

DOCTORAL THESIS

Data-driven Approaches to Improved Understanding of Brain-behaviour Relationships

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Abstract

The question of how the brain works has been the core interest of neuroscientists. To address this question, studies have been done to investigate the brain mechanism to receive, process, and transmit information. One of the approaches is to develop neuronal models to directly capture the microscopic activities and dynamics of the brain. Another approach emerges by explaining the brain organization to control human cognitive abilities as the mental expression of human behaviors which differ across individuals. This research direction has attracted scientists from different fields and is commonly known as brain-behavior relationships. In its development, this topic receives support from the advanced technology of brain imaging and behavioral tests, resulting in the availability of big and freely accessible data. Coupled with the development of mathematical techniques, recent perspective of brain-behavior study has shifted into data-driven approach which emphasizes on data exploration rather than initial hypothesis validation. Thus, some questions arise: (i) to ask whether data-driven approach in brain-behavior study, aside from providing new information, is also able to consistently capture the previously established knowledge at the level of single and multiple behaviors, (ii) towards its complexity, to inquire whether data-driven approach based on nonlinear model performs better than linear model in prediction and feature extraction, and (iii) to develop a general framework of fully nonlinear data-driven approach to improved the understanding of brain-behavior relationships.

This thesis answers the first inquiry in Chapter 3 and Chapter 4 for single and multiple behaviors, respectively. In single behavior, a study on reading ability is performed by predicting the reading performance using brain structural and functional properties coming from brain area and connections measures. Aside from the prediction performances of reading ability, the study also interprets the features extracted from

linear data-driven method. Interestingly, the features presented as reading-related brain areas confirm the reading areas established in the literature and provide more understanding on the involvement of motor cortex in reading ability. Chapter 4 focuses on the comparison between cognitive abilities structure explored from the brain properties with the one established from hypothesis of performance covariance in multiple behaviors. Similarly, this study also shows the consistency of the data-driven approaches compared to hypothesis-driven approaches and reveals some interpretable dissimilarities in terms of cognitive ability structure.

Research in Chapter 5 and Chapter 6 are carried out to address inquiries 2 and 3 focusing on the methods in data-driven approach. Chapter 5 systematically compares linear and nonlinear models to study the brain and behavior relationships. Engaging linear correlation and regression for the linear model and artificial neural network for nonlinear model, this study shows that the mapping between brain and behavior is better captured by nonlinear relationships. Further, the analyses on the features of both models reveal that the consistently captured features by both models are interpretable and relevant with the previous studies. In addition, the nonlinear model is also able to capture more interpretable features not identified in the linear model. Motivated by this finding, Chapter 6 proposes a framework to implement fully nonlinear data-driven approach towards improved understanding of brain-behavior relationships. This study recruits Graph Neural Networks, t-distributed Stochastic Neighbor Embedding, and k-Means Clustering to find brain clusters based on its structural properties. The proposed framework shows promising results. First, the structural clusters are partially consistent with the Resting State Networks identified from functional brain properties. Second, the structural properties of the brain belonging to each cluster similarly performs well to predict the performance of behavioral measures. Lastly, the wide variety of the

behavioral measures which can be predicted by the clusters suggests that the clusters may reflect how the cognitive functions are organized in the brain.

Altogether, this thesis shows the advantages of using data-driven approach to study brain-behavior relationships in single and multiple behavior levels. It also suggests that exploration using nonlinear approaches may provide better mapping and more interpretable features in brain and behavior studies.

Table of Contents

DECLARATION	i
Abstract	ii
Acknowledgements	v
Table of Contents	vi
List of Tables	xi
List of Figures	xii
List of Abbreviations	xiv
Chapter 1 Introduction	1
1.1 Background	1
1.1.1. Human Brain and Behaviors	1
1.1.2. The State of the Art of Brain and Behavior Studies	4
1.1.3. Data-Driven Approaches Towards the Understanding of Brain and Behavior Relationships	8
1.1.4. The Advances of Mathematical Non-Linear Modeling to Map Brain and Behavior Relationships	11
1.2 Open Questions	14
1.3 Objectives	15
1.3.1. To predict reading ability from brain structural and functional properties	16

1.3.2. To explore cognitive ability structure nested in brain anatomical properties	16
1.3.3. To compare linear and nonlinear models in prediction of behavioral outcomes from brain properties	17
1.3.4. To use graph neural network for brain clustering and interpretation	18
Chapter 2 Human Connectome Project (HCP) Database	20
2.1 Overview	20
2.2 Brain Parcellation	20
2.3 Structural MRI	22
2.4 Diffusion MRI	24
2.5 Functional MRI	25
2.6 Behavioral Data	26
Chapter 3 Predicting Reading Ability from Brain Anatomy and Function: From Areas to Connections	30
3.1 Chapter Introduction	30
3.2 Materials and Methods	32
3.2.1. Materials	32
3.2.2. Methods	34
3.3 Results	45
3.3.1. Predicting Reading Ability from Whole Brain Measures	45
3.3.2. Reading Networks Identified by Reading-Related Features in Area Measures	48

3.3.3. Reading-Related Connections.....	49
3.4 Discussion and Conclusion	57
Chapter 4 What the Structural Brain Properties Tell Us about the Ontology of Human Intelligence	69
4.1 Chapter Introduction	69
4.2 Materials and Methods.....	72
4.2.1. Materials	72
4.2.2. Methods.....	74
4.3 Results.....	79
4.3.1. Task-Related Brain Areas	79
4.3.2. Ontologies of human intelligence derived from psychometric and brain properties.....	84
4.3.3. Brain areas corresponding to the inferred abilities of brain-based ontology	91
4.3.4. Structural connection analysis on ability-related brain areas	95
4.4 Discussion and Conclusion	96
Chapter 5 Predicting Task Performances from Brain Structural Properties: Linear vs Non-Linear Approach.....	105
5.1 Chapter Introduction	105
5.2 Materials and Methods.....	107
5.2.1. Materials	107
5.2.2. Methods.....	107

5.3 Results.....	114
5.3.1. Performance Comparisons of Linear and Nonlinear Models	114
5.3.2. The Overlapping of Task-Related Brain Areas Identified from Linear and Nonlinear Models.....	116
5.4 Discussion and Conclusion.....	118
Chapter 6 Functionally Relevant Clusters of Brain Areas from Graph Neural Network	123
6.1 Chapter Introduction	123
6.2 Materials and Methods.....	125
6.2.1. Materials	125
6.2.2. Methods.....	126
6.3 Results.....	132
6.3.1. Brain Clusters Identified from Structural Area and Connection Measures	132
6.3.2. Prediction Performances of Structural Brain Clusters	133
6.3.3. Comparison of the Brain Structural Clusters with the Ability Factors Identified in Chapter 4	136
6.4 Discussion and Conclusion.....	137
Chapter 7 Summary and Outlook.....	140
7.1 Summary.....	140
7.2 Limitation and Outlook.....	143
References.....	145

Curriculum Vitae 167

List of Tables

Table 2.1. Area names in the MMP atlas.....	21
Table 2.2. Behavioral measures in terms of cognitive tasks sampled from HCP database.....	26
Table 3.1. Prediction Results using (a) LOOV and (b) novel-prediction.	46
Table 4.1. Cognitive tasks and associated domain specific abilities.	73
Table 4.2. Task-related brain areas in MMP atlas	82
Table 4.3. Summary of CFA and EFA model fit estimated to identify brain derived ontological entities of human intelligence.	86
Table 4.4. Standardized factor loadings and factor correlations of CFA applied in task scores correlation matrix.....	86
Table 4.5. The result of Chi-square difference test to determine the number of factors in EFA.	87
Table 4.6. Standardized factor loading and factor correlations estimated by EFA applied on the positive IOU matrix.....	89
Table 4.7. Standardized factor loading and factor correlations estimated by EFA applied on the negative IOU matrix.....	90
Table 4.8. The comparison of brain-based ontologies using $p < .05$ and $p < .01$ thresholds.	91
Table 4.9. Brain areas corresponding to the ontological entities.....	95
Table 5.1. The performance comparison of ANN with different number of neurons.....	111
Table 6.1. The best five predicted task performances by each brain structural clusters.	136

List of Figures

Figure 1.1. Illustration of brain anatomy and the structural features.....	1
Figure 1.2. Structure of cognitive abilities based on CHC theory.....	4
Figure 1.3. Brain areas and networks related to behavioral outcomes.....	6
Figure 1.4. Hypothesis-driven and data-driven approaches to study brain-behavior relationships.....	11
Figure 1.5. Open questions arising from the overview of brain-behavior study.....	15
Figure 2.1. The MMP brain atlas.....	22
Figure 2.2. Illustration of structural, diffusion, and functional MRI.....	26
Figure 3.1. The full pipeline of the methods used in this study.....	37
Figure 3.2. Correlations of the measures of reading-related areas with reading scores across participants.....	39
Figure 3.3. Correlations between brain properties across participants.....	41
Figure 3.4. Prediction of reading scores using structural and functional brain measures.....	45
Figure 3.5. Reading networks obtained from area measures.....	51
Figure 3.6. Reading networks illustrated as circular graphs.....	52
Figure 3.7. Correlation of brain measures across participants between core areas from positive and negative networks.....	53
Figure 3.8. Reading-related connection density.....	54
Figure 3.9. Matrices of reading-related connections in the 44-atlas.....	55
Figure 3.10. Brain-visualized connection matrices.....	57
Figure 3.11. Reading networks developed from training participant excluding the left-handed participants ($Nr = 458$).....	65
Figure 4.1. Depiction of full framework of the present work.....	79

Figure 4.2. Task-related brain areas and their distribution.	82
Figure 4.3. Illustration of correlation matrix, positive IOU matrix, and negative IOU matrix.	85
Figure 4.4. Scree plots of factor analyses.	86
Figure 4.5. Comparison of psychometrics-based and brain-based ontologies of human intelligence.	89
Figure 4.6. Brain areas corresponding to the ontological entities.	94
Figure 4.7. Comparison of the structural connection density of ability-related brain areas (core areas) to that among the other task-related areas (extended areas).	96
Figure 5.1. The architecture of the ANNs.	110
Figure 5.2. The prediction results of cognitive task scores from linear and nonlinear models.	115
Figure 5.3. The prediction results of latent ability scores from linear and nonlinear models.	116
Figure 5.4. The overlapping features between linear and non-linear models.	119
Figure 6.1. Framework of the present study.	126
Figure 6.2. The unsupervised training process of GNN.	129
Figure 6.3. Brain structural clusters and comparison with functional clusters.	133
Figure 6.4. The performance of brain clusters to predict behavioral measures.	135
Figure 6.5. The comparison of ability factors and brain clusters.	137