# CHARACTERISING BRAIN STRUCTURES USING FRACTAL ANALYSIS FOR HUFFAZ GROUP

BY

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A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy in Health Sciences

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JUNE 2020

# ABSTRACT

Memorising the holy Quran has been the motivation for most Muslims due to the advantages that it offers, in this life and the hereafter. The robust process of memorising the holy Quran is expected to cause changes in the brain regions which is associated with the memory encoding, storage, and retrieval capacity. The main areas in the brain that are involved with memory encoding, storage, and retrieval capacity are the amygdala, hippocampus, cerebellum, and prefrontal cortex. At the moment, the analysis of neuroplasticity is limited to be analysed in binary image because gray-scale analysis requires the usage of more robust image processing techniques. Therefore, this study aims to investigate and characterise the complexity of textual memorisation brain structures using fractal analysis between huffaz and non-huffaz by means of global box-counting analysis, global FFD analysis, and VOI-based analysis. The study recruited 47 participants (mean±SD age, 22.55±1.472 years) from students of IIUM Kuantan Campus. Huffaz group had their 18 months of memorisation training at Darul Quran, Kuala Kubu Bharu, Selangor. The brain MRI images were acquired before being pre-processed using Voxel-Based Morphometry (VBM) toolboxes with MATLAB as platform. Processed images were then thresholded with three thresholding techniques to find the best thresholding method; Otsu, midpoint and hysteresis. Otsu method was proven to be the best thresholding technique (mean±SD, 2.3801±0.953) with a significant difference ($p<0.01$) tested with ANOVA. Global box-counting and FFD analysis were conducted on the brain MRI images concurrently with VBM to find out the possible brain regions with neuroplasticity. Both analyses found no significant statistical difference between brains of huffaz and non-huffaz ($p>0.05$), with VBM analysis also could not find any activated voxel brain regions. VOI-based analysis found nine significant areas ($p<0.05$); two for box-counting analysis (angular gyrus and medial temporal gyrus), six for FFD analysis (BA20, BA30, anterior cingulate, fusiform gyrus, inferior temporal gyrus and frontal lobe), and only a single area (BA33) have shown significant volume differences between huffaz and non-huffaz using VOI-based analysis. BA20 is part of the temporal cortex in the brain, BA30 is located at isthmus of the cingulate gyrus, while BA33 is located at the anterior cingulate gyrus of the brain cortex. All these Brodmann areas involve heavily in memory encoding, memory storage, and retrieval capacity of humans. The results have highlighted the sensitivity of VOI-based analysis because of its local analysis, as compared to the global analysis by box-counting and FFD. These findings have shown that brain neuroplasticity was managed to be detected using VOI-based analysis, and that neuroplasticity due to memorisation process occurred by involving multiple brain areas and regions, and not solely on a single area or a region. To conclude, the application of ability of fractal analysis has been proven to detect structural changes occurrence in brains of huffaz as compared to non-huffaz.

# خلاصة البحث

حفظ القرآن الكريم غاية معظم المسلمين لما له من منافع في هذه الدنيا والآخرة. تسبب العملية النشطة لحفظ القرآن الكريم، كما هو متوقع، في إحداث تغييرات في مناطق الدماغ المرتبطة بسعة ترميز وتخزين واسترجاع الذاكرة. مناطق الدماغ الرئيسية المسؤولة عن ترميز وتخزين واسترجاع الذاكرة هي: اللوزة، الحصين، المخيخ، والقشرة الجبهية الأمامية. يقتصر تحليل المرونة العصبية حاليا على تحليلها كصور ثنائية لأن التحليل على تدرج رمادي يتطلب استخدام تقنية معالجة صورية أكثر قوة. ولذلك هدفت هذه الدراسة إلى توصيف والتحقيق في مدى تعقيد الحفظ النصي لتراكيب الدماغ باستخدام التحليل الكسري بين المشاركين الحفاظ وغير الحفاظ بواسطة تحليل عد الصناديق العام، وتحليل FFD العام، والتحليل المبني على VOI. أشركت الدراسة 47 شخصا (المتوسط±الانحراف المعياري للعمر، 22.55±1.472 سنة) من طلاب الجامعة الإسلامية العالمية الماليزية بمدينة كوانتان. تلقت مجموعة الحفاظ تدريب الحفظ لمدة 18 شهرًا من في معهد دار القرآن في كوالا كوبو بارو بولاية سيلانجور. تم مسبقا الحصول على صور التصوير بالرنين المغناطيسي للدماغ قبل معالجتها باستخدام أدوات قياس الأشكال المعتمدة على فوكسل (VBM) وبواسطة MATLAB كمنصة. ثم تم تحديد عتبة الصور المعالَجة بثلاثة طرق للعثور على أفضل طريقة لتحديد العتبة وهي: أوتسو، ونقطة المنتصف، والتباطؤ. أثبتت طريقة أوتسو أنها أفضل تقنية لتحديد العتبة (2.3801±0.953) مع اختلاف ملحوظ ($p<0.01$) تم اختباره بواسطة ANOVA. تم إجراء عد الصناديق العام وتحليل FFD العام على صور الرنين المغناطيسي في الدماغ بالتزامن مع VBM للعثور على مناطق الدماغ المرنة عصبيا. لم يجد كلا التحليلين اختلافًا إحصائيًا كبيرًا بين أدمغة الحفاظ وأدمغة غير الحفاظ ($p>0.05$)، لم يعثر تحليل VBM أيضًا على أي منطقة دماغية فوكسلية نشطة. وجد التحليل المبني على VOI تسعة مناطق مهمة ($p<0.05$)؛ اثنان لتحليل عد الصناديق العام (التلفيف الزاوي والتلفيف الصدغي الإنسي)، وستة لتحليل FFD (BA20، و BA30، والحزامية الأمامية، والتلفيف المغزلي، والتلف الصدغي السفلي، والفص الجبهي)، وكان هناك منطقة واحدة فقط (BA33) ذات اختلاف كبير في الحجم بين الحفاظ وغير الحفاظ باستخدام التحليل المبني على VOI. BA20 هو جزء من القشرة الصدعية في الدماغ، أما BA30 فيقع في برزخ التلفيف الحزامي، ويقع BA33 في التلفيف الحزامي الأمامي لقشرة الدماغ. تشارك جميع مناطق برودمان هذه بشكل كبير في ترميز وتخزين واسترجاع الذاكرة في البشر. سلطت النتائج الضوء على حساسية التحليل المبني على VOI بسبب التحليل المحلي المستعمل وذلك مقارنة بالتحليل العام لعد الصناديق وFFD. أشارت هذه النتائج إلى إمكانية الكشف عن المرونة العصبية في الدماغ باستخدام التحليل المبني على VOI، وأن المرونة العصبية الناتجة عن عملية الحفظ تحدث في مناطق متعددة في الدماغ، وليس فقط في منطقة واحدة. في الختام تم إثبات قدرة تطبيق التحليل الكسري على الكشف عن حدوث التغيرات الهيكلية في أدمغة الحفاظ مقارنة بأدمغة غير الحفاظ.

# APPROVAL PAGE

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# DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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# ACKNOWLEDGEMENT

Bismillahirrahmannirrahim. Praise and thanks to The Almighty Allah S.W.T for blessing me with strength, grit and determination to finish the research for my PhD thesis. Undertaking this PhD has been a truly life-challenging experience for me, and it would not have been possible to complete without the support and guidance that I received from many people.

I would like to express my countless gratitude to my supervisor, Assoc. Prof. Dr. Mohd. Zulfaezal Che Azemin and co-supervisor, Asst. Prof. Dr. Mohd Izzuddin Mohd Tamrin for their advice, beneficial and constructive comments, patience, and kindness through this whole time guiding me without fail. Sincere thanks are also extended to Assoc. Prof. Dr. Radhiana Hassan for helping me with radiological procedures and allowing me an access to the MRI suite.

I shall thank all the lecturers and staffs from Diagnostic Imaging and Radiotherapy Department (DDIR), especially Br. Abdul Halim Sapuan for helping me with pre-processing procedures, Br. Mohd. Radzuan Md. Noor for image conversion assistance, Assoc. Prof. Dr. Sayed Inayatullah Shah as Head of Department for constantly checking up on me, as well as other lecturers and staffs from Kulliyyah of Allied Health Sciences (KAHS) IIUM, and Department of Radiology from IIUM Medical Centre for your time and kind assistance during data acquisition in your facility. Not to forget Azmir, Azri, Baddrul, Yusri, Hazman, Dr. Zafri, Fadzil, Zairul, Amin, Arshad, Azuwan, Dr. Lokman, Dr. Kamil and many whom I do not mention here, for your continuous support throughout this four year.

Also, sincere thanks to the Ministry of Education (MoE) Malaysia for their continuous financial support.

Lastly, my special appreciation would be to my both parents, my late father Jamaludin bin Dahalan and Hamidah binti Harun, my wife Faizah bin Sapian, Ihsan Faris, Irdina Faqihah, Irham Fariq, siblings, mother in-law and my family for always believe and being thoughtful for every single thing I have done to complete this journey. Millions of thanks for their untold commitment, continuous support and understanding throughout my PhD journey. May each and every single person who involves in this journey, directly or indirectly, is granted with His blessings for this life and hereafter.

Thank you.

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# LIST OF SYMBOLS / SI UNITS

| | |
|---|---|
| cm | Centimetre |
| mm | Millimetre |
| µm | Micrometre |
| ms | Milliseconds |
| mT/m | Millitesla per Metre |
| T/m/s | Tesla per Metre per Second |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| 4G | 4th Generation |
| ALS | Amyotrophic Lateral Sclerosis |
| ANOVA | Analysis of Variance |
| ATI | Array Technology Inc |
| BA | Brodmann Area |
| BA20 | Brodmann Area 20 |
| BA30 | Brodmann Area 30 |
| BA33 | Brodmann Area 33 |
| BC | Box-Counting |
| CAD | Computer Aided Design |
| CSF | CerebroSpinal Fluid |
| CT | Computed Tomography |
| DARTEL | Diffeomorphic Anatomical Registration Through Exponentiated Lie |
| DICOM | Digital Imaging and Communications in Medicine |
| DTI | Diffusion Tensor Imaging |
| FA | Fractal Analysis |
| FD | Fractal Dimension |
| FFD | Fourier Fractal Dimension |
| FWE | Family Wise Error |
| FWHM | Full Width-Half Maximum |
| FOV | Field-of-View |
| GHz | GigaHertz |
| GLM | General Linear Model |
| GM | Gray Matter |
| HD | Hard Disk |
| i.e. | id est |
| IIUM | International Islamic University Malaysia |
| IREC | IIUM Research Ethical Committee |
| IQ | Intelligent Quotient |
| KAHS | Kulliyyah of Allied Health Sciences |
| KPGRC | Kulliyyah PostGraduate and Research Committee |
| LTM | Long-Term Memory |
| MATLAB | Matrix Laboratory |
| MB | Megabytes |

| | |
|---|---|
| MNI | Montreal Neurological Institute |
| MPRAGE | Magnetisation-Prepared Rapid Gradient Echo |
| MRI | Magnetic Resonance Imaging |
| MTL | Medial Temporal Lobe |
| NEMA | The National Electrical Manufacturers Association |
| NIfTI | Neuroimaging Informatics Technology Initiative |
| PET/CT | Positron Emission Tomography/Computerised Tomography |
| RF | Radio-Frequency |
| SAR | Specific Absorbtion Rate |
| SD | Standard Deviation |
| SNR | Signal-to-Noise Ratio |
| SPM | Statistical Parametric Mapping |
| STM | Short-Term Memory |
| TD | Talairach Daemon |
| TIM | Total Imaging Matrix |
| UIAM | Universiti Islam Antarabangsa Malaysia |
| VBM | Voxel-Based Morphometry |
| VOI | Volume-of-Interest |
| WAIS | Weschler Adult Intelligent Scale |
| WFU | Wake Forest University |
| WM | White Matter |

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND OF THE STUDY

The advancement of technology in medical imaging grows rapidly nowadays. Current medical imaging modalities which was scarce 30 years ago such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), are almost easily accessible nowadays. With the availability of modern medical imaging modalities, quality of services provided to the patients in term of radiological services and procedures have increased, leading to the inclining quality of life for human. Advanced medical imaging modalities such as CT and MRI have proven to be the heart of radiological services, providing better radiological images which not only help radiologists to diagnose the disease better, but also predicting the manifestation of the pathology in earlier stage. However, due to the total reliance for visual diagnosis of the radiological images by the radiologists, the time taken for the diagnosis to be made may be compromised, leading to longer decision management for the patient. The timing for diagnosis can be further cut down with the usage of Computer Aided Design (CAD) software such as Voxel-Based Morphometry (VBM) and Fractal Analysis (FA) (Farahibozorg et al., 2015). This software will help the radiologists to make a diagnosis decision based on the algorithm setting depending on the pixels and voxels appearance on the radiological images, reducing their time for visual and manual diagnosis of the radiological images.

FA has been extensively used in clinical and medical fields (Di Ieva et al., 2015). Since its development by Mandelbrot, (1983), FA is capable of representing an estimation of morphological complexity including the brain structure (Liu et al., 2003;

Squarcina et al., 2015; & Zhang et al., 2006). However, the lack of application of FA in characterizing brain structure as compared to its application in detecting pathologies in the brain as well as measuring the impact of aging to the brain. This study intends to evaluate the effectiveness of FA application in measuring the possible increase of plasticity within the brain cortex for huffaz (people who memorise the holy Quran). The study hypothesized that the brain of huffaz is expected to establish increase in plasticity and gray matter volume due to robust process of memorizing the Quran.

Previous study conducted to study the neuroplasticity caused by working memory mostly on ball jugglers (Draganski et al., 2004), medical students (Draganski et al., 2006), professional athletes (Macnamara et al., 2014), musicians (Suárez, Elangovan, & Au, 2016), taxi driver (Maguire et al., 2000) and Vedic scriptures memoriser (Hartzell et al., 2016; Kalamangalam & Ellmore, 2014). Most of these previous studies were conducted using VBM method to analyse the possible plasticity occurrence in the brain cortex. Recent finding by Hartzell et al., (2016) found a notable increase in gray matter and cortical thickness in visual, memory and language region on the Pandit (people who memorise the Vedic Sanskrit Books) brains. They measured and calculated the gray matter and cortical thickness using a well-established VBM method. From this basis, the study of the textual memorization brain structure for huffaz was conducted, with analysis and measurement done using FA application.

## 1.2 STATEMENT OF THE PROBLEM

Currently, there are few textural measures being used to characterize the textual memorization brain structures especially the gray matter. The well-established existing technique to assess the gray matter is VBM (Ashburner & Friston, 2001; Ashburner & Friston, 2000a; Whitwell, 2009). VBM has been vastly used not only for detecting the

pathological appearance (Good et al., 2001) but also for studying the neuroplasticity and brain changes related to working memory as discussed earlier. The aforementioned research works mostly analysed the brain structure using VBM technique (Jednoróg et al., 2015). VBM is an objective and well-established neuroimaging analysis tool for identifying brain morphological alteration in normal and diseased people. As the term implies, it examines the local composition for different brain tissue types on a voxel-by-voxel basis analysis. Another more recent technique is based on complexity measure using fractal analysis technique (Hashemi-Golpayegani et al., 2013; Squarcina et al., 2015). Among applications of FA are on both macroscopic (i.e. anatomic) and microscopic (i.e. histological) images as well as high-resolution radiological imaging (i.e. MRI) (Esteban et al., 2007). Apart from disease detection and measuring the aging effect, FA is also capable of estimating the topological complexity of an object (Di Ieva et al., 2013).

On the other hand, Koch et al., (2016) stated that VBM managed to measure the increased plasticity of the brain structures due to extensive learning. In their study, they detected neuroplasticity changes for the brain that undergoes continuous activity dependent. Hence, since the application of FA especially in studying the textual memorisation and possible increased of brain structure plasticity due to memorisation process is still lacking (Hartzell et al., 2016), this study is conducted in intention to fill such gap.

## 1.3 MOTIVATION OF THE STUDY

The role of FA in clinical application has caught an attention across a number of researchers in recent years. Albeit with the presence of quite a number of researches on its application in clinical and medical fields, there is still lack of discussion and new

information regarding the effectiveness of FA in analyzing textual memorisation brain structures of huffaz.

To date, the application of FA in textual memorisation has still not been extensively investigated yet. Therefore, this research sought to identify and locate the possible brain areas that underwent neuroplasticity changes due to memorisation process, by using the FA.

## 1.4 RESEARCH QUESTIONS

1. Which is the best thresholding techniques for binary conversion of gray scale MRI images between Otsu, midpoint and hysteresis techniques?
2. What are the Brodmann areas detected to be significant between huffaz and non-huffaz by using binary analysis?
3. How many Brodmann areas that differ between huffaz and non-huffaz can be detected when analysis using gray scale being conducted?
4. Which Brodmann areas that differ in volume between huffaz and non-huffaz when analysis using VOI-based being performed?

## 1.5 RESEARCH OBJECTIVES

### 1.5.1 General Objective

To study the textual memorization brain structure using fractal analysis between huffaz and non-huffaz groups.

### 1.5.2 Specific Objectives

1. To explore the effects of three different thresholding techniques (Otsu, midpoint and hysteresis) used on MRI images.

2. To identify specific brain areas that have significant changes due to memorization process according to Brodmann Area by using global binary complexity analysis.

3. To determine Brodmann areas affected by memorization process using global gray-scale complexity analysis.

4. To quantify the volume on brain structures between huffaz and non-huffaz in relation to neuroplasticity changes due to memorisation.

## 1.6 SIGNIFICANCE OF THE STUDY

The importance and originality of this study are that it explores the usage of regional fractal analysis in binary and gray-scale images. By providing the findings from this study, it makes important contribution to the society and medical imaging field by promoting the availability and efficacy of using fractal analysis in helping the radiologist making decision, apart from the current visual diagnosis practice by them.

In general, this study contributes to the recent continuous researches of fractal analysis in mapping and locating the abnormalities in the MRI brain images. Apart from that, this study shows not only fractal analysis is sensitive to detect abnormalities, but it also capable of finding the neuroplasticity dynamics due to memorisation process. This finding is believed to be able to fill the gap in both previous and future literature, as well as providing an exciting opportunity to increase the understanding of fractal analysis methodology and effects.

On the other hand, the subjects used for this study were match with age, gender, IQ level and academic background. The method used in this study can serve as initiation factor for future interest in examining the consequences of memorisation process on the brain.

## 1.7 SCOPE OF THE RESEARCH

Prior commencement of the main study, the brain images were acquired using MRI, and pre-processed using Statistical Parametric Mapping (SPM) under MATLAB platform. The images were then being analysed using General Linear Model by VBM, 2D and 3D Box-Counting Fractal Dimension, 3D Fourier Fractal Dimension and VOI-based analysis. Figure 1.1 summarises the overall experimental research scope and activities.

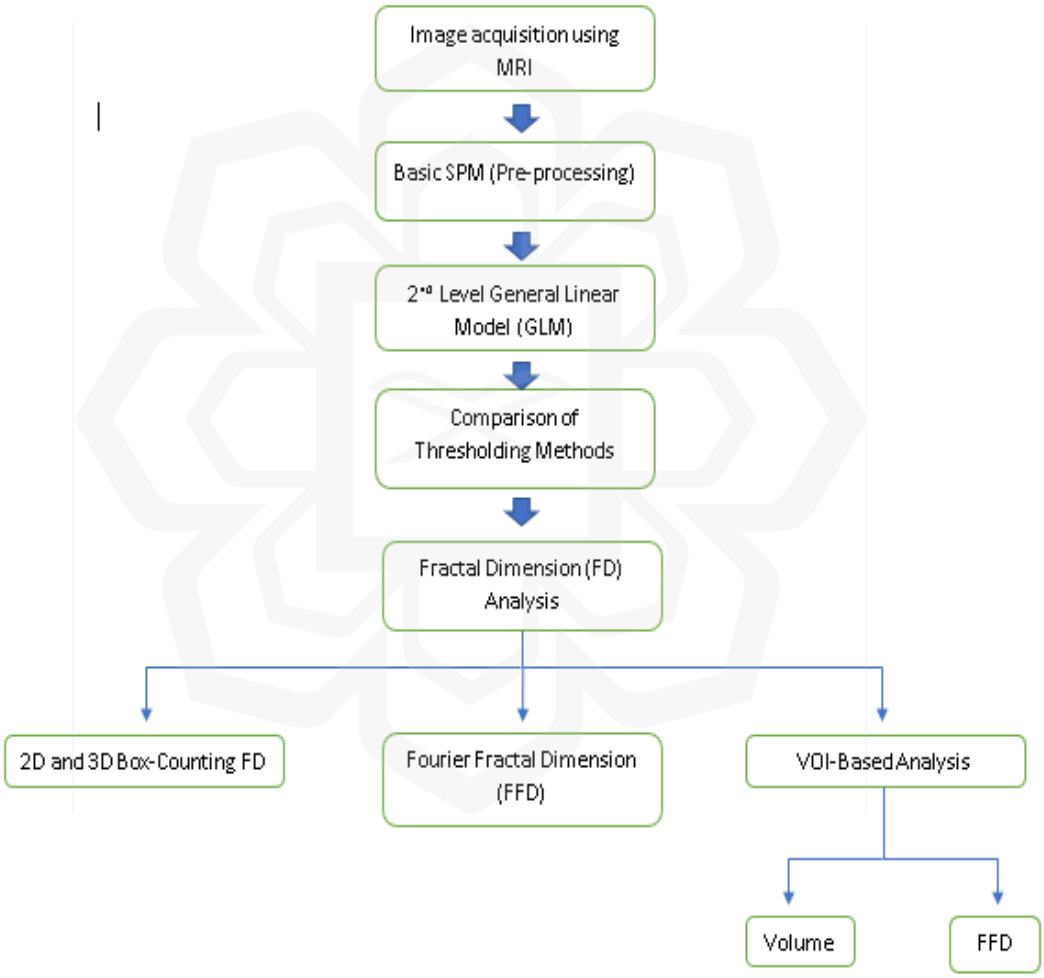


Figure 1.1 Scope of the research activities using Fractal Dimension.

## 1.8 SUMMARY OF METHODOLOGY

Recruitment of 47 volunteers aged between 20 to 25 years for huffaz and non-huffaz group were conducted and divided into two groups, 23 volunteers for huffaz group and 24 volunteers for non-huffaz group. The image acquisition of brain images was scanned using 3 Tesla MRI at Department of Radiology, IIUM Medical Centre for twelve weeks. The brain MRI images were then converted from Digital Imaging and Communications in Medicine (DICOM) into NeuroImaging Informatics Technology Initiative (NIfTI) format at the Radiography Lab, Kulliyyah of Allied Health Sciences IIUM Kuantan Campus before being pre-processed using Statistical Parametric Mapping (SPM). Analysis of the images was conducted using VBM, box-counting fractal analysis (2D and 3D), Fourier Fractal Dimension (FFD) analysis and Volume-of-Interest (VOI)-based analysis under MATLAB platform. The values of fractal dimension obtained were then be tested statistically using two-sample t-test by Statistical Package for Social Sciences (SPSS, version 24.0; IBM-SPSS, Chicago, IL). The details of research methodology will be discussed thoroughly in Chapter Three in this thesis later.

## 1.9 OUTLINE OF THE THESIS

The thesis consists of six chapters. Chapter One opens with introductory content for this study. A brief overview of huffaz, memorisation process, textual brain memorization and fractal analysis will be introduced here. The problem statement, research scope, research questions and research objectives of the study will also be presented in Chapter One. Chapter Two will be the part for literature review of the relevant component with regards to this study. An in-depth analysis of literature especially the fractal analysis contribution in this field will be discussed here. Previous studies that provide the sturdy basis for this study will also be presented, discussed, criticised and analysed. This will