Abstract

Vision is arguably the most vital sense for humans, providing a medium by which they perceive, interpret and interact with the world. It is the seamless association between the eyes, brain and several neural pathways that generates our perception of the surrounding environment. Central to this process is stereopsis, an ability to perceive 3-dimensional (3D) world based on the inputs received from both eyes simultaneously. Nevertheless, not everyone possesses an ideal association of the ocular and cerebral functions. Individuals having visual disorders such as eye misalignment (or squint or strabismus), lazy eye (amblyopia), cataracts and even refractive errors have disruptions in the accurate perception of depth. Consequently, to understand the perceptual and neural aspects of stereopsis, I utilize psychophysics and Functional Magnetic Resonance Imaging (fMRI) in patients with stereo-deficits and age-matched visually healthy population.

First, I redefine a crucial interval from birth to surgery for achieving stereopsis in patients with congenital cataract. For this, I use a systematic quantitative approach that integrates the results of existing studies to evaluate the presence of stereopsis post-cataract extraction. I take the study-specific proportions of stereopsis from 923 children using a random-effects model and stratify them based on the intervention age and the presence of strabismus. I find that birth to surgery interval of 4–6 months is crucial for stereopsis in congenital cataract. I also find that stereopsis drops by 9%–16% in congenital cataracts with pre-existing strabismus.

Then, I turn towards the creation of a random-dot stereogram (RDS) based stereoacu-

ity test for the detection and evaluation of stereopsis. In the current clinical scenario, the routinely used stereoacuity tests rely on expensive and imported printed books. These books are difficult to procure and fade over time involving recurrent costs. Therefore, I first create a digital stereoacuity test and perform a disparity plate-wise comparison with a clinical stereotest - TNO (The Netherlands Organization) in a wide range of stereo-deficit patients and visually healthy controls. Next, I extend this test by (i) adjusting for the ambient lighting and, (ii) incorporating a comprehensive and continuous framework for the detection and evaluation of stereopsis. I find that there are subtle changes in observed stereoacuity when the ambient lighting is not adjusted for, specifically in stereo-deficit patients. I also show that the overall test can be performed in significantly lesser time (approximately 5-10 minutes) compared to other research grade computer-based stereoacuity tests.

In the latter part of the thesis, I explore the neural mechanisms of the static and dynamic stereopsis. Under static stereopsis, I investigate causal mechanisms of coarse and fine binocular disparity processing using fMRI with a clinically validated, custom anaglyph-based stimulus with four disparity magnitudes, namely - 800 arc-sec, 480 arc-sec, 240 arc-sec and 120 arc-sec. Consequently, I use graph theoretical metrics such as degree and participation coefficient metrics representing rich and diverse properties of the brain network, respectively. Through experiments on visually healthy controls, I find that distinct rich and diverse clubs exist across different disparity magnitudes. Among all, the Middle Temporal (MT) brain region serves as the only common rich and diverse region across all disparity magnitudes and in both hemispheres. I also demonstrate that diverse clubs exhibit better performance in decoding disparity magnitudes, thereby providing further support to the growing evidence that diverse clubs are indeed the integrative core for processing disparities. Lastly, I show that there are subtle inter-hemispheric differences across different disparity conditions.

To explore dynamic stereopsis, I analyse the neural response of patients having Intermittent Exotropia (IDS) and age-matched visually healthy controls to a continu-

ously moving target in 3D Brownian motion. Specifically, I use One-vs-One Support Vector Classifier (OVO-SVC) to decode fronto-parallel (x & y) and depth (z) positions while the participants gaze at the moving target. In visually healthy controls, I find that both fronto-parallel and depth positions could be decoded with above chance accuracy, however, these depth positions are decoded slower compared to fronto-parallel counterparts. Notably, there is no such association in IDS patients.

In summary, the work presented in this thesis offer a comprehensive understanding of stereopsis in terms of both translational and fundamental visual science. It not only enables interactive assessment of stereopsis for ophthalmologists and optometrists but also contribute to advancing our knowledge of the neural mechanisms related to oculomotor behavior in both clinical and visually healthy populations.