and cognition when the subject is looking at the figure, a simultaneous coexistence of alternatives relates the mental state of the subject . It is resolved and represented by a mental function that mathematically may be represented in a superposition of probabilistic alternatives

$$\left|Mental\ State\ of\ the\ subject\right\rangle = c_1\left|I\ like\right\rangle + c_2\left|I\ do\ not\ like\right\rangle$$

$|c_1|^2$ and $|c_2|^2$ define the probabilities that finally the subject will select only one of the alternatives . It is easily understandable that when the two probabilities have different values corresponding to the inner mental dynamics of the subject (as example 0.9 and 0.1) , the inner conflict of the subject in relation to the final decision will be very moderate while instead if one probability will result to be 0,51 and the other 0.49, the inner conflict will be high. In the case of the Rorschach ink blots the subject is not called to select between two alternatives as in the simple previous example, Owing to the high complexity of the posed ink-blots he/she will determine in himself a large number of similar alternatives and thus he/she will be in a great condition of inner conflict. Such inner conflict will determine in the subject a situation based in memory that will be linked to his/her story, he/she will be able to decide and give an answer on the basis of his conflicting ambivalent situation, his emotional state, his intellectual functioning and his /her affective/cognitive level of integration. Emotional responses and connected cognitive engagement are always associated with previous experiences of a subject, particularly relating the childhood and his /her link to parental figures. The complexity of the figure will determine the inner situation of conflict among simultaneous alternatives and complexity which should be related to the multifractal structure of the images used . Therefore, we have questions that deserve consideration.
1) To establish if Rorschach's ink blots exhibit really a multifractal structure.
2) When Rorschach's ink blots are given as perceptive input to a subject, may we use his/her psycho-physiological measurement of the recorded GSR as response of the subject , connecting physiological parameters resulting of interest in basic as well as in clinical applications? We know that GSR has definite neurological correlates (Norman et al., 2016a-b) . Consequently, if points (1) and (2) could be firmly established, we could conclude to have performed a preliminary approach of basic importance in neurology and psychiatry.

2. Materials and Methods

The details of the method of elaboration have been reported elsewhere (Gu and Zhou 2006; Wang C. et al., 2014; Wang et al., 2015) and the reader is invited to examine all the basic features of the method reading the original works.
In essence, the method consists of five steps of analysis that are reported in Appendix A
In accordance with the instructions of the International Association for Rorschach and Projective Tests (http://www.rorschach.com/index.php?id=2) the ten colored Rorschach cards were downloaded and saved in a computer in .jpg file . The images were explored through their elaboration and analysis consisting in a partition of the visible surface into a $M_S x N_S$ non- overlapping square sub-surface of equal length*s* and elaborated on the basis of the procedure indicated in Appendix A and reassumed in five steps.
Soon after ten normal subjects were selected with age 20-45 years old. All the subjects expressed their formal consent to participate to the experiment after detailed explanation of its content. All the experimental investigation was performed at our laboratory in Casarano (Lecce, Italy) under the direction of one of the authors (F.C.) and the direct collaboration and assistance of the specialized authors of the present paper.
Psychotherapeutic and psychiatric scholars interview previously the subjects and subjects were selected not having psychological disorders or other psychiatric pathologies and excluding also subjects having high blood pressure, cardiocirculatory insufficiency, diabetes or other chronic diseases. In particular, subjects who contracted heart related disease or coronary artery disease, or CAD, heart failure, irregular heartbeat, were excluded. We dismissed subjects having abnormal Q wave, WPW syndrome. Subjects with hypertrophy on the left ventricles of the heart or heart hypertrophy were dismissed. Subjects having less than 90% of normal RR interval were also dismissed. Subjects who smoked or used alcohol were excluded. No food within one hour prior to the exam was permitted . The test was performed at 10.30 a.m. Recording was performed with the subject sitting comfortably , maintaining soft and distant indoor light and appropriate indoor temperatures (20°C - 23°C) and in condition of absolute calm without noise or disturbances. Galvanic Skin Response (GSR), recording in real time tone and phase values, was performed by using Elemaya device with two Ag-electrodes connected respectively to the index and ring fingers of the left hand. No conversation was allowed during the recording. The exam was performed with the subject's eyes open. Rorschach cards were given to the subjects using by a 15-inch computer monitor without any image distortion and in temporal sequence at preselected intervals of one minute between one card and those subsequent. The subject was given the time of two minutes to look at each picture viewing it for two minutes. During the observation of the picture no issue or question was posed to the subject so to evaluate his perceptual activity and cognitive processing through the real time GSR recording and not verbal expression or

spoken conceptual elucidation or enquiry . Tone and phase of each GSR recording were stored in the computer interfaced with the device. For each GSR recording the latency, the rise time, the Peak value and the Half Time Recovery as well as the mean values of the GSR Tone were estimated by our methods of analysis and we will publish the results in a separate publication.
The time series of the values of the GSR Tone and Phase obtained for each figure and for each subject were subsequently submitted to 1-D-DFA multifractal analysis. This is the one dimensional that is the one dimension version of the analysis reported in Appendix A.
In conclusion we first performed the multifractal analysis of the ten Rorschach ink blots and subsequently, following a procedure experienced for years in our laboratory, we examined the psycho-physiological monitoring, elaboration and analysis of the electrophysiological GSR signal derived from each subject when presented with each figure and performing his/her personal, subjective vision (perception) and cognition without providing any verbal information .

3. Results

First let us examine the results that we obtained by examination of the Rorschach ink blots.
First of all, let us verify that we have really obtained that the examined images represent a multifractal structure. The results relating *h(q)*, $\tau(q)$, α and $f(\alpha)$ are given in Figures 1- 4 respectively.

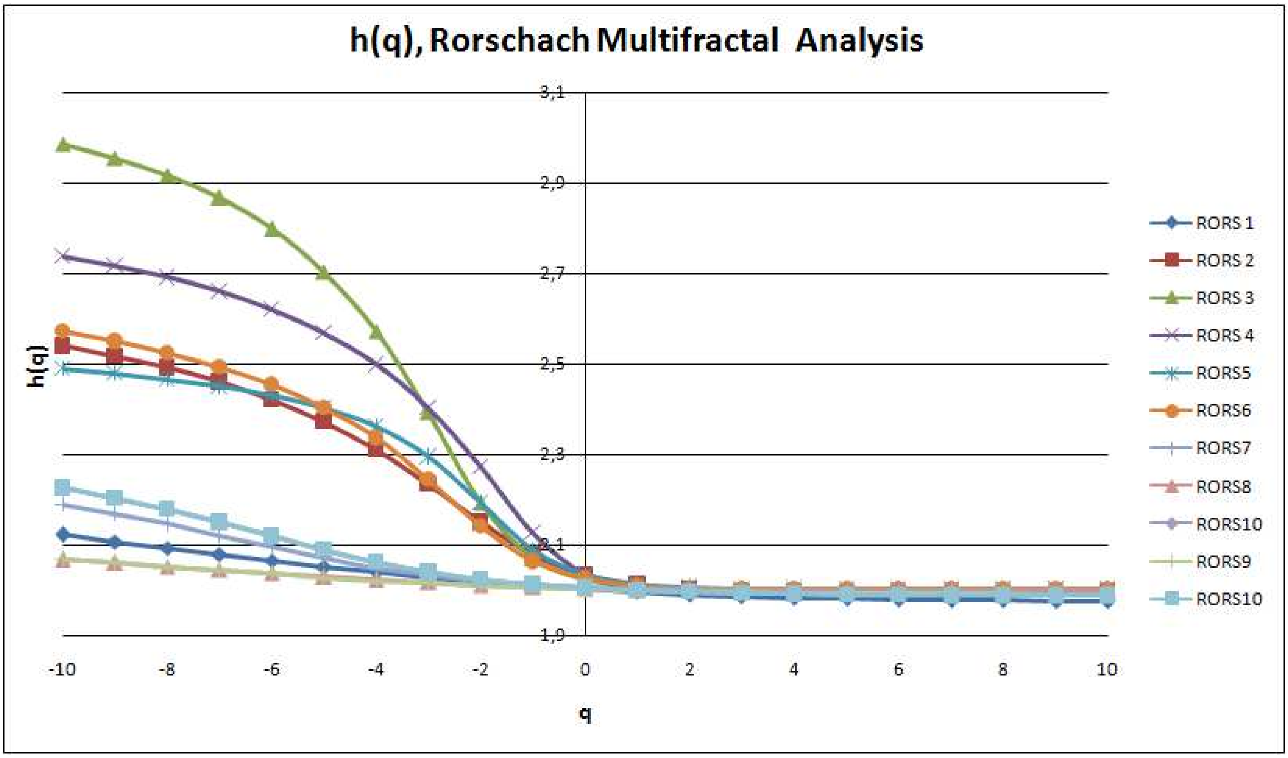

Figure 1 . *h(q)* estimated values of the ten examined Rorschach ink-blots

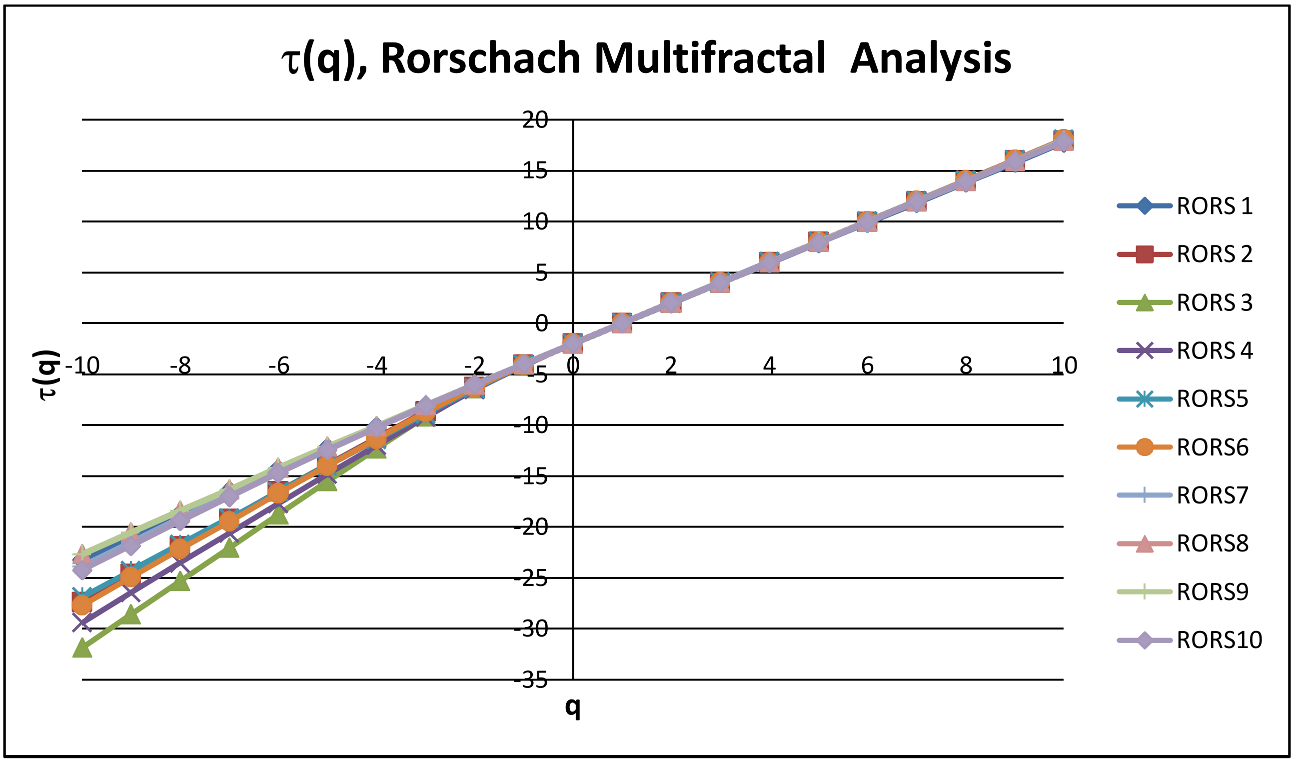

Figure 2. $\tau(q)$ estimated values of the ten examined Rorschach ink-blots

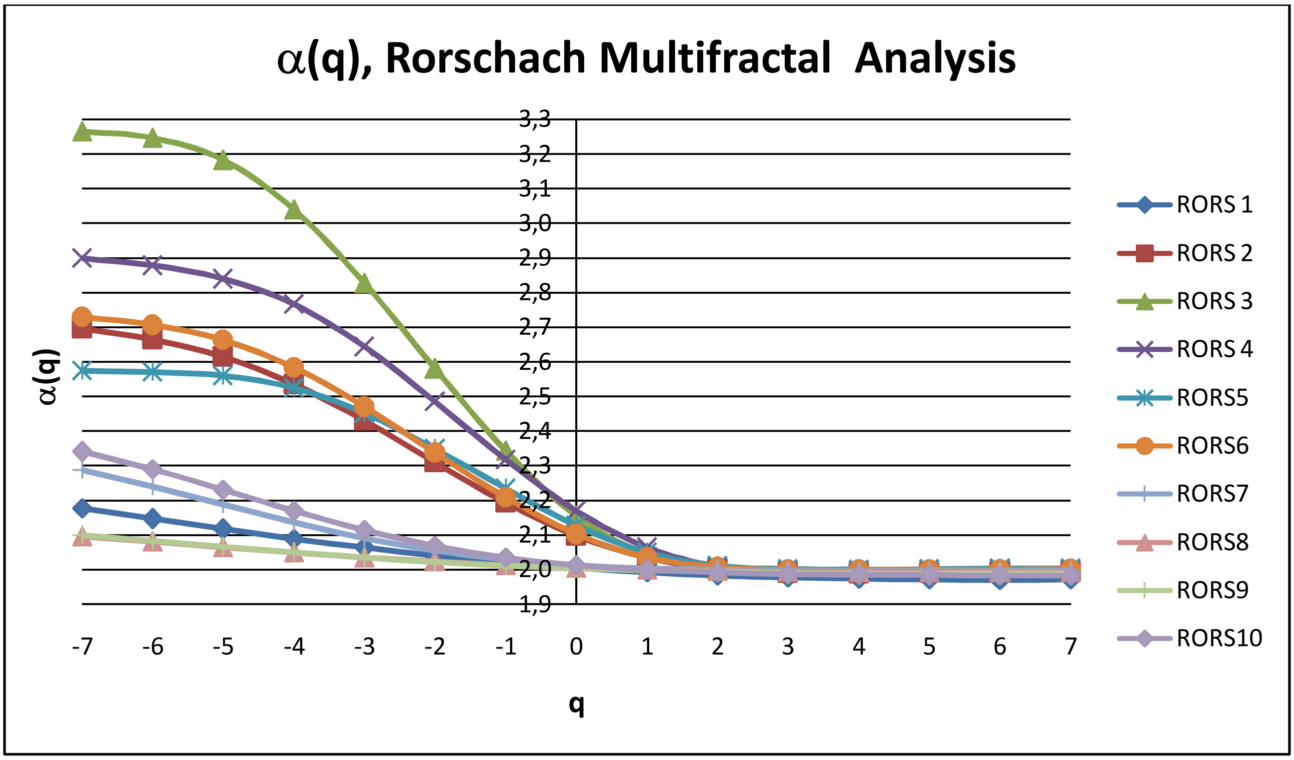

Figure 3. $\alpha(q)$ estimated values of the ten examined Rorschach ink-blots

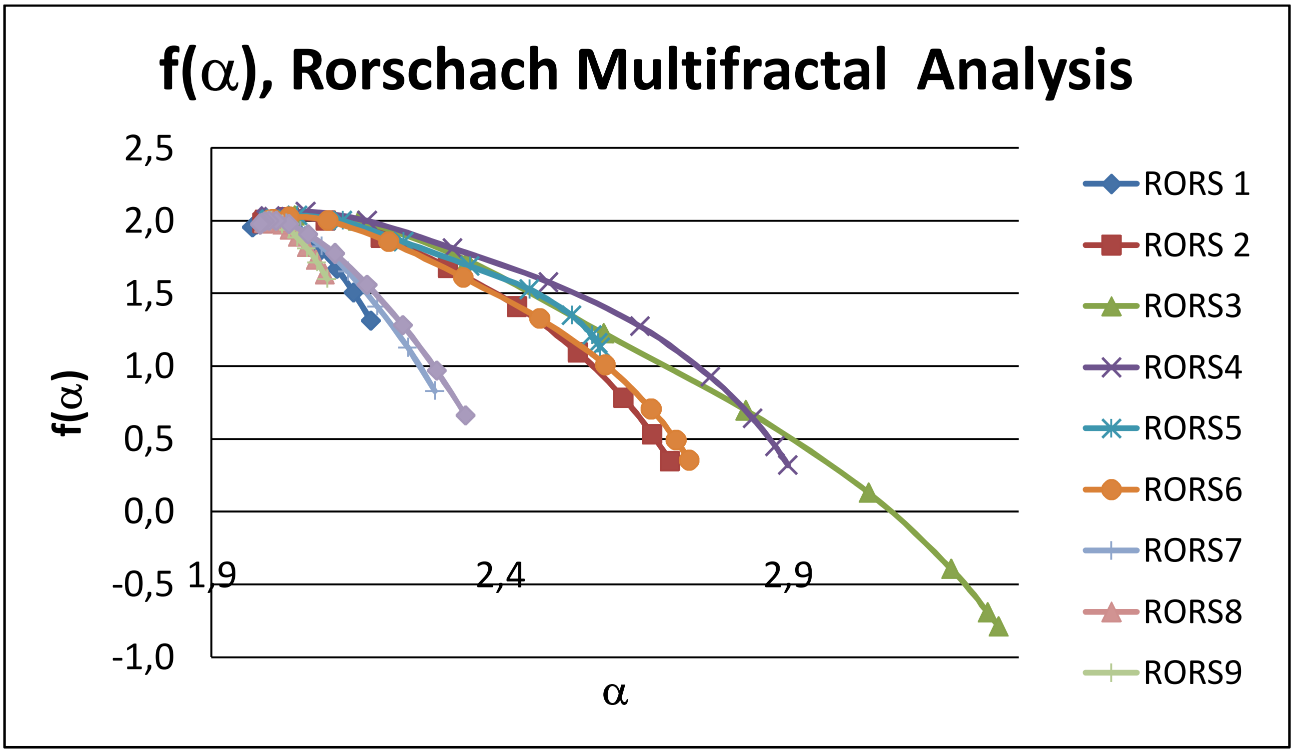

Figure 4. $f(\alpha)$ estimated values of the ten examined Rorschach ink-blots

The corresponding results are given in Tables 1-3.

	h(q)									
q	**RORS 1**	**RORS 2**	**RORS 3**	**RORS 4**	**RORS5**	**RORS6**	**RORS7**	**RORS8**	**RORS9**	**RORS10**
-10	2,122	2,539	2,986	2,738	2,490	2,571	2,190	2,067	2,069	2,226
-9	2,107	2,517	2,955	2,717	2,478	2,550	2,169	2,059	2,060	2,204
-8	2,093	2,491	2,917	2,691	2,465	2,525	2,146	2,052	2,052	2,178
-7	2,079	2,459	2,866	2,659	2,450	2,494	2,121	2,044	2,044	2,150
-6	2,065	2,420	2,798	2,619	2,430	2,455	2,095	2,036	2,036	2,119
-5	2,052	2,371	2,704	2,567	2,402	2,404	2,070	2,029	2,028	2,088
-4	2,039	2,309	2,572	2,498	2,361	2,336	2,049	2,022	2,021	2,060
-3	2,028	2,233	2,392	2,402	2,294	2,245	2,032	2,016	2,015	2,039
-2	2,018	2,149	2,193	2,273	2,191	2,141	2,020	2,011	2,009	2,023
-1	2,009	2,078	2,070	2,127	2,090	2,063	2,012	2,007	2,005	2,012
0	2,002	2,034	2,024	2,034	2,034	2,025	2,007	2,003	2,001	2,004
1	1,995	2,012	2,008	2,003	2,013	2,010	2,003	2,000	1,998	1,999
2	1,990	2,001	2,001	1,996	2,005	2,004	2,001	1,998	1,996	1,995
3	1,986	1,996	1,998	1,995	2,003	2,002	1,999	1,997	1,994	1,992
4	1,983	1,994	1,997	1,995	2,002	2,001	1,999	1,996	1,993	1,991
5	1,980	1,993	1,996	1,996	2,002	2,001	1,998	1,995	1,992	1,989
6	1,979	1,993	1,996	1,997	2,002	2,001	1,998	1,994	1,991	1,988
7	1,977	1,993	1,996	1,997	2,002	2,001	1,998	1,994	1,991	1,988
8	1,977	1,993	1,997	1,998	2,003	2,001	1,998	1,994	1,990	1,987
9	1,976	1,993	1,997	1,999	2,003	2,001	1,998	1,994	1,990	1,987
10	1,976	1,994	1,997	1,999	2,003	2,001	1,998	1,994	1,990	1,987

Table 1. Estimated values of $h(q)$

τ(q)										
q	RORS 1	RORS 2	RORS 3	RORS 4	RORS5	RORS6	RORS7	RORS8	RORS9	RORS10
-10	-23,216	-27,394	-31,855	-29,375	-26,895	-27,706	-23,898	-22,666	-22,686	-24,255
-9	-20,966	-24,657	-28,599	-26,449	-24,305	-24,947	-21,524	-20,534	-20,542	-21,833
-8	-18,743	-21,929	-25,334	-23,528	-21,722	-22,196	-19,170	-18,414	-18,415	-19,427
-7	-16,551	-19,214	-22,062	-20,616	-19,147	-19,454	-16,846	-16,309	-16,305	-17,048
-6	-14,389	-16,519	-18,787	-17,717	-16,577	-16,727	-14,568	-14,218	-14,213	-14,713
-5	-12,258	-13,855	-15,519	-14,837	-14,012	-14,019	-12,350	-12,145	-12,140	-12,440
-4	-10,157	-11,238	-12,289	-11,991	-11,446	-11,343	-10,195	-10,089	-10,084	-10,241
-3	-8,084	-8,699	-9,176	-9,205	-8,881	-8,734	-8,096	-8,048	-8,044	-8,115
-2	-6,036	-6,298	-6,387	-6,545	-6,383	-6,282	-6,040	-6,022	-6,019	-6,045
-1	-4,009	-4,078	-4,070	-4,127	-4,090	-4,063	-4,012	-4,007	-4,005	-4,012
0	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
1	-0,005	0,012	0,008	0,003	0,013	0,010	0,003	0,000	-0,002	-0,001
2	1,980	2,002	2,002	1,991	2,011	2,008	2,002	1,997	1,992	1,990
3	3,958	3,989	3,994	3,984	4,008	4,005	3,998	3,990	3,983	3,977
4	5,931	5,976	5,987	5,980	6,008	6,004	5,994	5,983	5,971	5,962
5	7,901	7,966	7,981	7,979	8,010	8,003	7,990	7,974	7,959	7,946
6	9,871	9,958	9,977	9,980	10,012	10,004	9,986	9,966	9,947	9,930
7	11,841	11,951	11,974	11,981	12,016	12,005	11,984	11,958	11,935	11,914
8	13,813	13,945	13,972	13,984	14,020	14,007	13,981	13,951	13,922	13,898
9	15,787	15,941	15,971	15,987	16,024	16,009	15,980	15,944	15,911	15,882
10	17,763	17,937	17,970	17,990	18,029	18,011	17,979	17,938	17,900	17,868

Table 2. Estimated values of $\tau(q)$

α(q)										
q	RORS 1	RORS 2	RORS 3	RORS 4	RORS5	RORS6	RORS7	RORS8	RORS9	RORS10
-7	2,177	2,696	3,265	2,900	2,574	2,729	2,288	2,097	2,101	2,341
-6	2,147	2,665	3,247	2,878	2,570	2,706	2,240	2,081	2,083	2,291
-5	2,117	2,615	3,183	2,839	2,560	2,663	2,188	2,065	2,066	2,232
-4	2,089	2,536	3,040	2,766	2,525	2,584	2,136	2,050	2,049	2,170
-3	2,064	2,431	2,827	2,643	2,451	2,470	2,091	2,036	2,035	2,114
-2	2,041	2,311	2,581	2,485	2,348	2,337	2,055	2,023	2,022	2,068
-1	2,022	2,194	2,344	2,318	2,234	2,208	2,030	2,013	2,012	2,035
0	2,006	2,098	2,156	2,170	2,127	2,103	2,014	2,006	2,004	2,013
1	1,993	2,034	2,045	2,064	2,049	2,036	2,005	2,000	1,998	2,000
2	1,984	2,002	2,004	2,009	2,011	2,007	2,000	1,996	1,994	1,992
3	1,978	1,991	1,995	1,996	2,001	2,000	1,997	1,994	1,991	1,988
4	1,974	1,990	1,994	1,997	2,001	1,999	1,997	1,993	1,989	1,986
5	1,972	1,991	1,995	1,999	2,002	2,000	1,997	1,992	1,988	1,984
6	1,971	1,992	1,996	2,001	2,003	2,001	1,997	1,992	1,988	1,984
7	1,972	1,994	1,997	2,002	2,004	2,001	1,997	1,993	1,988	1,984

Table 3. Estimated values of $\alpha(q)$

As expected *h(q)* shows monotonically decreasing values as function of q. $\tau(q)$ evidences its typical non linear dependence upon q, and $f(\alpha)$ has the typical distribution of a multifractal spectrum.

In conclusion, we have reached demonstration that the Rorschach ink-blots usually used in psychology and psychiatry as structure not having a definite meaning, really do possess a complex multifractal structure.

In Table 4 and Figures 5-6 we report the results obtained in estimation of the Hurst exponent, the generalized fractal dimension and the strength of multifractality .

Hurst Exponent									
RORS 1	**RORS 2**	**RORS 3**	**RORS 4**	**RORS5**	**RORS6**	**RORS7**	**RORS8**	**RORS9**	**RORS10**
1,990	**2,001**	**2,001**	**1,996**	**2,005**	**2,004**	**2,001**	**1,998**	**1,996**	**1,995**

Table 4. Hurst exponents of the Rorschach ink-blots

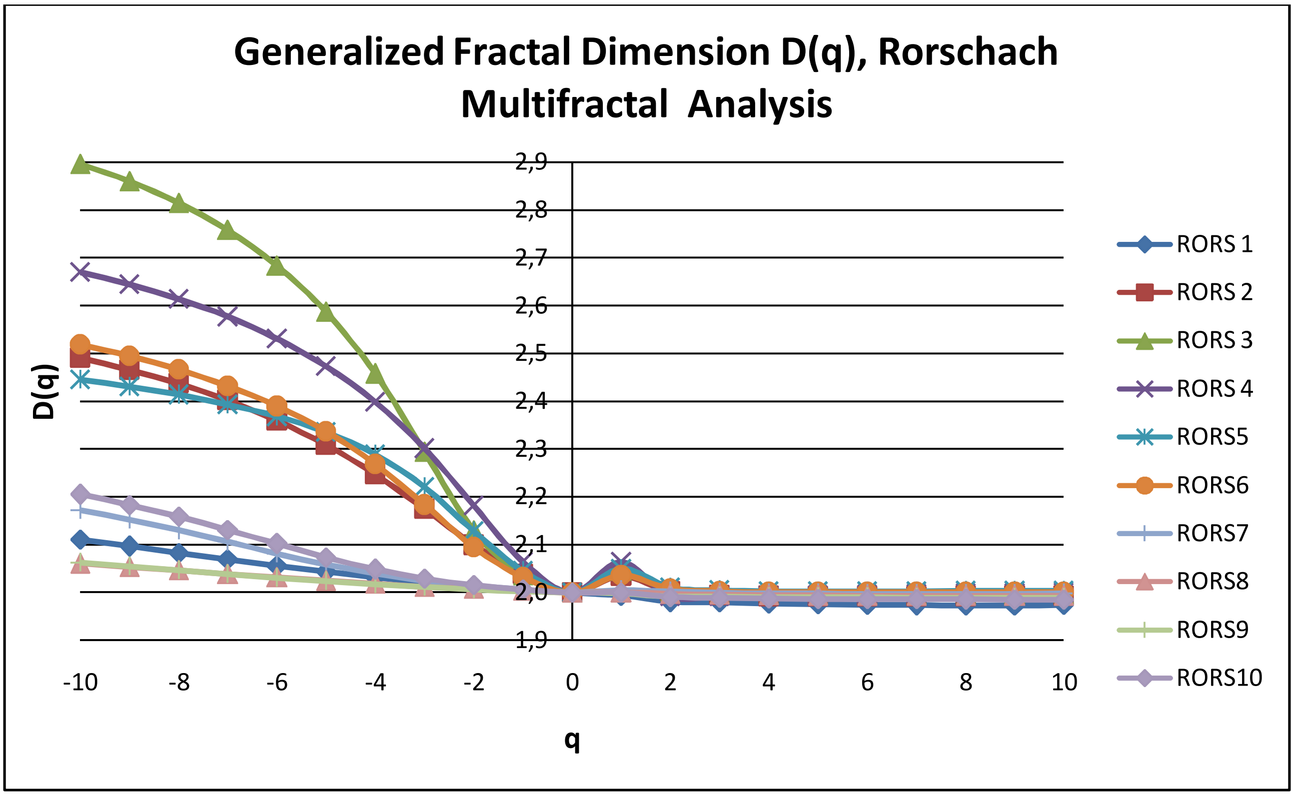

Figure 5. D(q) estimated values of the Generalized Fractal Dimension.

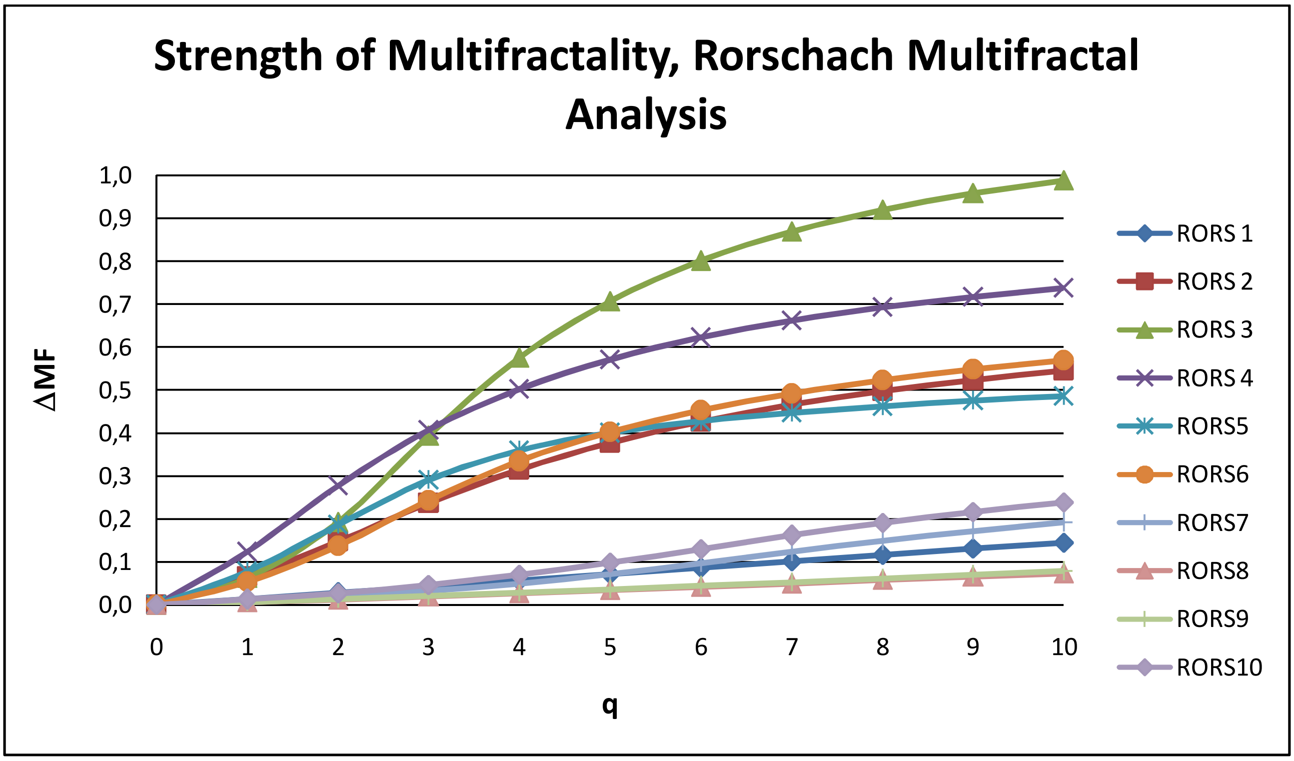

Figure 6 . ΔMF estimated values, strength of multifractality.

The corresponding values are given in Tables 5 and 6.

D(q)										
q	**RORS 1**	**RORS 2**	**RORS 3**	**RORS 4**	**RORS5**	**RORS6**	**RORS7**	**RORS8**	**RORS9**	**RORS10**
-10	**2,111**	**2,490**	**2,896**	**2,670**	**2,445**	**2,519**	**2,173**	**2,061**	**2,062**	**2,205**
-9	**2,097**	**2,466**	**2,860**	**2,645**	**2,431**	**2,495**	**2,152**	**2,053**	**2,054**	**2,183**
-8	**2,083**	**2,437**	**2,815**	**2,614**	**2,414**	**2,466**	**2,130**	**2,046**	**2,046**	**2,159**
-7	**2,069**	**2,402**	**2,758**	**2,577**	**2,393**	**2,432**	**2,106**	**2,039**	**2,038**	**2,131**
-6	**2,056**	**2,360**	**2,684**	**2,531**	**2,368**	**2,390**	**2,081**	**2,031**	**2,030**	**2,102**
-5	**2,043**	**2,309**	**2,587**	**2,473**	**2,335**	**2,337**	**2,058**	**2,024**	**2,023**	**2,073**
-4	**2,031**	**2,248**	**2,458**	**2,398**	**2,289**	**2,269**	**2,039**	**2,018**	**2,017**	**2,048**
-3	**2,021**	**2,175**	**2,294**	**2,301**	**2,220**	**2,184**	**2,024**	**2,012**	**2,011**	**2,029**
-2	**2,012**	**2,099**	**2,129**	**2,182**	**2,128**	**2,094**	**2,014**	**2,007**	**2,006**	**2,015**
-1	**2,005**	**2,039**	**2,035**	**2,063**	**2,045**	**2,032**	**2,006**	**2,003**	**2,002**	**2,006**
0	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
1	**1,993**	**2,034**	**2,045**	**2,064**	**2,049**	**2,036**	**2,005**	**2,000**	**1,998**	**2,000**
2	**1,980**	**2,002**	**2,002**	**1,991**	**2,011**	**2,008**	**2,002**	**1,997**	**1,992**	**1,990**
3	**1,979**	**1,994**	**1,997**	**1,992**	**2,004**	**2,003**	**1,999**	**1,995**	**1,991**	**1,989**
4	**1,977**	**1,992**	**1,996**	**1,993**	**2,003**	**2,001**	**1,998**	**1,994**	**1,990**	**1,987**
5	**1,975**	**1,992**	**1,995**	**1,995**	**2,002**	**2,001**	**1,998**	**1,994**	**1,990**	**1,987**
6	**1,974**	**1,992**	**1,995**	**1,996**	**2,003**	**2,001**	**1,997**	**1,993**	**1,989**	**1,986**
7	**1,974**	**1,992**	**1,996**	**1,997**	**2,003**	**2,001**	**1,997**	**1,993**	**1,989**	**1,986**
8	**1,973**	**1,992**	**1,996**	**1,998**	**2,003**	**2,001**	**1,997**	**1,993**	**1,989**	**1,985**
9	**1,973**	**1,993**	**1,996**	**1,998**	**2,003**	**2,001**	**1,997**	**1,993**	**1,989**	**1,985**
10	**1,974**	**1,993**	**1,997**	**1,999**	**2,003**	**2,001**	**1,998**	**1,993**	**1,989**	**1,985**

Table 5. Estimated values of the Generalized Fractal Dimension.

Strength of Multifractality										
q	**RORS 1**	**RORS 2**	**RORS 3**	**RORS 4**	**RORS5**	**RORS6**	**RORS7**	**RORS8**	**RORS9**	**RORS10**
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	**0,014**	**0,066**	**0,063**	**0,123**	**0,077**	**0,053**	**0,009**	**0,006**	**0,007**	**0,013**
2	**0,028**	**0,148**	**0,192**	**0,277**	**0,186**	**0,137**	**0,019**	**0,013**	**0,013**	**0,028**
3	**0,042**	**0,237**	**0,394**	**0,407**	**0,291**	**0,243**	**0,033**	**0,019**	**0,021**	**0,046**
4	**0,057**	**0,315**	**0,576**	**0,503**	**0,359**	**0,335**	**0,050**	**0,027**	**0,028**	**0,070**
5	**0,071**	**0,378**	**0,708**	**0,572**	**0,401**	**0,403**	**0,072**	**0,034**	**0,036**	**0,099**
6	**0,086**	**0,427**	**0,802**	**0,623**	**0,428**	**0,454**	**0,097**	**0,042**	**0,044**	**0,131**
7	**0,101**	**0,466**	**0,870**	**0,662**	**0,447**	**0,493**	**0,123**	**0,050**	**0,053**	**0,162**
8	**0,116**	**0,498**	**0,920**	**0,693**	**0,463**	**0,524**	**0,149**	**0,058**	**0,062**	**0,191**
9	**0,131**	**0,524**	**0,959**	**0,718**	**0,476**	**0,549**	**0,172**	**0,065**	**0,070**	**0,217**
10	**0,145**	**0,546**	**0,989**	**0,739**	**0,487**	**0,570**	**0,192**	**0,073**	**0,079**	**0,239**

Table 6 Estimated values of the Strength of Multifractality

All the results confirm multifractality . In addition, the other important result is that each analysis evidences that we have a net differentiation in the values for each figure . Consequently each image contains a detailed multifractal structure that is differentiated from the others and we consequently expect that this specialized multifractal structure of each ink blot , will induce different neurological as well as psychological reaction in the subjects during the direct observation of each ink-blot. In Table 7 we give also the results of $\Delta\alpha$ and of Δf , as defined in the appendix A. Such basic indices indicate that we are in presence of images having elevated and differentiated roughness, irregularity and complexity in each ink-blot .

	RORS 1	**RORS 2**	**RORS 3**	**RORS 4**	**RORS5**	**RORS6**	**RORS7**	**RORS8**	**RORS9**	**RORS10**
$\Delta\alpha$	**0,206**	**0,706**	**1,270**	**0,904**	**0,574**	**0,730**	**0,291**	**0,104**	**0,113**	**0,357**
Δf	**0,648**	**1,661**	**2,796**	**1,712**	**0,882**	**1,653**	**1,168**	**0,357**	**0,380**	**1,314**

Table 7. Estimated Complexity in each Rorscahch ink-blot

According to the discussion elaborated in the introduction, we retain that such level of roughness, irregularity and complexity have their decisive role in determining our condition of inner emotion and conflict, reaction and answer when each figure is submitted to perception and cognition.

The first point of the present paper is thus established. Rorschach ink -blots are multifractals and their high and differentiated complexity is at the origin of the reaction that subjects manifest in normal as well as in pathological conditions when these ink-blots are submitted to their direct observation and, in case, to spontaneous or requested cognitive interpretation when they are used as test.

In the context of such our novel interpretation of the Rorschach ink-blots, it should be important to obtain that the high multifractal and complexity structure of the ink-blots induces a corresponding multifractal dynamics in the basic neurological and psycho-physiological GSR signal that is recorded when the subject is called to observe each ink-blot and thus engaging only his /her perception of each figure without posing him/her any question. Therefore, we may now expose the results relating the second section of our experiment, the psychophysiological GSR recording during the direct perception of each figure.

We repeat that we applied the methodology of Appendix A but related to the case of an 1-D-DFA time series regarding the recorded GSR time series.

In order to explain the results let us consider briefly a little premise. Let us admit to consider three kinds of time series, the first being white noise, the second relating a monofractal time series and , finally , a multifractal time series. One of the possible salient features of the multifractal time series, respect to the monofractal and white nose cases, is that in the multifractal case we may have small as well as large fluctuations in the values. As we know, the GSR recording relates values in the Tone that in normal condition of the subject cover the range between 100 KOhm and 300 KOhm (10 microSiemens and 3.3 microSiemnes) with decreasing values responding to the particular emotive and cognitive condition of the subject. The phase in the GSR monitoring reveals important parameters as the baseline values, the latency time respect to the reaction to a given inner or outer stimulus, the rise time, the peak value as well as the half peak time value. These are parameters describing the sudden neurological as well as psychological changes in the mental and neurological states of the monitored subjects . Every scholar in GSR monitoring, knows that, during the GSR recording of a subject, large and rapid fluctuations in the values of the Tone and , in particular, of the Phases are observed in correspondence of the rapid changes in the neurological and mental status of the subject at each moment. Therefore, the 1-D-DFA analysis of the GSR is expected to give results only in correspondence of such large fluctuations.

This is precisely the result that we obtained in our experiments . First we obtained and thus we confirmed that the GSR time series recorded when the subject looking at each ink-blot is a multifractal for the tone and for the phase and, in particular, we had that such multifractal regime is realized only for large fluctuations , that is to say, for sudden and relevant modifications in the neurological and mental state of the subject during his /her observation of each figure.

The results are reported in Figures 7 and 8 (and Tables 8,9) for the GSR Tone and Phase respectively for $h(q)$. The values confirm that the subject responds to the visual inspection of ink-blots following a neurological and mental multifractal dynamics. All the normal subjects responded with very similar values with modest variations contained within the 10 % .

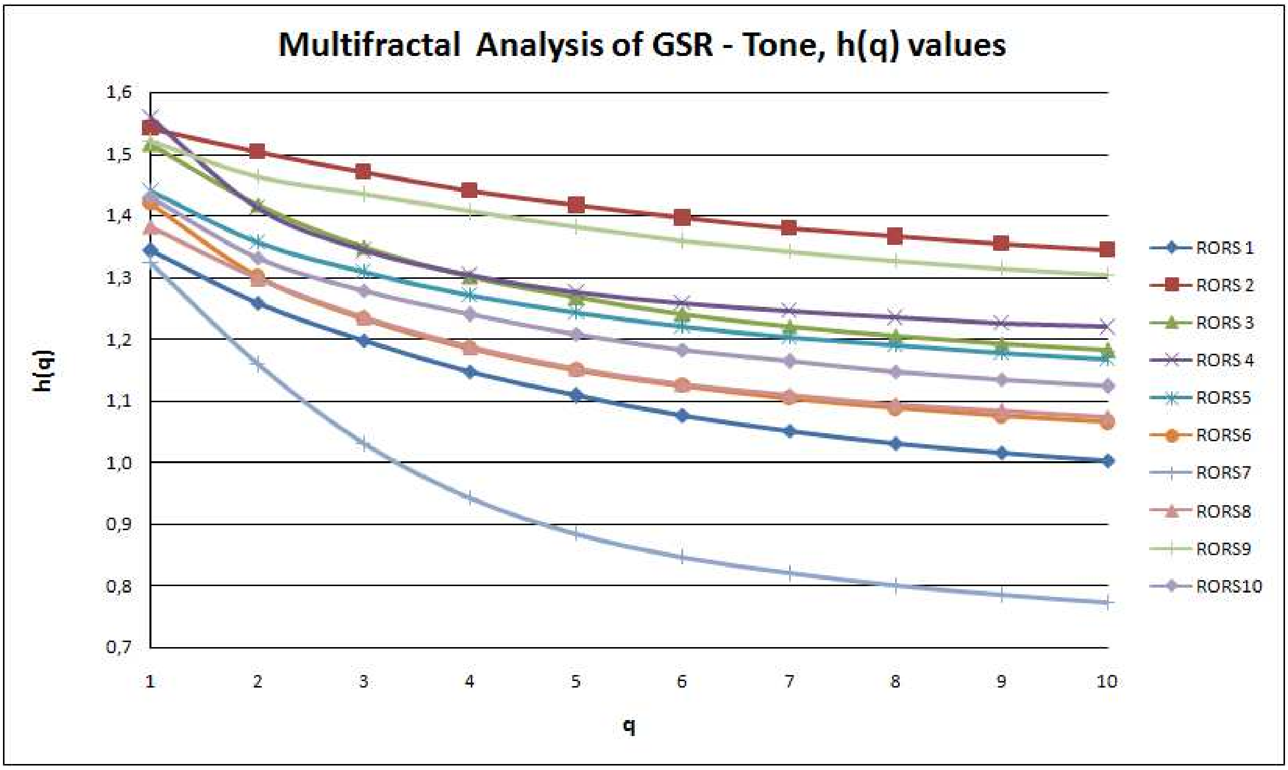

Figure 7. Multifractal GSR analyis, $h(q)$ - GSR-Tone values.

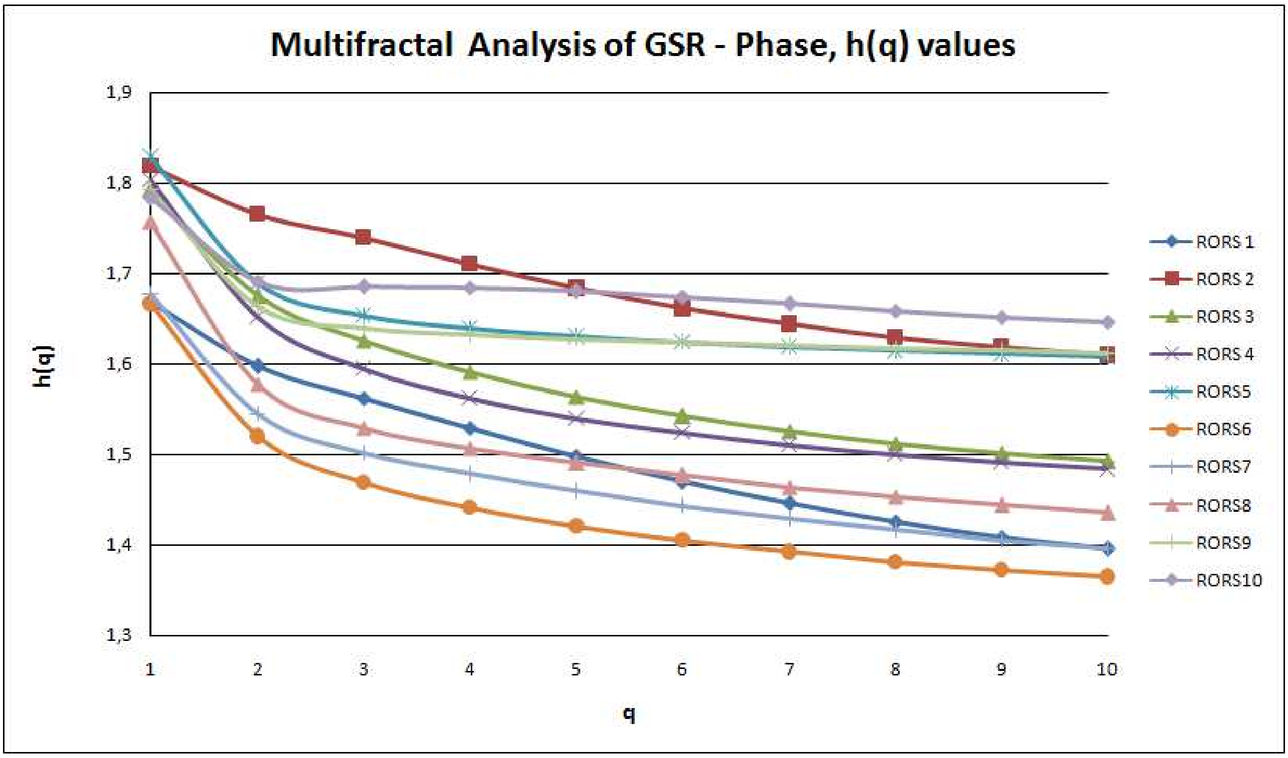

Figure 8. Multifractal GSR analyis, $h(q)$ - GSR- Phase values

Multifractal Analysis of GSR - Tone, h(q) values										
q	**RORS 1**	**RORS 2**	**RORS 3**	**RORS 4**	**RORS5**	**RORS6**	**RORS7**	**RORS8**	**RORS9**	**RORS10**
1	**1,343**	**1,542**	**1,516**	**1,559**	**1,439**	**1,419**	**1,324**	**1,382**	**1,520**	**1,430**
2	**1,258**	**1,503**	**1,417**	**1,412**	**1,356**	**1,300**	**1,158**	**1,297**	**1,463**	**1,331**
3	**1,197**	**1,470**	**1,350**	**1,343**	**1,308**	**1,232**	**1,030**	**1,234**	**1,434**	**1,278**
4	**1,148**	**1,441**	**1,302**	**1,302**	**1,272**	**1,185**	**0,942**	**1,186**	**1,406**	**1,239**
5	**1,108**	**1,416**	**1,267**	**1,276**	**1,243**	**1,150**	**0,885**	**1,152**	**1,381**	**1,208**
6	**1,076**	**1,396**	**1,240**	**1,258**	**1,221**	**1,123**	**0,846**	**1,127**	**1,359**	**1,183**
7	**1,051**	**1,379**	**1,220**	**1,245**	**1,203**	**1,103**	**0,820**	**1,109**	**1,341**	**1,163**
8	**1,031**	**1,366**	**1,204**	**1,234**	**1,189**	**1,088**	**0,800**	**1,094**	**1,326**	**1,147**
9	**1,016**	**1,354**	**1,192**	**1,226**	**1,177**	**1,075**	**0,785**	**1,083**	**1,314**	**1,134**
10	**1,003**	**1,345**	**1,181**	**1,219**	**1,168**	**1,065**	**0,773**	**1,073**	**1,303**	**1,123**

Table 8 . Multifractal Analysis of the GSR -Tone, $h(q)$ values.

Multifractal Analysis of GSR - Phase, h(q) values										
q	**RORS 1**	**RORS 2**	**RORS 3**	**RORS 4**	**RORS5**	**RORS6**	**RORS7**	**RORS8**	**RORS9**	**RORS10**
1	**1,668**	**1,819**	**1,793**	**1,803**	**1,828**	**1,666**	**1,677**	**1,757**	**1,792**	**1,783**
2	**1,597**	**1,765**	**1,674**	**1,651**	**1,689**	**1,519**	**1,544**	**1,577**	**1,663**	**1,691**
3	**1,561**	**1,739**	**1,626**	**1,594**	**1,653**	**1,469**	**1,502**	**1,529**	**1,639**	**1,685**
4	**1,529**	**1,710**	**1,591**	**1,562**	**1,638**	**1,441**	**1,478**	**1,507**	**1,632**	**1,684**
5	**1,498**	**1,683**	**1,564**	**1,540**	**1,630**	**1,421**	**1,459**	**1,490**	**1,627**	**1,680**
6	**1,469**	**1,661**	**1,542**	**1,523**	**1,624**	**1,405**	**1,443**	**1,476**	**1,623**	**1,673**
7	**1,445**	**1,643**	**1,525**	**1,510**	**1,619**	**1,392**	**1,428**	**1,464**	**1,620**	**1,666**
8	**1,425**	**1,629**	**1,512**	**1,499**	**1,614**	**1,381**	**1,416**	**1,453**	**1,617**	**1,659**
9	**1,409**	**1,618**	**1,501**	**1,491**	**1,611**	**1,372**	**1,405**	**1,444**	**1,614**	**1,652**
10	**1,395**	**1,609**	**1,492**	**1,483**	**1,607**	**1,364**	**1,396**	**1,435**	**1,611**	**1,646**

Table 9. Multifractal Analysis of the GSR - Phase, $h(q)$ values.

4. Conclusions

The use of Rorschach ink-blots in neurological as well psychological and psychiatric sciences has represented the matter of a long and debated question relating their meaning and the actual and accredited use as projective test .
Starting with 2009 we planned a research project having the finality to investigate the actual structure of such ink-blots and we obtained the first result to evidence that they are a fractal structure.
By using the 2D-DFA procedure we advanced in the exploration of this thematic and, in fact, in the present study we have obtained two results.
The first result is that we have demonstrated that the Rorschach ink-blots actually are multifractals. In detail, we have shown that they may be described with accuracy using the standard multifractal variables and on this basis we may conclude that they are all strongly differentiated and evidence an high level of complexity. The $\Delta\alpha$ and the Δf values discriminate in an excellent manner the ten figures also confirming the relevant complexity of some figures respect to the others .
As discussed in detail in the introduction, it is such high complexity of such figures to induce in the subject a large intrinsic and irreducible indetermination that of course induces an inner conflict with an elevated level of emotional and cognitive dynamics in the subject. We consider that emotional responses and connected cognitive engagement are associated with previous experiences of a subject, particularly relating the childhood and his /her link to parental figures. Therefore we conclude for a particular relevance of these figures as basic test.
As second step of the present investigation we have monitored the GSR signal of the subjects when asking them only to look at each figure for two minutes without asking them to express comments or interpretation but remaining in silence only observing the figures. Obviously, in this experimental condition , the perceptive structure of the subject was involved also if we expect obviously that also the cognitive dynamics of the subject was engaged in such two minutes of observation.
Our 1D-DFA analysis of the recorded GSR revealed that the subject responds to the visual inspection of the figures by a neurological, psychological . and mental dynamics that has a direct multifractal structure.
We estimated the $h(q)$ values for GSR Tone and Phase and for all the ten Rorschach ink-blots. We obtained that such $h(q)$ values are discriminated for each ink blot. We reported also the value of the Hurst $h(2)$ exponent.
Our conclusion is that the high complexity of the Rorschach ink-blots activates a corresponding very complex neurological and mental dynamics that is estimated in the present paper by the variable $h(q)$.
From the view point of basic and computational neuroscience, both such results seem to be of interest in the general framework of the applications of the Science of Complexity in understanding our basic neurological foundations and psychology.
On the other hand the possibility to estimate the index $h(q)$ in each subject by the GSR and for each ink-bolt, opens a new perspective of interest also for clinical applications since for the first time we have such variable that connects Rorschach ink-blots with the GSR recorded psychophysiological , neurological and mental condition of the subject, and it may be estimated with high accuracy. Therefore it may be evaluated in normal as well as in pathological cases. Having in this case a basic science as the theory of complexity as fundamental support, we expect that it will be very helpful and able in clinical applications to study cases of pathological interest.

APPENDIX A

Step 1

Consider a gray image as a self-similar surface and represent it by an MxN matrix $X=X(i.j)$, $i=1,2,....,M$; $j=1,2,....,N$. Partition the surface into a $M_S x N_S$ non- overlapping square sub-surface of equal lengths s where $M_S=M/_S$ and $N_S=N/_S$. Each sub-surface is denoted by $X_{m,n}=X_{m,n}(i,j)$ where $X_{m,n}(i,j) =X(r+i,t+j)$ for $1 \leq i , j \leq s$ and $r=(m-1)\ s$, $t=(n-1)\ s$.

Note that M and N are not necessarily multiples of the length s . Therefore, the sub-surfaces in the upper-right and the bottom may not be taken into consideration. We can then repeat the partitioning procedure starting from the other three corners.

Step 2

For each sub-domain $G_{m,n}$, find the cumulative sum as given in detail in (Wang et al. 2015)

Step 3

For each surface $G_{m,n}$ we can obtain a local trend $\overline{G}_{m,n}$ by fitting it with a pre-chosen bivariate polynomial function

$\overline{G}_{m,n}(i,j) = ai+bj+c$

And we can determine the residual matrix

$y_{m,n}(i,j) = G_{m,n}(i,j) - \overline{G}_{m,n}(i,j)$

Step 4

We calculate the detrended Fluctuation Function $F(m,n,s)$ of the segment $X_{m,n}$

$$F^2(m,n,s) = \frac{1}{s^2}\sum_{i=1}^{s}\sum_{j=1}^{s} y_{m,n}(i,j)^2$$

and the q-order Fluctuation Function $F_q(s)$

$$F_q(s) = \left[\frac{1}{M_s N_s}\sum_{m=1}^{M_s}\sum_{n=1}^{N_s}\left[F(m,n,s)\right]^q\right]^{1/q} \quad \text{for } q \neq 0$$

and

$$F_q(s) = \exp\left[\frac{1}{M_s N_s}\sum_{m=1}^{M_s}\sum_{n=1}^{N_s}\ln(F(m,n,s)\right] \text{for } \; q = 0$$

Step 5

Vary the value of s ranging from 6 to min $(M,N)/4$. In the cases in which the surfaces $G_{m,n}$ are long range power law correlated, $F_q(s)$ behaves, for large values of s, as a power law,

$F_q(s) \propto s^{h(q)}$

$h(2)$ is the Hurst index h of the surface, and h(q) the generalized Hurst index of the surface. $h(2)$ can be related to the fractal dimension D_f of the two-dimensional surface by means of the relationship $h = 3-D_f$.

The classical multifractal scaling exponents $\tau(q)$ are obtained by

$\tau(q)=qh(q)-D$

where D denotes the fractal dimension of the geometric support of the multifractal measure, for the two-dimensional measure, $D = 2$. It is also easy to obtain the generalized multifractal dimensions

$$D_q = \frac{\tau(q)}{q-1} = \frac{qh(q)-2}{q-1}$$

for $q \neq 1$ (for details see Wang et al. 2015)

In addition we have to characterize the multifractal surface via the singularity strength or Hölder exponent α and singularity spectrum $f(\alpha)$. They are related to $\tau(q)$ via a Legendre transform

$$\alpha(q) = \frac{d\tau(q)}{dq}$$

and

$$f(\alpha) = q\alpha(q) - \tau(q)$$

In addition we use the following indices of characterization:

a) $I = |h(q)-h(-q)|$(strength of multifractality)

expressing the degree of multifractality.
b) $\Delta\alpha = \alpha_{max} - \alpha_{min}$
c) $\Delta f = f(\alpha_{max})\text{-}f(\alpha_{min})$
for all q respectively.
The larger the value of $\Delta\alpha$ is, the smaller the even distribution of probability measure is, and the more roughness image texture surface will usually be expected. The latter is Hausdorff dimension of the measured object, which is used to measure the degree of irregularity and complexity.

References

Smith Jr T.G., Lange G.D., and Marcks W.B. (1996). Fractal methods and results in cellular morphology - dimensions, lacunarity and multifractals. *Journal of Neuroscience Methods*, **69**, 123-136.

Fernández E. and Jelinek H. F. (2001). Use of fractal theory in neuroscience: methods, advantages, and potential problems. *Methods*, **24**, 309-321.

Jelinek H.F., Cornforth D.J., Roberts T., Landini G., Bourke P., and Bossomaier T. (2004a). Image processing of finite size rat retinal ganglion cells using multifractal and local connected fractal analysis. In: *Complex Systems Conference*, Cairns, Australia.

Jelinek H, A. Karperien, T. Bossomaier, and Buchan A. (2004b). Differentiating grades of microglia activation with fractal analysis. Proceedings of the 7th AsiaPacific Conference on Complex Systems, pp. 605-612, Cairns, Australia

Cornforth D. and Jelinek H.F. (2005). Automated classification of dementia subtypes from post-mortem cortex images. In: AI2005: *Advances in Artificial Intelligence*, pp. 1285-1288, Sydney, Australia.

Losa G. (2014). On the fractal design of human brain and Nervous Tissue. *Applied mathematics*, **5**, 1725-1732.

Losa G. (2015). The living realm depicted by the fractal geometry. *Fractal Geometry and Nonlinear Anal in Med and Biol*, **1**(1), 11-15.

Delignières D., Fortes M.,Ninot G., (2004), The fractal dynamics of Self-Esteem and physical self, *Non Linear dynamics in Psychology and LifeSciences,* 8,479-510

Mattei TA. (2014). Unveiling complexity: non-linear and fractal analysisi in neuroscience and cognitive psychology. *Frontiers in Computational Neureoscience*, **8**, article 17.

Di Leva A., Esteban F.J., Grizzi F., Klonowski W., Landrove M.M. (2015). Fractals in the Neurosciences, Part II: Clinical Applications and Future Perspectives. *The Neuroscientist*, **21**(1), 30-43.

Jelinek H.F., Steinke A.B. (1996). Determination of the fractal dimension of cat retinal ganglion cells using a new method on the world wide web. *Proc Austr Neurosci Soc*, **7**:139-146

Nonnenmacher T.F., G. Baumann, A. Barth, and G.A. Losa (1994). Digital image analysis of self-similar cell profiles. *International Journal of Bio-Medical Computing*, **37**, 131-138

Ristanović D., B.D. Stefanović, N.T. Milošević, M. Grgurević, and V. Štulić (2002). Fractal and nonfractal analysis of cell images: comparison and application to neuronal dendritic arborization. *Biological Cybernetics*, **87**, 278-288.

Ristanovich D., Losa GA. (2013). A contribution to definitions of some fractal concepts. *The Fractal Laboratory Journal*, **2**, 2**.**

Smith Jr T.G., Lange G.D., and Marcks W.B. (1996). Fractal methods and results in cellular morphology - dimensions, lacunarity and multifractals. *Journal of Neuroscience Methods*, **69**, 123-136

Karperien A. Ahammer E, Jelinek H.F. (2013). Quantitating the subtleties of microglial morphology with fractal analysis. *Front Cell Neurosci.*, **7**: 3.

Gisiger T (2001). Scale invariance in biology: coincidence or footprint of a universal mechanism? *Biological Reviews of the Cambridge Philosophical Society,* **76** (2): 161-209

Mandelbrot B.B. (1983). The fractal geometry of nature. Freeman and Co, New York.

Schroeder M. (1991). Fractals, chaos, power laws. W.H Freeman and Co, New York

Iannaccone P.M. and Khokha M. (1995). Fractal geometry in biological systems: an analytical approach, CRC Press, New York.

Fu-Zen Shaw, Ruei-Feng Chen, Hen-Wai Tsao, Chen-Tung Yen (1999). Algorithmic complexity as an index of cortical function in awake and pentobarbital-anesthetized rats**.** *Journal of Neuroscience Methods*, **93** (2), 101–110.

Nazahah M., Trevor S. Ahearn, Gordon D. Waiter, Alison D. Murray, Lawrence J. Whalley, Roger T. Staff (2012). Brain structural complexity and life course cognitive change. *NeuroImage,* **61**, 694–701.

Block A., von Bloh W., and Schnellhuber H.J. (1990). Efficient box-counting determination of generalised fractal dimensions. *Physical Review A,* **42**, 1869-1874

Norman R., Mendolicchio L., Mordeniz C., Pierangeli E., Pannarale P., Orsucci F., Conte E.(2016a), Galvanic skin response and its neurological correlates, Journal of Consciousness Exploration and Research, 7,1,553-572; Mind Science ViXra .org 1606:0140;1606:0095.

Norman R., Mordeniz C, Mendolicchio L., Pierangeli E., Pannarale P., Orsucci F., Conte E.(2016b),A basic biofeedback primer, Mind Science, ViXra.org, 1606:0140.

Jian Li, Qian Du, Caixin Sun (2009). An improved box-counting method for image fractal dimension estimation. *Pattern Recognition*, **42** (11), 2460–2469.

Wang C., Allegaert K., Peeters M.Y.M., Tibboel D., Danhof M., and Knibbe C.A.J. (2014). The allometric exponent for scaling clearance varies with age: a study on seven propofol datasets ranging from preterm neonates to adults. *British Journal of Clinical Pharmacology,* **77** (1) 149–159.

Wang F., Li J. W., Shi W., Liao G. P. (2014a). Leaf image segmentation method based on multifractal detrended fluctuation analysis. *J Appl Phys*., **114** (21):214905.

Wang F., Li Z. S., Liao G. P. (2014b). Multifractal detrended fluctuation analysis for image texture feature representation. *International Journal of Pattern Recognition and Articial Intelligence,* **28** (3),1-20.

Wang F., Deng wen Liao, Jin wen Lii, Giung -Ping Jao (2015). Two-dimensional Multifractal detrended fluctuation analysis of plant identification. *Plant Methods*, **11** (12), 1-12.

Wang G., Huang H., Xie H., Wang Z., Hu X. (2007). Multifractal analysis of ventricular fibrillation and ventricular tachycardia. *Med. Eng. Phys*., **29**: 375–379

Voss R. M. and Wyatt J. C. Y. (1991). Multifractals and local connected fractal dimension: Classification of early chinese landscape paintings. In: Applications of fractals and chaos (A. J. Crilly, R. A. Earnshaw and H. Jones. (Eds)), Springer-Verlag, Berlin

Stanley H.E., Amaral L.A.N., Goldberger A.L., Havlin S., Ivanov P.Ch., and Peng C.K. (1999). Statistical physics and physiology: Monofractal and multifractal approaches. *Physics A*, **270**, 309-324.

Chhabra A. and Jensen R. V. (1989). Direct determination of the f(a) singularity spectrum. *The American Physical Society*, **62**, 1327-1330.

Vicsek T. (1992). Fractal Growth Phenomena, World Scientific, Singapore

Jestczemski F. and Sernetz M. (1996). Multifractal approach to inhomogeneous fractals. *Physica A*, **223**, 275-282.

Jelinek H.F. and Fernández E. (1998). Neurons and fractals: how reliable and useful are calculations of fractal dimension?. *Journal of Neuroscience Methods*, **81**, 9-18.

Bullmore Ed., Barnes A., Bassett D. S., Fornito A., Kitzbichler M., Meunier D., Suckling J. (2009). Generic aspects of complexity in brain imaging data and other biological systems. *NeuroImage*, **47** (3),1125–1134

Fernández E., Bolea J.A., Ortega G., and Louis E. (1999). Are neurons multifractals?. *Journal of Neuroscience Methods*, **89**, 151-157.

Conte E., Mastrolonardo M., Zbilut J.P. (2006). A fractal Analysis of Skin Pigmented lesions using the novel feature of the variogram. *Chaos, Solitons and Fractals*, **28**, 1119-1135.

Conte E., Todarello O., Mendolicchio L., Corfiati L., Macina A., Pieri G., Zbilut J.P. (2008a). A Psycho-physical Model of of Rorschach's ink-blots using fractal analysis with estimation of the generalized fractal dimension and fractal variance function. *Chaos and Complexity Letters* , **4** (1), 77-84.

Conte E., Farronato G., Farronato D., Maggipinto C., Maggipinto G., Zbilut J.P.(2008b). Recurrence quantification Analysis, Variability Analysis and Fractal Dimension Estimation in ^{99m}Tc-HDP Nuclear Scintigraphy of Maxillary Bones in subjects with Osteoporosis. *Chaos and Coomplexity Letters*, **3** (2), 111-142.

Conte E., Todarello O., Mendolicchio L., Corfiati L., Macina A., Federici A., Pierri G., Zbilut J.P. (2012a). A Psycho-physical Model of of Rorschach's ink-blots using fractal analysis with estimation of the generalized fractal dimension and fractal variance function. *On the Borders of Complexity*. Nova Science Publishers Inc.

Conte E., Pierri G., Federici A., Mendoloccio L, Zbilut J.P. (2009). The Fractal variogram Analysis as General Tool to Measure Normal and Altered Metabolism States and the Genetic Instability: an application to the case of the cutaneous malignat melanoma. *Chaos and Complexity Letters*, **3** (3), 273-280.

Peng C-K, Buldyrev S.V., Havlin S, Simons M, Stanley H.E., Goldberger A.L. (1994). Mosaic organization of DNA nucleotides. *Phys Rev E*, **49**, 1685-1689.

Kantelhardt, J.W.; Zschiegner, S.A.; Koscielny-Bunde, E.; Havlin, S.; Bunde, A.; Stanley, H.E. (2002). Multifractaldetrended fluctuation analysis of nonstationarytime series. *Phys. A Stat. Mech.Appl*., **316**, 87–114.

Gu G. F., Zhou W. X. (2006). Detrended fluctuation analysis for fractals and multifractals in higher dimensions. *Phys Rev E.* , **74**: 061104.

Ivanov PC, Amaral LA, Goldberger AL, Havlin S, Rosenblum MG, Struzik ZR, and Stanley HE. (1999). Multifractality in human heartbeat dynamics. *Nature,* **399**: 461–465

Peng C. K., Mietus J. E., Liu Y., Lee C., Hausdorff J. M., Stanley H. E., Goldberger A. L., Lipsitz L. A. (2002). Quantifying fractal dynamics of human respiration: age and gender effects. *Ann. Biomed. Eng*., **30**: 683–692.

Zheng Y., Gao J. B., Sanchez J. C., Principe J. C., Okun M. S. (2005). Multiplicative multifractal modeling and discrimination of human neuronal activity. *Phys. Lett. A,* **344**: 253–264

Hausdorff J. M. (2007). Gait dynamics, fractals and falls: finding meaning in the stride-to-stride fluctuations of human walking. *Hum. Mov. Sci*., **26**: 555–589

Bassingthwaighte J., Van Beek J., King R. (1990). Fractal branchings: the basis of myocardial flow heterogeneities? *Ann. N. Y. Acad. Sci.,* **591**: 392–401

Abbound S., Berenfeld O., Sadeh D. (1991). Simulation of high-resolution QRS complex using ventricular model with a fractal conduction system. Effects of ischemia on high-requency QRS potentials. *Circ. Res*., **68**: 1751–1760

Weibel E. R. (1991). Fractal geometry: a design principle for living organisms. *Am. J. Physiol.,* **261**: 361–369

Krenz G., Linehan J., Dawson C. (1992). A fractal continuum model of the pulmonary arterial tree. *J. Appl. Physiol*., **72**: 2225–2237

Parkinson I., Fazzalari N. (1994). Cancellous bone structure analysis using image analysis. *Australas. Phys. Eng. Sci. Med*., **470**: 64–70

Atupelage C., Nagahashi H., Yamaguchi M., Sakamoto M., Hashiguchi A. (2012). Multifractal feature descriptor for histopathology. *Anal. Cell. Pathol.* (Amst.) **35**: 123–126

Conte E., Wang F., Norman R., Mordeniz C., Conte S., Licata I. (2016a) A Multifractal Analysis of Connectomics, Neuron Locations, And Calcium Activity In C-Elegans . *Chaos and Complexity Letters,* **10 (**2): 111-127

Conte E., Norman R., Mordeniz C., Conte S., Marvulli R., Ianieri G., Megna M., Wang F. (2016b) A Multifractal Analysis of Neuron Locations and Calcium Activity in C-Elegans. *Chaos and Complexity Letters,* **10 (**1): 1-23

Goldberger A. L. (1996). Non-linear dynamics for clinicians: chaos theory, fractals, and complexity at the bedside. *Lancet,* **347**: 1312–1314

Goldberger A. L., Amaral L. A., Hausdorff J. M., Ivanov P. C., Peng C. K., Stanley H. E. (2002). Fractal dynamics in physiology: alterations with disease and aging. *Proc. Natl. Acad. Sci. U.S.A*., **99**: 2466–2472

Conte E., Norman R. (2016c). Some Brief Comments on Recent Studies on Quantum Cognition *NeuroQuantology* **14** (3):514-523

Conte E., Licata I., Alelù Paz R. (2015a) Formulation of the Quantum Neurological Model of Perception - Cognition and Awareness in Ambiguous Figures and in the Particular Case of the Dalmatian dog. *Journal of Behavioral and Brain Science* **5**(12): 533-549

Conte E., Rui Freire L. (2015b) First Time Demonstration of the Quantum Interference Effect during Integration of Cognition and Emotion in Children. *World Journal of Neuroscience*, **5**: 91-98.

Conte E. (2015c). What Path Monitor: A Brief Note on Quantum Cognition and Quantum Interference, the Role of the Knowledge Factor. *Psychology*, **6**: 291-296.

Conte, E. (2011a). On the Logical Origins of Quantum Mechanics Demonstrated by Using Clifford Algebra: A Proof That Quantum Interference Arises in a Clifford Algebraic Formulation of Quantum Mechanics. *Electronic Journal of Theoretical Physics*, **8**: 109-126.

Conte, E. (2011b). On the Logical Origins of Quantum Mechanics Demonstrated by Using Clifford Algebra. *Neuroquantology*, **9**: 231-242.

Conte, E. (2011c). Advances in Application of Quantum Mechanics in Neuroscience and Psychology: A Clifford Algebraic Approach. New York: Nova Science Publishers.

Conte, E. (2013a). Are Information, Cognition, and the Principle of Existence Intrinsically Structured in the Quantum Model of Reality? *Advanced Studies in Theoretical Physics*, **7**: 797-818.

Conte, E. (2013b). A Clifford Algebraic Analysis Gives Mathematical Explanation of Quantization of Quantum Theory and Delineates a Model of Quantum Reality in Which Information, Primitive Cognition Entities and a Principle of Existence Are Intrinsically Represented Ab Initio. *World Journal of Neuroscience*, **3**: 157-170.

Conte, E., Khrennikov, A. Y., Todarello, O., De Robertis, R., Federici, A., & Zbilut, J. P. (2011d). On the Possibility That We Think in a Quantum Mechanical Manner: An Experimental Verification of Existing Quantum Interference Effects in Cognitive Anomaly of Conjunction Fallacy. *Chaos and Complexity Letters*, **4:** 123-136.

Conte, E., Khrennikov, A. Y., Todarello, O., Federici, A., Mendolicchio, L., & Zbilut, J. P. (2009b). Mental States Follow Quantum Mechanics during Perception and Cognition of Ambiguous Figures. *Journal of Open Systems and Information Dynamics*, **16**: 1-17.

Conte, E., Santacroce, N., Laterza, V., Conte, S., Federici, A., & Todarello, O. (2012b). The Brain Knows More Than It Admits: A Quantum Model and Its Experimental Confirmation. *Electronic Journal of Theoretical Physics*, **9**: 72-110.

Conte, E., Todarello, O., Federici, A., Vitiello, F., Lopane, M., Khrennikov, A. Y., & Zbilut, J. P. (2007). Found Experimental Evidence of Quantum Like Behavior of Cognitive Entities. An Abstract Quantum Mechanical Formalism to Describe Cognitive Entities and Its Dynamics. *Chaos, Solitons and Fractals*, **3**: 1076-1088.

Conte, E., Todarello, O., Laterza, V., Khrennikov, A.Y., Mendolicchio, L. and Federici, A. (2010) A preliminary experimental verification of violation of bell inequality in a quantum model of Jung theory of personality formulated with Clifford algebra. *Journal of Consciousness Exploration & Research*, **1**: 831-849.

Conte, E., Khrennikov, A.Y., Todarello, O., Federici, A. and Zbilut, J.P. (2009c) On the existence of quantum wave function and quantum interference effects in mental states: An experimental confirmation during perception and cognition in humans. *Neuroquantology*, **7**: 204-212.

Conte, E., Khrennikov, A.Y., Todarello, O., Federici, A. and Zbilut, J.P. (2008c) A preliminary experimental verification on the possibility of bell inequality violation in mental states. *Neuroquantology*, **6**: 214-221.

Mitina O.V,Abraham F.D., The use of fractals for the study of the psychology of perception, http://www.blueberry-brain.org/dynamics/mitina-fractal-perception.htm

Conte E., Pieralice M., Tamburiello G., Battista E. (1991). Preliminary Results in mathematical, *Cybernetics*, IV/70: 2-14

Orsucci F., Petrosino R., Paoloni G., Canestri L., Conte E., Reda M.A.,(2013) Fulcheri M., Prosody and synchronization in cognitive neuroscience, *EPJ Non Linear Biomedical Physics*, **1** (6): 1-11

Schroeder M., (1991), Fractals, Chaos, Power Laws: Minutes from an Infinite Paradise, W. H. Freeman & Co, 1991 New York