

UNDERSTANDING NEURAL CORRELATES OF OBJECT RECOGNITION

SHEFALI GUPTA



DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2024

UNDERSTANDING NEURAL CORRELATES OF OBJECT RECOGNITION

by

SHEFALI GUPTA

Department of Electrical Engineering

Submitted

in the fulfillment of the requirements for the degree of

Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2024

*Dedicated to **my family**.....*

"The eye sees only what the mind is prepared to comprehend."

—Robertson Davies

"The important thing is to not stop questioning. Curiosity has its own reason for existing."

— Albert Einstein

The purpose of life is not to be happy. It is to be useful, to be honorable, to be compassionate, to have it make some difference that you have lived and lived well."

— Ralph Waldo Emerson

"The greatest glory in living lies not in never falling, but in rising every time we fall."

— Nelson Mandela

"Success is not the key to happiness. Happiness is the key to success. If you love what you are doing, you will be successful."

— Albert Schweitzer

"Research is to see what everybody else has seen, and to think what nobody else has thought."

— Albert Szent-Gyorgyi

Certificate

This is to certify that the thesis titled “**Understanding Neural Correlates of Object Recognition**” being submitted by **Shefali Gupta** to the **Department of Electrical Engineering**, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of the original, bonafide research work carried out by her under our supervision and guidance. In our opinion, the thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The work presented in this thesis has not been submitted elsewhere, either in part or in full, for the award of any degree or diploma to the best of our knowledge.

Prof. Tapan Kumar Gandhi

Department of Electrical Engineering
Indian Institute of Technology Delhi
New Delhi-110016, India

Prof. Pawan Sinha

Dept. of Brain and Cognitive Sciences
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA

Acknowledgements

I would like to express my heartfelt gratitude to my supervisors, **Prof. Tapan Kumar Gandhi** and **Prof. Pawan Sinha**, for their unwavering support, invaluable guidance, and constant encouragement throughout my PhD journey. Their expertise, patience, and mentorship have been instrumental in shaping my research and personal growth. I consider myself fortunate to have had the opportunity to work under the mentorship of these two outstanding individuals.

I am deeply grateful to Prof. Tapan for believing in me and granting me the opportunity to be a part of his research lab. His confidence in my abilities has been a source of inspiration and motivation throughout my journey. His guidance and support have been instrumental in my growth as a researcher. Prof. Tapan's encouragement has not only helped me overcome challenges but has also pushed me to strive for excellence in all my endeavors. Working under his mentorship has been a transformative experience, and I am immensely thankful for the valuable insights and knowledge he has imparted to me.

I feel truly blessed and lucky to have the opportunity to work with Prof. Pawan. I am incredibly grateful to Tapan Sir for introducing me to him. I still vividly remember meeting Prof. Pawan for the first time on January 5, 2018, at Shroff Hospital. Before the meeting, I was quite nervous, but his kind words and demeanor transformed that day into one of the best days of my life. I was astonished by how humble, kind, and simple a professor from MIT could be. It's always a pleasure to be around him. He is such an amazing and wonderful person who genuinely cares for everyone he knows. I will cherish the time I have spent with him and the MIT science team for the rest of my life.

I express my gratitude to the members of my SRC committee, Professor Sumantra Dutta Roy, Professor Lalan Kumar, and Professor Amit Mehndiratta, for their insightful suggestions, constructive feedback, and encouragement at every stage of my research. Their expertise and guidance have immensely enriched my work. Their suggestions have consistently guided me forward on my research journey.

I am thankful to all my labmates from the Multimedia Lab, specifically Shubham Choudhary, for the numerous discussions about research and life. Your insights and camaraderie have been invaluable throughout this journey. My heartfelt thanks also go to all my labmates from the Neurocomputing Lab, including Sapna, Raghav, Rohit, Kritika, Dr. Rijul, Chandra Bhushan, Shipra, Anupam, Dr. Sidharth Gautam, Aashirbad, Amit, Dr.

Taranjit, and Dr. Chetan. I am especially grateful to Sapna and Raghav for their valuable feedback on proofreading my work, which has greatly improved its quality.

I am profoundly grateful to Prof. Tapan and Prof. Pawan for involving me in Project Prakash. Working with the Project Prakash MIT Science team, including Sharon Gilad-Gutnick, Shlomit Ben-Ami, Sruti Raja, and many others, has been an enriching and rewarding experience. From collecting data to recording for various media platforms, this journey has been unforgettable and has significantly shaped my academic and personal growth.

I also want to thank everyone from Shroff Charity Eye Hospital (Project Prakash unit), including Dr. Priti, Shakeela Bi, Rakesh, Ajay, and Abhishek, for the coordination and support required to work with Project Prakash subjects. It was always a pleasure to work with all the Project Prakash participants, whose involvement was crucial to the success of the research.

Additionally, I would like to express my sincere appreciation to all the participants who generously contributed their time and efforts to my research studies. Without their cooperation, this work would not have been possible. Special thanks are due to the Ethical Committee of IIT Delhi for approving the experimental protocols and ensuring the ethical conduct of my research.

I would also like to acknowledge the role of my family and friends outside the academic sphere. Their unwavering support, patience, and encouragement have been a constant source of strength. My family's belief in my abilities has always motivated me to strive for excellence, and my friends' understanding and patience have allowed me to dedicate the necessary time and effort to my studies without feeling isolated.

This PhD journey has been a challenging yet immensely rewarding experience, and I am grateful to everyone who has been a part of it. Finally, I extend my deepest thanks to all those who, in one way or another, have played a role in my academic journey but whose names may not appear here. Your support, however indirect, has been invaluable and is deeply appreciated.

This experience has been a time of not only academic growth but also personal development. Each challenge and success has contributed to shaping me into a better researcher and individual. To everyone who has been a part of this journey, thank you for your unwavering support and encouragement.

Shefali Gupta

Abstract

Object perception refers to the process by which an organism recognizes, interprets, and understands objects in its environment. It involves the brain's ability to take in sensory information from the surroundings, such as visual, auditory, tactile, or other sensory inputs, and make sense of these inputs to identify and understand objects. Object perception is crucial for various cognitive processes, including navigation, social interactions, problem-solving, and everyday tasks. It involves complex interactions between sensory systems, brain regions, and cognitive processes to create a coherent and meaningful representation of the world. This thesis primarily focuses on understanding the neural underpinning of object perception in the brain. The main objective is to evaluate how the brain learns to see and perceive an object.

A pivotal question emerges concerning whether object recognition abilities are predominantly inherent or influenced by environmental factors. In other words, it unfolds an inquiry into how experience-dependent plasticity shapes object recognition skills compared to the potential contribution of innate neural structures that facilitate particular aspects of object recognition. We are presented with a unique opportunity to work with individuals from 'Project Prakash'. This initiative uniquely combines the humanitarian goal of restoring sight to curably blind children with the scientific objective of investigating fundamental questions about brain development and visual learning.

In this thesis, we have attempted to understand the neural mechanism of object recognition in detail using electrophysiological techniques, i.e. EEG on different subject groups, viz., healthy controls and Project Prakash subjects. The healthy controls were the participants with normal sight. We explored two facets of object perception in the two groups: basic structure perception, encompassing perceptual grouping ability, and complex structure perception, involving face perception ability.

These unique Project Prakash subjects were assessed in two dimensions: firstly, by examining the evolution of object perception skills following extended periods of post-surgical visual experiences, and secondly, by monitoring the development of object recognition skills in post-surgery and follow-up assessments. In the first case, they are referred to as long-term subjects (LTS), and in the second case, they are called newly-sighted subjects (NSS). Our focus is on investigating whether congenitally blind children, treated several years after birth, possess the capacity to perceive and comprehend objects in a manner congruent with that of typically sighted children. Moreover, our studies highlight

whether these abilities are innate or acquired through experience, while also addressing the significance of a sensitive period in their development.

Firstly, this thesis examines how perceptual grouping ability develops for LTS over extended periods following visual surgery. Participants who had undergone cataract surgery were exposed to images containing structured and non-structured elements and were tasked with identifying structures within them. Healthy individuals of similar age, social, and economic backgrounds were included as controls. EEG data was collected from both the cataract group and the control group, and the resulting ERPs were analyzed to identify different ERP components. Our findings reveal high brain activation in response to structured stimuli, indicating enhanced perceptual grouping compared to random stimuli. This suggests the acquisition of perceptual grouping skills among those who underwent surgery between one to five years prior to the study.

Our work also investigates the development of face (i.e., complex object) perception ability in NSS (i.e., visually deprived children after visual restoration surgery). Analysis of ERP responses from occipito-temporal electrodes in these subjects reveals an ability to discriminate faces from objects post-surgery, with this capability improving over time. Interestingly, the ERP responses of these subjects converge towards those of healthy individuals as time progresses, indicating significant enhancements in face categorization abilities after vision restoration interventions among previously visually impaired individuals. These improvements manifest in various aspects, including visual acuity, behavioral responses, and EEG patterns observed in Project Prakash subjects. These findings suggest that the development of face perception ability may be influenced by experience rather than solely relying on early visual input.

The thesis aims to comprehend object recognition processes in the brain, utilizing EEG and behavioral experiments to gather relevant brain signals and understand basic and complex object perception. Conclusions drawn from ERP, functional connectivity, and acuity results imply that object perception abilities may be influenced by experiences and environmental factors beyond early visual exposure, offering avenues for further exploration into how experiences shape complex object perception, particularly in cases with limited early visual input. The thesis suggests utilizing data from these unique subjects for future investigations, enriching the understanding of the interplay between experience, brain function, and object perception. The collected data from these unique subjects holds the potential to address even more intriguing questions.

सार

वस्तु धारणा (ऑब्जेक्ट परसेप्शन) उस प्रक्रिया को संदर्भित करती है जिसके माध्यम से एक जीव अपने वातावरण में वस्तुओं को पहचानता, व्याख्या करता और समझता है। इसमें मस्तिष्क की यह क्षमता शामिल होती है कि वह अपने परिवेश से दृश्य, श्रवण, स्पर्श या अन्य संवेदी इनपुट जैसी संवेदी जानकारी ले और इन इनपुट्स का उपयोग करके वस्तुओं की पहचान और समझ कर सके। वस्तु धारणा विभिन्न संज्ञानात्मक प्रक्रियाओं के लिए महत्वपूर्ण है, जिसमें नेविगेशन, सामाजिक संपर्क, समस्या-समाधान, और दैनिक कार्य शामिल हैं। इसमें संवेदी प्रणालियों, मस्तिष्क क्षेत्रों और संज्ञानात्मक प्रक्रियाओं के बीच जटिल अंतःक्रियाएँ शामिल होती हैं ताकि दुनिया का एक सुसंगत और सार्थक प्रतिनिधित्व तैयार किया जा सके। यह शोध प्रबंध मुख्य रूप से मस्तिष्क में वस्तु धारणा की तंत्रिका आधार को समझने पर केंद्रित है। मुख्य उद्देश्य यह मूल्यांकन करना है कि मस्तिष्क वस्तु को देखना और समझना कैसे सीखता है। एक महत्वपूर्ण प्रश्न उभरता है कि क्या वस्तु पहचान की क्षमताएँ मुख्य रूप से जन्मजात होती हैं या पर्यावरणीय कारकों से प्रभावित होती हैं। दूसरे शब्दों में, यह सवाल उठता है कि अनुभव-निर्भर लचीलापन (एक्सपीरियंस-डिपेंडेंट प्लास्टिसिटी) वस्तु पहचान की क्षमताओं को कैसे आकार देता है, इसकी तुलना में कि किस हद तक जन्मजात तंत्रिका संरचनाएँ (न्यूरल स्ट्रक्चर) वस्तु पहचान के विशिष्ट पहलुओं को सुगम बनाती हैं। हमें 'प्रोजेक्ट प्रकाश' के अंतर्गत व्यक्तियों के साथ काम करने का एक अनूठा अवसर मिला है। यह पहल उन बच्चों की दृष्टि बहाल करने के मानवीय लक्ष्य को वैज्ञानिक उद्देश्य के साथ अद्वितीय रूप से जोड़ती है जो इलाज योग्य अंधे हैं, और साथ ही मस्तिष्क विकास और दृश्य अधिगम (विसुअल लर्निंग) के बारे में बुनियादी सवालों की जांच करता है। इस शोध प्रबंध में, हमने विभिन्न विषय समूहों पर विद्युत् शरीर क्रियाविज्ञान तकनीकों (जैसे एलेक्ट्रोएन्सेफेलोग्राफी (ईईजी)) का उपयोग करके वस्तु पहचान के तंत्रिका तंत्र को विस्तृत रूप से समझने का प्रयास किया है, जिसमें स्वस्थ नियंत्रण समूह और प्रोजेक्ट प्रकाश के विषय शामिल हैं। स्वस्थ नियंत्रण वे प्रतिभागी थे जिनकी दृष्टि सामान्य थी, जबकि प्रोजेक्ट प्रकाश के विषय वे बच्चे थे जिनकी दृष्टि बहाल की गई थी। हमने दोनों समूहों में वस्तु धारणा के दो पहलुओं का अध्ययन किया: मूलभूत संरचना धारणा, जिसमें धारणा समूहण क्षमता (पर्सपेक्टिव गुपिंग एबिलिटी) शामिल है, और जटिल संरचना धारणा, जिसमें चेहरे की पहचान क्षमता (फेस परसेप्शन एबिलिटी) शामिल है। इस अध्ययन का उद्देश्य यह समझना है कि स्वस्थ और दृष्टि बहाल किए गए व्यक्तियों के बीच वस्तु पहचान कैसे भिन्न होती है और तंत्रिका तंत्र इसमें क्या भूमिका निभाता है। इन अनूठे प्रोजेक्ट प्रकाश विषयों का मूल्यांकन दो आयामों में किया गया: सबसे पहले, शल्य चिकित्सा के बाद विस्तारित अवधियों के दृश्य अनुभवों के बाद वस्तु धारणा कौशल के विकास की जांच करके, और दूसरा, शल्य चिकित्सा के बाद और अनुवर्ती मूल्यांकन में वस्तु पहचान कौशल के विकास की निगरानी करके। पहले मामले में, उन्हें दीर्घकालिक विषय (एलटीएस) कहा जाता है, और दूसरे मामले में, उन्हें नवदृष्ट विषय (एनएसएस) कहा जाता है। हमारा ध्यान इस बात की जांच पर है कि जन्मजात दृष्टिहीन बच्चे, जिन्हें जन्म के कई साल बाद उपचारित किया गया है, क्या वस्तुओं को देखने और समझने की क्षमता रखते हैं जो सामान्य दृष्टि वाले बच्चों के समान होती है। इसके अलावा, हमारे अध्ययन यह भी स्पष्ट करते हैं कि क्या ये क्षमताएं जन्मजात हैं या अनुभव के माध्यम से अधिग्रहित की जाती हैं, साथ ही उनके विकास में एक संवेदनशील अवधि के महत्व को भी संबोधित करते हैं। इन अनूठे प्रोजेक्ट प्रकाश विषयों का मूल्यांकन दो आयामों में किया गया: सबसे पहले, शल्य चिकित्सा के बाद विस्तारित अवधियों के दृश्य अनुभवों के बाद वस्तु धारणा कौशल के विकास की जांच करके, और दूसरा, शल्य चिकित्सा के बाद और अनुवर्ती मूल्यांकन में वस्तु पहचान कौशल के विकास की निगरानी करके। पहले मामले में, उन्हें दीर्घकालिक विषय (एलटीएस) कहा जाता है, और दूसरे मामले में, उन्हें नवदृष्ट विषय (एनएसएस) कहा जाता है। हमारा ध्यान इस बात

की जांच पर है कि जन्मजात दृष्टिहीन बच्चे, जिन्हें जन्म के कई साल बाद उपचारित किया गया है, क्या वस्तुओं को देखने और समझने की क्षमता रखते हैं जो सामान्य दृष्टि वाले बच्चों के समान होती है। इसके अलावा, हमारे अध्ययन यह भी स्पष्ट करते हैं कि क्या ये क्षमताएं जन्मजात हैं या अनुभव के माध्यम से अधिग्रहित की जाती हैं, साथ ही उनके विकास में एक संवेदनशील अवधि के महत्व को भी संबोधित करते हैं।

हमारा कार्य नवदृष्ट विषयों (एनएसएस) में चेहरे (यानी जटिल वस्तु) धारणा क्षमता के विकास की भी जांच करता है, जो दृश्य पुनर्स्थापना सर्जरी के बाद दृश्य से वंचित बच्चे हैं। इन विषयों में ऑक्सिपिटो-टेम्पोरल इलेक्ट्रोड्स से प्राप्त ईआरपी प्रतिक्रियाओं का विश्लेषण दर्शाता है कि सर्जरी के बाद यह बच्चे चेहरों और वस्तुओं के बीच अंतर करने की क्षमता रखते हैं, और समय के साथ यह क्षमता सुधरती जाती है। दिलचस्प बात यह है कि इन विषयों की ईआरपी प्रतिक्रियाएं समय के साथ स्वस्थ व्यक्तियों की प्रतिक्रियाओं के समान होती जाती हैं, जिससे संकेत मिलता है कि दृश्य पुनर्स्थापना हस्तक्षेपों के बाद पूर्व दृष्टिहीन व्यक्तियों में चेहरे की श्रेणीकरण क्षमताओं में महत्वपूर्ण सुधार होता है। ये सुधार विभिन्न पहलुओं में दिखाई देते हैं, जिसमें दृश्य तीक्ष्णता, व्यवहारिक प्रतिक्रियाएं, और प्रोजेक्ट प्रकाश विषयों में देखे गए ईईजी पैटर्न शामिल हैं। ये निष्कर्ष सुझाव देते हैं कि चेहरे की पहचान क्षमता का विकास प्रारंभिक दृश्य इनपुट पर निर्भर रहने के बजाय अनुभव से प्रभावित हो सकता है।

यह थीसिस मस्तिष्क में वस्तु पहचान प्रक्रियाओं को समझने का उद्देश्य रखती है, जिसके लिए ईईजी और व्यवहारिक प्रयोगों का उपयोग किया गया है ताकि संबंधित मस्तिष्क संकेतों को एकत्र किया जा सके और मूलभूत और जटिल वस्तुओं (बेसिक एंड काम्प्लेक्स ऑब्जेक्ट्स) की धारणा को समझा जा सके। ईआरपी, फंक्शनल कनेक्टिविटी, और तीक्ष्णता (एक्यूटी) के परिणाम से निकाले गए निष्कर्ष इस इशारे करते हैं कि वस्तु पहचान क्षमताएं प्रारंभिक दृश्य प्रवेश से परे अनुभव और पर्यावरणीय कारकों से प्रभावित हो सकती हैं, जो जटिल वस्तु पहचान में कैसे अनुभवों का निर्माण करते हैं उसे और अधिक अध्ययन के लिए मार्ग प्रस्तुत करते हैं, विशेष रूप से उन मामलों में जहां प्रारंभिक दृश्य प्रवेश सीमित होता है। यह थीसिस सुझाव देती है कि इन अद्वितीय विषयों से प्राप्त डेटा का भविष्य के लिए अध्ययन उच्चतम करने के लिए उपयोग किया जाए, जिससे अनुभव, मस्तिष्क कार्य, और वस्तु धारणा (ऑब्जेक्ट परसेप्शन) के बीच के संबंध को समझा जा सके। इन अद्वितीय विषयों से संकलित डेटा और भी रोमांचक प्रश्नों का समाधान करने की संभावना रखता है।

Contents

Certificate	i
Acknowledgements	ii
Abstract	v
सार	vii
Contents	ix
List of Figures	xiii
List of Tables	xxv
Abbreviations	xxvii
1 Introduction	1
1.1 Introduction	1
1.2 Related Works	4
1.2.1 Object Perception	4
1.2.2 Perception to basic structures or Perceptual Grouping	5
1.2.3 Perception to complex structures or Faces	6
1.2.4 Critical Period for Object Learning	7
1.2.5 Why EEG?	9
1.2.5.1 EEG Technology and Apparatus setup	10
1.2.5.2 Subjects	11
1.2.6 Functional Connectivity	13
1.2.7 Graph Theoretical Analysis	14
1.3 Motivation	15
1.4 Aims and Objectives	16
1.5 Ethics Statement	17
1.6 Thesis Organisation	18
2 Understanding Neural Underpinning of Object Perception	21
2.1 Introduction	21

2.2	Study 1: Understanding Human Perception to Basic Structure	22
2.2.1	Participant Screening	23
2.2.2	Behavioral Experiment Protocol	23
2.2.3	ERP Experiment Design	24
2.2.4	Experiment Protocol	24
2.2.5	Understanding Neural Underpinning of Perceptual Grouping	25
2.2.5.1	EEG Pre-processing	25
2.2.5.2	ERP Analysis	26
2.2.5.3	Results	27
2.2.5.4	Discussion	32
2.2.6	Hemispherical Processing of Perceptual Grouping in the Human Brain	33
2.2.6.1	EEG Preprocessing	33
2.2.6.2	ERP Analysis	34
2.2.6.3	Results	34
2.2.6.4	Discussion	39
2.3	Study 2: Understanding Human Perception to Complex Objects	40
2.3.1	Participant Screening	40
2.3.2	Behavioral Experiment Protocol	40
2.3.3	ERP Experiment Design	40
2.3.4	Experiment Protocol	41
2.3.5	Hemispherical Processing of Face Perception in the human brain	42
2.3.5.1	EEG Preprocessing	42
2.3.5.2	ERP Analysis	42
2.3.5.3	Results	42
2.3.5.4	Discussion	44
2.4	Summary	44
3	Beyond ERP: Functional Connectivity and Graph Theoretical Analysis	47
3.1	Introduction	47
3.2	Concept of Functional Connectivity and Graph Theoretical Analysis	48
3.2.1	Functional Connectivity using PLV	49
3.2.2	Graph Theoretical Analysis	50
3.2.2.1	Weighted Graph Analysis	50
3.2.2.2	Binary Graph Analysis	53
3.2.2.3	MST Graph Analysis	53
3.3	Study 1: Understanding Human Perception to Basic Structures	54
3.3.1	Functional Connectivity and Graph Theoretical Analysis for Perceptual Grouping	54
3.3.1.1	Results	55
3.3.1.2	Discussion	58
3.3.2	Hemispherical Functional Connectivity for Perceptual Grouping	59
3.3.2.1	Results	59
3.3.2.2	Discussion	62
3.4	Study 2: Understanding Human Perception to Complex Objects	63

3.4.1	Functional Connectivity and Graph Theoretical Analysis for Face Perception	63
3.4.1.1	Dynamic Functional Connectivity for Face Perception	64
3.4.1.2	Results	64
3.4.1.3	Discussion	68
3.4.2	MST Dynamic Functional Connectivity for Face Perception	71
3.4.2.1	Dynamic MST Network Measures Analysis	72
3.4.2.2	Results	72
3.4.2.3	Discussion	74
3.5	Summary	80
4	Development of Object Perception Ability after Longer Periods of Post-operative Visual Experience	83
4.1	Introduction	83
4.1.1	Project Prakash	86
4.2	Understanding Long-Term Subjects' Perception of Basic Objects	88
4.2.1	Participant Screening	88
4.2.1.1	Experimental Subjects	88
4.2.1.2	Age-matched Healthy Control Subjects	89
4.2.2	Behavioral Experiment Protocol	89
4.2.3	ERP Experiment Design	90
4.2.4	Experiment Protocol	90
4.2.5	ERP Analysis of Long-Term Subjects	91
4.2.6	GERP Analysis	92
4.2.7	Acuity	92
4.3	Results and Discussion	93
4.3.1	Behavioral results	93
4.3.2	ERP results	94
4.3.3	ERP Component Amplitude Comparison	102
4.3.4	GERP results	104
4.3.5	Acuity	106
4.3.6	Discussion	107
4.4	Understanding Long-Term Subjects' Perception of Complex Objects	108
4.4.1	Participant Screening	108
4.4.1.1	Experimental Subjects	108
4.4.1.2	Age-matched Healthy Control Subjects	109
4.4.2	Behavioral Experiment Protocol	109
4.4.3	ERP Experiment Design	110
4.4.4	Experiment Protocol	110
4.4.5	ERP Analysis of Long-Term Subjects	111
4.4.6	Functional Connectivity Analysis	111
4.4.7	Acuity	112
4.5	Results and Discussion	113
4.5.1	Behavioral results	113

4.5.2	ERP results	114
4.5.3	Right Hemisphere dominance	115
4.5.4	N170 Amplitude Comparison	116
4.5.5	N170 Latency Comparison	119
4.5.6	Functional Connectivity Comparison	120
4.5.7	Acuity	122
4.5.8	Discussion	123
4.6	Summary	125
5	Tracking Development of Object Perception Ability after Sight Onset	127
5.1	Introduction	127
5.2	Understanding Newly Sighted Subjects' Perception of Complex Objects . .	129
5.2.1	Participant Screening	129
5.2.1.1	Prakash Subjects	129
5.2.1.2	Age-matched Healthy Control Subjects	129
5.2.2	Behavioral Experiment Protocol	130
5.2.3	ERP Experiment Design	130
5.2.4	Experiment Protocol	131
5.2.5	Longitudinal ERP Analysis	131
5.2.6	Longitudinal Functional Connectivity Analysis	131
5.2.7	Acuity	132
5.3	Results and Discussion	134
5.3.1	Behavioral Results	134
5.3.2	Longitudinal ERP Results	134
5.3.3	N170 Amplitude Comparison	136
5.3.4	Right Hemisphere dominance	138
5.3.5	Longitudinal Functional Connectivity Results	140
5.3.6	Acuity	146
5.3.7	Discussion	147
5.4	Summary	149
6	Conclusion and Future Scope	151
6.1	Summary	151
6.2	Contributions	155
6.3	Conclusions and Future Scope	157
	Bibliography	161
	Publications	185
	Biography	187
	Glossary	189

List of Figures

1.1	EEG Device: consisting Actichamp EEG Amplifier and Active Electrodes with Acticap electrode cap	10
1.2	EEG Acquisition Apparatus: The EEG acquisition apparatus setup consists of two computer systems, viz., the recorder system and the presentation system, which are synchronized with each other. The amplifier in an EEG device amplifies the electrical signals detected by the electrodes positioned on the scalp of human participants. The recorder captures and stores the amplified signals received from the brain.	11
1.3	Cohort of Subjects screened for different EEG studies performed under this thesis work.	12
1.4	Description of research objectives with the different cohort of subjects (Keys: PP: Project Prakash, FC: Functional Connectivity)	17
2.1	Stimuli Design Overview (A) Examples of stimuli i.e. ‘Structure’ and ‘Non-Structure’; the image displays random dots with some appearing to create perceptual line segments referred to as ‘Structures’ while the other image solely consists of random dots, referred to as ‘Non-Structures’ (B) Outlook of stimulus presentation: Each image was displayed on the screen for 1000 <i>ms</i> , followed by an inter-stimulus interval (ISI) ranging from 1200 <i>ms</i> to 2300 <i>ms</i> between successive images. In total, 200 stimuli, comprising 100 structure images and 100 non-structure images, were presented randomly to the participants.	25
2.2	Behavioral Study measures (A) represents the distribution of reaction time over the number of target trials for all the subjects participated in the study (B) represents median reaction time and accuracy trade-off for each subject (dashed line indicates linear regression)	28

2.3	(A) ERP at the Frontal region averaged for electrodes Fp1, Fp2, AF7, AF3, AF4, AF8, F5, and F6 (depicted in the scalp map in the top right corner) following the presentation of Structure-NonStructure stimulus. ERP components P200, FN400, and LPC exhibit larger amplitudes in response to structures (red line) compared to non-structures (blue line). The black line shows the difference between the two events (B) ERP at the Occipital region averaged for electrodes PO7, PO8, PO3, PO4, O1, O2, and Oz (represented in the scalp map at the top right corner) following the presentation of Structure-NonStructure stimulus. ERP components P100, N200, P300, and LPC exhibit larger amplitudes in response to structures (red line) compared to non-structures (blue line). The black line shows the difference between the two events.	29
2.4	ERP at the V1 region averaged for electrodes P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO8, POz, PO3, PO4, O1, Oz, and O2 (represented in the scalp map at the right corner) following the presentation of Structure-NonStructure stimulus. ERP components P100, N200, and P300 exhibit larger amplitudes in response to structures (red line) compared to non-structures (blue line). The black line shows the difference between the two events.	30
2.5	Grand ERP: (A) shows GERP for frontal region electrodes over 15 subjects, and (B) shows GERP for occipital region electrodes over 15 subjects (C) Difference curve averaged over all considered frontal electrodes, displayed for each of the 15 subjects (D) Difference curves averaged over all considered occipital electrodes, displayed for each of the 15 subjects (E) Mean T-Score averaged over all 15 subjects for frontal electrodes (F) Mean T-Score averaged over all 15 subjects for occipital electrodes.	31
2.6	Topographical maps showing ERP difference between the events Structure and Non-Structure, where black color indicates no activity while white color represents the ERP activity.	32
2.7	Figure displays the electrode sites selected for the structure-nonstructure ERP Analysis in the right hemisphere (RH) and the left hemisphere (LH) of the brain. These electrodes are the ones with significant differences between the two events, statistically (with $p < 0.05$) as well as visually in the occipitotemporal region of the brain.	35
2.8	Frontal region ERP: ERP at the Frontal region averaged for electrodes Fp1, AF7, AF3, and F7 in the Left Hemisphere (left side in the figure) and averaged over electrodes Fp2, AF4, AF8, F4, F6, F8 in the Right Hemisphere (right side of the figure) following the presentation of Structure-NonStructure stimulus is evaluated for healthy controls. ERP components P200, FN400, and LPC exhibit larger amplitudes in response to structures (red line) compared to non-structures (blue line). LF and RF refer to the Left Frontal and Right Frontal hemispheres.	36

2.9	Occipital region ERP: ERP at the Occipital region averaged for electrodes P1, P3, P5, P7, PO3, PO7, O1 in the Left Hemisphere (left side in the figure) and averaged over electrodes P2, P4, P6, P8, PO4, PO8, O2 in the Right Hemisphere (right side of the figure) following the presentation of Structure-NonStructure stimulus is evaluated for healthy controls. ERP components P100, N200, and P300 exhibit larger amplitudes in response to structures (red line) compared to non-structures (blue line). LO and RO refer to the Left Occipital and Right Occipital hemispheres.	36
2.10	Mean peak amplitude analysis for different ERP components in Frontal and Occipital region across participants in a healthy control group. The pink and blue boxplot represent the left and right hemispheres respectively. . . .	38
2.11	Stimuli Design Overview: (A) Examples of stimuli, i.e. 'Face' and 'Object', (B) Outlook of stimulus presentation: The 'Face' and 'Object' stimuli were displayed for 300 ms each, with the gap between them varying randomly from 800 ms to 1500 ms. A total of 200 visual stimuli events were presented randomly.	41
2.12	Grand Event-Related Potential (GERP) in the left hemisphere at electrodes P5, P7, and PO7 and in the right hemisphere at electrodes P6, P8, and PO8 for face and object stimuli. The solid red and blue lines represent the grand average of all subjects for face and object event respectively. The shaded region above and below it indicates the +/- standard deviation of the mean.	43
3.1	Connectivity and Graph Analysis Pipeline: Schematic Overview of Graph Analysis for Connectivity Matrix in three ways	51
3.2	Connectivity Matrix and Connectivity Map : A and D denote Weighted Connectivity Matrix and Weighted Connectivity Map respectively for Structure, B, and E denote Binary Connectivity Matrix and Binary Connectivity Map respectively for Structure, C, and F denote Spanning Matrix and Spanning Map respectively for Structure while A' and D' denote Connectivity Matrix and Connectivity Map respectively for Non-Structure, B' and E' denotes Binary Connectivity Matrix and Binary Connectivity Map respectively for Non-Structure, C' and F' denotes Spanning Matrix and Spanning Matrix respectively for Non-Structure	52
3.3	Functional Connectivity for the events Structure and Non-Structure is evaluated over the EEG frequency bands (Theta, Alpha, Beta, and Gamma) represented using boxplot for the events Structure (red box) and Non-Structure (green box). The boxplot represents a high functional connectivity (Mean PLV) value (with $p < 0.05$ significance) for structure as compared to non-structure in the alpha band.	55
3.4	Functional Connectivity for the events Structure and Non-Structure is evaluated over the EEG frequency bands (Theta, Alpha, Beta, and Gamma). High functional connectivity (Mean PLV) value (with $p < 0.05$) for structure as compared to non-structure in the alpha band is observed. The difference between the functional connectivity of events is also represented.	56

3.5	Graph Measures of Weighted PLV matrix: Clustering Coefficient and Path Length calculated for EEG frequency bands (Theta, Alpha, Beta, and Gamma) represented using boxplot for the events Structure (red box) and Non-Structure (green box). The boxplot represents a high CC value (with $p < 0.05$ significance) for structure as compared to non-structure while a low PL value (with $p < 0.05$ significance) for structure as compared to non-structure in the alpha band.	57
3.6	MST Graph Measures: Leaf Fraction and Tree Hierarchy calculated for EEG frequency bands (Theta, Alpha, Beta, and Gamma) represented using boxplot for the events Structure (red box) and Non-Structure (green box). The boxplot represents a high LF value (with $p < 0.05$ significance) for structure as compared to non-structure while a high TH value (with $p < 0.05$ significance) for structure as compared to non-structure in the alpha band.	57
3.7	Frontal Circular Graph for Perceptual Grouping: illustrates the connectivity of the left frontal electrodes to all other electrodes (on the left side) with colored connections, and the connectivity of the right frontal electrode to all other electrodes (on the right side) using colored connections. All the electrode sites were positioned around the circumference of the circle. The values of colored connections are encoded based on the displayed color bar, where red color indicates high connectivity and blue indicates low connectivity. All the other electrodes' connectivity is represented in gray. The findings demonstrate a greater number of connections and higher functional connectivity in the right hemisphere.	60
3.8	Occipital Circular Graph for Perceptual Grouping: illustrates the connectivity of the left occipital electrodes to all other electrodes (on the left side) with colored connections, and the connectivity of the right occipital electrode to all other electrodes (on the right side) using colored connections. All the electrode sites were positioned around the circumference of the circle. The values of colored connections are encoded based on the displayed color bar, where red color indicates high connectivity while blue indicates low connectivity. All the other electrodes' connectivity is represented in gray. The findings demonstrate a greater number of connections and higher functional connectivity in the right hemisphere.	61
3.9	Connectivity Matrix for Face and Object: The Channels are specified using numbers from 1 to 63 and also by different colors	65
3.10	Connectivity Maps: showing functional connectivity (calculated using PLV) between every pair of electrodes for the brain responses corresponding to events Faces and Objects	65
3.11	Functional Connectivity for events: Face and Object in 3D	66
3.12	Functional Band Connectivity: showing Connectivity Maps for Face and Object in Delta, Theta, Alpha, Beta, and Gamma frequency bands for the events Face and Object. The results unveil increased connectivity in theta and gamma bands.	67

3.13	Dynamic Functional Connectivity for Face : showing Connectivity Maps in all EEG frequency bands (Delta, Theta, Alpha, Beta, and Gamma) over the time length of stimulus presentation in time segments of 100 <i>ms</i> i.e. 0 – 100 <i>ms</i> , 100 – 200 <i>ms</i> , and so on till 600 – 700 <i>ms</i> . The results show increased theta band connectivity between the frontal and parieto-occipital regions in the 100 – 200 <i>ms</i> and 200 – 300 <i>ms</i> time segments after stimulus onset, and increased gamma band connectivity for faces at parieto-occipital electrodes in the 100 – 200 <i>ms</i> segment.	69
3.14	Graph Measures of Weighted PLV matrix: Clustering Coefficient and Path Length calculated for EEG frequency bands (Delta, Theta, Alpha, Beta, and Gamma) represented using boxplot for the events Face (red box) and Object (green box). The boxplot represents a high CC value (with $p < 0.05$ significance) for the face as compared to the object while a low PL value (with $p < 0.05$ significance) for the face as compared to the object in the theta band.	70
3.15	Workflow Pipeline A: Data collection from human presenting face paradigm on the display, B: data was collected on all 64 sensors and preprocessed for further analysis, C: Dynamic MST matrices were calculated in 5 EEG frequency bands over different time segments of stimuli presentation, D: MST graphs and MST measures for events; face and object were calculated and statistically checked and presented using boxplot.	71
3.16	MST matrix and its corresponding MST graph and MST tree in different EEG frequency bands: (A) Delta band, (B) Theta band, (C) Alpha band, (D) Beta band for the events- face and object.	75
3.17	MST Dynamic Connectivity over time-segments along the length of stimuli presentation in different EEG frequency bands for the events face and object. The MST Dynamic Connectivity is shown for only dissimilar face and object MST matrices. T100 refers to the 0 – 100 <i>ms</i> time segment after stimulus onset, T200 refers to the 100 – 200 <i>ms</i> time segment after stimulus onset, and so on. The size and color of each node change depending on the number of edges falling on a node and also the connectivity value associated with the edges. The changing network for faces and objects is represented and the significance values are mentioned in Table 3.1.	76
3.18	The p-values for MST measures calculated in Table 1 are represented as boxplot. The pink boxplot represents Faces while the blue boxplot represents Objects (* means $p - value < 0.05$).	77
4.1	Figure displays details about Project Prakash. The visual from sight restoration surgery is shown. One of the Prakash subjects' pictures before and after surgery is also presented.	87

4.2	Stimuli Design Overview (A) Examples of stimuli, i.e. ‘Structure’ and ‘Non-Structure’; the image displays random dots, with some appearing to create perceptual line segments referred to as ‘Structures’ while the other image solely consists of random dots, referred to as ‘Non-Structures’ (B) Outlook of stimulus presentation: Each image was displayed on the screen for 1000 <i>ms</i> , followed by an inter-stimulus interval ranging from 1200 <i>ms</i> to 2300 <i>ms</i> between successive images. In total, 200 stimuli, comprising 100 structure and 100 non-structure images, were presented randomly to the participants.	91
4.3	Figure displays the electrode sites selected for the structure-nonstructure ERP Analysis of the LTS group. These electrodes have significant differences between the two events, statistically (with $p < 0.05$ as well as visually in the left and right hemispheres of the occipitotemporal region.	92
4.4	Figure displays the Hit rates or Mean Accuracy in the behavioral task of basic structure perception (Structure-NonStructure Perception) for Control and the LTS subject groups. The accuracy of the LTS group is determined as the mean of the accuracy scores of all participants within that group during the last follow-up. The LTS group showed comparable accuracy as the control group in the behavioral task.	94
4.5	Event Related Potential of LTS subjects (SUB 01, SUB 02, SUB 03, and SUB 04) and age-matched Control subjects’ individual EEG response to events- structure and non-structure in the left hemisphere (averaged for electrodes P1, P3, P5, P7, PO3, PO7, and O1) and Right Hemisphere (averaged for electrodes P2, P4, P6, P8, PO4, PO8 and O2). The details of all PP subjects are mentioned in Table 4.1. The significance values for comparison between events and subject groups for each ERP component are tabulated in Table 4.2 and Table 4.3.	95
4.6	Topographic maps of the P100, N200, and P300 to Structure, NonStructure, and difference Structure-NonStructure shown separately for the Control and PP-LTS subjects group.	96
4.7	P100, N200, and P300 ERP component amplitudes (first, second, and third rows, respectively) in the left and right hemisphere to structures and non-structures shown separately for individual LTS (PP-Sub1, PP-Sub2, PP-Sub3, and PP-Sub4) and age-matched control subjects were compared for the events-Structure and Non-Structure(‘*’ represents $p - value < 0.05$, ‘**’ represents $p - value < 0.01$). The details of PP subjects are mentioned in Table 4.1. The significance values for the comparison shown are tabulated in Table 4.2 and 4.3.	101
4.8	Grand mean ERP indicating LTS and Control subject group mean response respective to events- structure, and non-structure at Left Hemisphere (averaged for electrodes P1, P3, P5, P7, PO3, PO7, and O1) and Right Hemisphere (averaged for electrodes P2, P4, P6, P8, PO4, PO8, and O2). Our findings illustrate the GERP components P100, N200, and P300 exhibit larger amplitudes in response to structures (red line) compared to non-structures (blue line) for both the LTS and Control subject groups. The significance values for amplitude comparison between hemispheres and subject groups are tabulated in Table 4.4 and 4.5.	105

4.9	Stimuli Design Overview: (A) Examples of stimuli, i.e. 'Face' and 'Object', (B) Outlook of stimulus presentation: The 'Face' and 'Object' stimuli were displayed for 300 <i>ms</i> each, with the gap between them varying randomly from 800 <i>ms</i> to 1500 <i>ms</i> . A total of 200 visual stimuli events were presented randomly.	110
4.10	Figure displays the electrode sites selected for the face-object ERP Analysis of the LTS group. These electrodes have significant differences between the two events, statistically (with $p < 0.05$ as well as visually in the left and right hemispheres of the occipitotemporal region.	111
4.11	Figure displays the Mean Accuracy in the behavioral task of complex structure perception (Face-Object Perception) for Control and the LTS subject groups. The accuracy of the LTS group is determined as the mean of the accuracy scores of all participants within that group during the last follow-up. The LTS group showed comparable accuracy as the control group in the behavioral task.	114
4.12	Figure depicts ERP responses of LTS-GroupA subject and Control subject averaged for electrodes P7, P5, and PO7 in the Left Hemisphere and averaged for electrodes P6, P8, and PO8 in the Right Hemisphere corresponding to events faces and objects, following the presentation of the Face-Object paradigm during their last follow-up assessment. The responses of the LTS-GroupA subject and age-matched Control subject are compared for ERP component N170 amplitude and latency. A solid red line indicates the Control subject's response to the face while a solid blue line indicates the Control subject's response to the object. The dotted red line indicates the LTS-GroupA subject's response to the face while a dotted blue line indicates the LTS-GroupA subject's response to the object. Description of the participants including their presurgical and last postsurgical visual acuity, and the last follow-up assessment duration after PostOp are mentioned in Table 4.6.	115
4.13	Figure depicts ERP responses of LTS-GroupB subject and Control subject averaged for electrodes P7, P5, and PO7 in the Left Hemisphere and averaged for electrodes P6, P8, and PO8 in the Right Hemisphere corresponding to events faces and objects, following the presentation of the Face-Object paradigm during their last followup assessment. The responses of the LTS-GroupB subject and age-matched Control subject are compared for ERP component N170 amplitude and latency. A solid red line indicates the Control subject's response to the face while a solid blue line indicates the Control subject's response to the object. The dotted red line indicates the LTS-GroupB subject's response to the face while a dotted blue line indicates the LTS-GroupB subject's response to the object. Description of the participants including their presurgical and last postsurgical visual acuity, and the last follow-up assessment duration after PostOp are mentioned in Table 4.7.	116

4.14	Right Hemisphere dominance for Group-B Subjects: Figure above represents the left and right hemisphere ERP comparison of 4 individual PP LTS Group-B subjects for face and object responses showing right hemisphere dominance. The figure below represents electrode response in the right hemisphere of a PP LTS Group-B subjects showing Right Hemisphere dominance	117
4.15	N170 Amplitude comparison for 4 individual LTS Group-A (PP-Sub1, PP-Sub2, PP-Sub3, PP-Sub4 as in figure) and age-matched control subjects in the Left and Right Hemispheres. (*' represents $p - value < 0.05$). The details of LTS Group-A subjects are mentioned in Table 4.6.	118
4.16	N170 Amplitude comparison for 4 individual LTS Group-B (PP-Sub1, PP-Sub2, PP-Sub3, PP-Sub4 as in figure) and age-matched control subjects in the Left and Right Hemispheres. (*' represents $p - value < 0.05$). The details of LTS Group-B subjects are mentioned in Table 4.7.	118
4.17	N170 Latency comparison for 4 individual PP LTS Group-A subjects and age-matched control subjects in the Left and Right Hemispheres. (*' represents $p - value < 0.05$). The details of LTS Group-A subjects are mentioned in Table 4.6.	119
4.18	N170 Latency comparison for 4 individual PP LTS Group-B subjects and age-matched control subjects in the Left and Right Hemispheres. (*' represents $p - value < 0.05$). The details of LTS Group-B subjects are mentioned in Table 4.7.	120
4.19	Functional Connectivity Maps of the LTS-GroupA subject for the last follow-up assessment and Control subject for the events Faces and Objects are observed. The analysis was done for LTS-GroupA SUB 01: M, 16 years, FollowUp2: 4 months after PostOp. The acuity details are mentioned in Table 4.6. The findings suggest that functional connectivity for LTS-GroupA subjects during the last follow-up assessment is comparable to Control subjects.	121
4.20	Functional Connectivity Maps of the LTS-GroupB subject for the last follow-up assessment and Control subject for the events Faces and Objects are observed. The analysis was done for LTS-GroupB SUB 01: F, 7 years, FollowUp2: 7 months after PostOp. The acuity details are mentioned in Table 4.7. The findings suggest that functional connectivity for LTS-GroupB subjects during the last follow-up assessment is comparable to Control subjects.	121
4.21	Functional Connectivity (PLV) of the LTS-GroupA and LTS-GroupB subject for the last follow-up assessment and Control subjects for the events Faces and Objects is presented. The analysis was done for LTS-GroupA SUB 01: M, 16 years, FollowUp2: 4 months after PostOp. The acuity details are mentioned in Table 4.6. The analysis was done for LTS-GroupB SUB 01: F, 7 years, FollowUp2: 7 months after PostOp. The acuity details are mentioned in Table 4.7. The red and green boxplots represent PLV values for face and object events respectively. The findings suggest that functional connectivity for LTS-GroupA and LTS-GroupB subjects during the last follow-up assessment is comparable to Control subjects.	122

5.1	Stimuli Design Overview: (A) Examples of stimuli, i.e. 'Face' and 'Object', (B) Outlook of stimulus presentation: The 'Face' and 'Object' stimuli were displayed for 300ms each, with the gap between them varying randomly from 800ms to 1500ms. A total of 200 visual stimuli events were presented randomly.	130
5.2	Figure displays the electrode sites selected for the face-object ERP Analysis of the NSS group. These electrodes have significant differences between the two events, statistically (with $p < 0.05$ as well as visually in the left and right hemispheres of the occipitotemporal region.	133
5.3	Mean of Behavioral Accuracy of both the NSS groups and Control groups for the behavioral task related to the face-object experiment. The improvement in behavioral accuracy following post-surgery and follow-up assessments is observed for NSS subjects.	134
5.4	Figure depicts ERP responses of NSS-GroupA subject and Control subject averaged for electrodes P7, P5, and PO7 in the Left Hemisphere corresponding to events faces and objects, following the presentation of the Face-Object paradigm across the duration of the intervention process, spanning PreOP, PostOP, FollowUP1, and FollowUP2. The responses of NSS-GroupA subject and Control subject are compared for ERP component N170 amplitude and latency. A solid red line indicates the Control subject's response to the face while a solid blue line indicates the Control subject's response to the object. The dotted red line indicates the NSS-GroupA subject's response to the face while a dotted blue line indicates the NSS-GroupA subject's response to the object. The details of the NSS-GroupA subject are the following- S01: M, 16 years, PostOP: 20 days after PreOp, FollowUp1: 30 days after PostOP, and FollowUp2: 4 months after PostOp. The acuity details are mentioned in Table 5.3.	135
5.5	Figure depicts ERP responses of NSS-GroupA subject and Control subject averaged for electrodes P6, P8, and PO8 in the Right Hemisphere corresponding to events faces and objects, following the presentation of the Face-Object paradigm across the duration of the intervention process, spanning PreOP, PostOP, FollowUP1, and FollowUP2. The responses of NSS-GroupA subject and Control subject are compared for ERP component N170 amplitude and latency. A solid red line indicates the Control subject's response to the face while a solid blue line indicates the Control subject's response to the object. The dotted red line indicates the NSS-GroupA subject's response to the face while a dotted blue line indicates the NSS-GroupA subject's response to the object. The details of the NSS-GroupB subject are the following- S01: M, 16 years, PostOP: 20 days after PreOp, FollowUp1: 30 days after PostOP, and FollowUp2: 4 months after PostOp. The acuity details are mentioned in Table 5.3.	136

5.6	Figure depicts ERP responses of NSS-GroupB subject and Control subject averaged for electrodes P7, P5, and PO7 in the Left Hemisphere corresponding to events faces and objects, following the presentation of the Face-Object paradigm across the duration of the intervention process, spanning PreOP, PostOP, FollowUP1, and FollowUP2. The responses of the NSS-GroupB subject and Control subject are compared for ERP component N170 amplitude and latency. A solid red line indicates the Control subject's response to the face while a solid blue line indicates the Control subject's response to the object. The dotted red line indicates the NSS-GroupB subject's response to the face while a dotted blue line indicates the NSS-GroupB subject's response to the object. The details of the NSS-GroupB subject are the following- S01: F, 7 years, PostOP: 5 days after PreOp, FollowUp1: 120 days after PostOP, and FollowUp2: 7 months after PostOp. The acuity details are mentioned in Table 5.4.	137
5.7	Figure depicts ERP responses of NSS-GroupB subject and Control subject averaged for electrodes P6, P8, and PO8 in the Right Hemisphere corresponding to events faces and objects, following the presentation of the Face-Object paradigm across the duration of the intervention process, spanning PreOP, PostOP, FollowUP1, and FollowUP2. The responses of the NSS-GroupB subject and Control subject are compared for ERP component N170 amplitude and latency. A solid red line indicates the Control subject's response to the face while a solid blue line indicates the Control subject's response to the object. The dotted red line indicates the NSS-GroupB subject's response to the face while a dotted blue line indicates the NSS-GroupB subject's response to the object. The details of the NSS-GroupB subject are the following- S01: F, 7 years, PostOP: 5 days after PreOp, FollowUp1: 120 days after PostOP, and FollowUp2: 7 months after PostOp. The acuity details are mentioned in Table 5.4.	138
5.8	N170 Amplitude comparison for 4 individual PP NSS-Group-A subjects and age-matched control subject in the Left Hemisphere following post-surgery and follow-up assessments (*' represents $p - value < 0.05$). The details of NSS-Group-A is mentioned in Table 5.1.	140
5.9	N170 Amplitude comparison for 4 individual PP NSS-Group-A subjects and age-matched control subject in the Right Hemisphere following post-surgery and follow-up assessments (*' represents $p - value < 0.05$). The details of NSS-Group-A is mentioned in Table 5.1.	141
5.10	N170 Amplitude comparison for 4 individual PP NSS-Group-B subjects and age-matched control subject in the Left Hemisphere following post-surgery and follow-up assessments (*' represents $p - value < 0.05$). The details of NSS-Group-B is mentioned in Table 5.2.	142
5.11	N170 Amplitude comparison for 4 individual PP NSS-Group-B subjects and age-matched control subject in the Right Hemisphere following post-surgery and follow-up assessments (*' represents $p - value < 0.05$). The details of NSS-Group-B is mentioned in Table 5.2.	143

5.12	Figure represents the right hemisphere dominance: Comparison of ERP responses in the LH and RH of four individual PP NSS GroupB subjects (in 4 boxes) over the timeline of surgery corresponding to face and object responses is presented. The red line indicates face responses while the green line indicates object responses in LH and RH. The high amplitude of the N170 peak was observed for faces rather than objects reflecting more activation in RH for NSS GroupB subjects for faces.	144
5.13	Longitudinal Functional Connectivity of the NSS-GroupA subjects for the events Faces and Objects is observed over the time, spanning from the Pre-operative period to post-operative and the follow-up assessments. The details of the NSS-GroupA subject are the following- S01: M, 16 years, PostOP: 20 days after PreOp, FollowUp1: 30 days after PostOP, and FollowUp2: 4 months after PostOp. The acuity details are mentioned in Table 5.3. The findings suggest increased functional connectivity during follow-up assessments.	145
5.14	Longitudinal Functional Connectivity of the NSS-GroupB subjects for the events Faces and Objects is observed over the time, spanning from the Pre-operative period to post-operative and the follow-up assessments. The details of the NSS-GroupB subject are the following- S01: F, 7 years, PostOP: 5 days after PreOp, FollowUp1: 120 days after PostOP, and FollowUp2: 7 months after PostOp. The acuity details are mentioned in Table 5.4. The findings suggest increased functional connectivity during follow-up assessments.	146
5.15	Functional Connectivity of the NSS Group-A and NSS Group-B subject over the time, spanning from the Pre-operative period to the post-operative and the follow-up assessments for the events Faces and Objects is presented. The details of the NSS-GroupA subject are the following- S01: M, 16 years, PostOP: 20 days after PreOp, FollowUp1: 30 days after PostOP, and FollowUp2: 4 months after PostOp. The details of the NSS-GroupB subject are the following- S01: F, 7 years, PostOP: 5 days after PreOp, FollowUp1: 120 days after PostOP, and FollowUp2: 7 months after PostOp. The red and green boxplots represent PLV values for face and object events respectively. The findings suggest increased functional connectivity during follow-up assessments.	147
1	EEG Acquisition Apparatus available in Neurocomputing lab, Indian Institute of Technology Delhi, indicating two synchronized PCs: one presents stimuli for the psycho-task to the participant while the other records signals using Brain Vision EEG software, coming from Amplifier through 64 channels on the scalp.	190

List of Tables

2.1	Comparison of the events-Structure vs Non-Structure and LH vs RH for the ERP components P200, N400, LPC in the frontal region for a healthy control group.	39
2.2	Comparison of the events-Structure vs Non-Structure and LH vs RH for the ERP components P100, N200, P300 in the occipital region for a healthy control group.	39
3.1	The p-values for the different MST measures and PLV average calculated over specific time segments in different EEG frequency bands for face and object (written as mean $\pm$ std)	78
4.1	Table displays the description of Long-Term Subjects (LTS) who participated in the Basic Object perception task, including their presurgical and last postsurgical visual acuity and the last follow-up assessment duration after PostOp	102
4.2	ANOVA Amplitude Comparison between Structure and Non-structure ERP components (P100, N200, and P300) in the left and right hemispheres for 4 PP LTS and the control subject. The significance values with $p < 0.05$ reflect that the brain responses of long-term subjects show a statistical difference between structure and non-structure at each ERP component. . .	103
4.3	ANOVA Amplitude Comparison between PP, LTS, and the control subject in the left and right hemispheres for Structure ERP components (P100, N200, and P300). The p-value equal to 1 reflects that the brain responses of long-term and control subjects are statistically the same concerning each ERP component.	103
4.4	ANOVA Amplitude Comparison between Structure and Non-Structure Grand ERP components in LH and RH for PP LTS and Control groups. The significance values with $p < 0.05$ reflect that the brain responses of long-term subjects show a statistical difference between structure and non-structure at each GERP component.	105
4.5	ANOVA Amplitude Comparison between PP LTS and Control groups in LH and RH for Grand ERP components. The p-value equal to 1 reflects that the brain responses of long-term and control subjects are statistically the same concerning each GERP component.	106
4.6	Table displays the description of LTS Group-A who participated in the Complex Object perception task, including their presurgical and last postsurgical visual acuity, and the last follow-up assessment duration after PostOp	123

4.7	Table displays the description of LTS Group-B who participated in the Complex Object perception task, including their presurgical and last post-surgical visual acuity, and the last follow-up assessment duration after PostOp	124
5.1	Description of the participants includes their age, gender, and the duration following the PreOp, PostOp, and follow-up assessments for NSS Group-A.	139
5.2	Description of the participants includes their age, gender, and the duration following the PreOp, PostOp, and follow-up assessments for NSS Group-B.	139
5.3	Acuity of NSS Group-A Subjects over the timeline of surgery from pre-op to follow-ups	148
5.4	Acuity of an NSS-GroupB Subject over the time from pre-Op to follow-ups	148

Abbreviations

EEG	E lectro E ncephalo G raphy
ERP	E vent R elated P otential
PLV	P hase L ocking V alue
MST	M inimum S panning T ree
PS	P hase S ynchronisation
PP	P roject P rakash
LTS	L ong T erm S ubject
NSS	N ewly S ighted S ubjects
LPC	L ate P ositive C omponent
LH	L eft H emisphere
RH	R ight H emisphere
LF	L eft F rontal
RF	R ight F rontal
LO	L eft O ccipital
RO	R ight O ccipital
ISI	I nterval S timulus I nterval
LE	L eft E ye
RE	R ight E ye
BE	B oth E ye
HM	H and M otion
FC	F inger C ounting
FCCF	F inger C ounting C lose to F ace
IEC	I nstitution E thics C ommittee
ICMR	I ndian C ouncil of M edical R esearch