Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Eye Tracking Evaluations of Control Populations and Children with Focal Epilepsy

A thesis submitted to the University of Dublin for the degree of

MSc by Research in Clinical Medicine

May 2021

Eileen Louise O'Flaherty

Under the supervision of Richard B. Reilly

School of Medicine

Trinity College Dublin

Abstract

Eye tracking has emerged as a powerful tool in studying the eye movements of children. Previous eye tracking studies have not examined eye movements of children with focal epilepsy.

The aim of this study was to develop a protocol for a remote eye tracker and to build a set of normal control data from healthy adults and children. The study then set out to examine if any differences in eye movements could be detected in children with focal epilepsy when compared with a group of normal controls.

This study provides a novel approach to measuring eye movements with an infrared eye tracker in both a hospital and community setting. Evidence is presented which shows that it is possible to differentiate children with focal epilepsy and their peers by use of this remote eye tracking protocol. As a result of these investigations, remote eye tracking will be offered to more patient cohorts within the field of Paediatric Neurology.

Acknowledgements

I must thank the OLCHC Board of Management for the award of the funding which enabled me to undertake this MSc through the OLCHC Bursary scheme.

I want to extend my thanks to Professor Richard Reilly for his help over the course of my studies in TCD, thank you for your encouraging feedback and support. I would like to express my gratitude to Dr John McHugh for his continuing help, guidance and support. In particular, I would like to thank Professor D Webb for the support he has shown from the beginning of this project.

Thank you to all of the volunteers who gave up their time to participate in this study. In particular, the students of Our Lady of Lourdes National School, Cork.

I am extremely grateful to my fellow Physiologists in the Department of Clinical Neurophysiology. Elaine, John, Niamh, Nicole and Ray generously afforded me assistance and the time to work on this project. A very special thank you goes out to Ailish who has been an unfailing source of encouragement and reassurance.

Finally, I must express my sincere appreciation to John and Séamus, my family and friends for their support and patience during this busy time.

Table of Contents

List of Figures

List of Equations

List of Tables

Glossary of Abbreviations

BGC	brainstem gaze centres
CEF	cingulate eye field
CN	caudate nucleus
DLPC	Dorsolateral prefrontal cortex
DLPN	Dorsolateral pontine nuclei
FEF	Frontal eye field
FEFsac	Saccade sub region of the frontal eye field
FEFsem	Pursuit sub region of the frontal eye field
FN	fastigial nucleus
GS	Gaze sample
KD	King-Devick
LGN	Lateral geniculate nucleus
MLF	Medial longitudinal fasciculus
MRF	Mesencephalic Reticular Formation
MST	Medial Superior Temporal
MT	Middle Temporal
m-TBI	Mild traumatic brain injury
NNVT	Number Naming Video Task

NRTP	nucleus reticularis tegmenti pontis
OKAN	Optokinetic after nystagmus
OKN	Optokinetic nystagmus
OKR	Optokinetic reflex
PEF	Parietal eye field
PPRF	Paramedian pontine reticular formation
PVN	Post-rotatory vestibular nystagmus
riMLF	Rostral interstitial nucleus of the medial longitudinal fasciculus
SC	Superior colliculus
SEF	Supplementary eye field
SMA	supplementary motor area
SNpc	Substantia nigra pars compacta
SNpr	Substantia nigra pars reticulata
TTFF	Time to First Fixation
VN	Vestibular nystagmus
WGS	Weighted gaze sample

Chapter 1 – Introduction

1.1 Inspiration for this study

Abnormality of eye-movement can be indicative of underlying neurological disease. Subtle abnormalities of eye movement can be manifestations of adult neurodegenerative disease for example (Anderson & MacAskill, 2013). In the paediatric population eye movement abnormalities have mostly been investigated in the area of neurodevelopment, for instance children with autism spectrum disorder and children following a mild traumatic brain injury (m-TBI) (Hecimovich et al., 2019; Sumner et al., 2018).

Eye tracking is an evolving field which is used across many research disciplines. The availability of remote eye trackers has extended research opportunities beyond co-operative adults to include children and infants (Hessels et al., 2015).

1.2 Study aims

This research study investigated eye movement characteristics in children with epilepsy and healthy controls.

The objectives of the study were to:

- Design and develop a protocol to quantitatively study fixations, and eye-movements in healthy adult and paediatric control cohorts, through the use of remote eye tracker technology.
- To compare measures of eye-movement between children with epilepsy and healthy controls.

- To examine the effects of age and video-game console usage on such measures of eye movement.

1.3 Eye Movements

The purpose of eye movements is to accurately hold an image on the fovea so that the central nervous system can process it. The fovea is situated in the central portion of the retina, known as the macula, which has the highest density of photoreceptors (Martini & Nath, 2009). The visual axis is made up of the pathway from the middle of the visual field, to the lens of the eye and onwards to the fovea (Fitzgerald et al., 2012).

There are 6 extraocular muscles which move the eye within its orbit: 4 rectus muscles and 2 oblique muscles. Three pairs of cranial nerves (CN) control eye movements. These consist of the oculomotor nerve (CN III), the trochlear nerve (CN IV) and the abducens nerve (CN VI) (Krebs et al., 2012).

Eye movements can be clinically assessed at the bedside, in the outpatient clinic or at the pitch side. Clinical assessment of eye movement requires subjects to pursue and saccade to the horizontal and vertical extremes of their vision whilst keeping the head still. Normal oculomotor function requires integration of activity from the central nervous system. An abnormality in eye movement can provide information on dysfunction in a specific region of the nervous system, including the frontal and supplementary eye fields, the dorsolateral prefrontal cortex, the posterior parietal cortex, basal ganglia, thalamus, superior colliculus and the cerebellum (Leigh & Zee, 2015; Luna & Velanova, 2011).

The six eye movement systems work together and often overlap. The eye movements which bring the object of interest onto the fovea are saccadic eye

movements, smooth pursuit eye movements and vergence eye movements. Once an object is on the fovea there are three systems which maintain the image with clarity, these are the fixation system, the vestibular system and the optokinetic system (Agnes M. F. Wong, 2008). Our study was carried out using an infrared Eye Tracker, as this Eye Tracker Measures Fixations and Saccades this introduction will focus on these Eye Movement systems. Smooth Pursuit Eye Movements are also detailed below as one of the Eye Tracking tasks was designed to elicit them.

1.3.1 Fixations

The purpose of fixation is to hold an object on the fovea while the head is steady. During fixation saccadic eye movements are inhibited but the eye is not still (Luna & Velanova, 2011). A fixation is made up of microsaccades, microdrift and micro tremor. When a person is fixating for a long time the visual nervous system begins to habituate to the image and a gradual fade out begins. Microdrift prevents a stationary image from disappearing from vision over time. During microdrift microsaccades are suppressed. This is necessary when completing tasks which require intense scrutiny (Leigh & Zee, 2015; Agnes M. F. Wong, 2008).

If a fixation is interrupted the person will experience oscillopsia “an illusion of movement of the stationary environment”. Oscillopsia can be caused by nystagmus, saccadic intrusions or oscillations and central disturbances such as infarcts (Agnes M. F. Wong, 2008). Saccadic intrusion is a sporadic oscillation whereas saccadic oscillations are sustained. Oscillopsia can also be caused by seizures, for example, seizures affecting the Occipital lobe (Agnes M. F. Wong, 2008).

Fixation involves areas in the brainstem (substantia nigra pars reticulata (SNpr) in the basal ganglia and the rostral pole of the superior colliculus) and the cerebral cortex (parietal eye field (PEF), supplementary eye field (SEF), dorsolateral prefrontal cortex (DLPC) and the areas V5 and V5A, which are located at the meeting of the occipital, parietal and temporal lobes (Schapira & Byrne, 2007; Agnes M. F. Wong, 2008).

1.3.2 Saccades

Saccades are rapid eye movements; one of the fastest movements that humans can generate, their function is to convey an image to the fovea of the retina (Ebenholtz, 2001). Both eyes move in a conjugate fashion. The medial longitudinal fasciculus (MLF) makes this coordination possible, it also adjusts the eyes based on the position of the head (Krebs et al., 2012). The neural generator of horizontal and vertical saccades are neurons in the paramedian pontine reticular formation (PPRF) located in the Pons and the mesencephalic reticular formation (MRF).

The unit of saccadic velocity is degrees per second (30-700°/sec). Saccadic amplitude refers to the angle subtended (5-40°) during a saccadic eye movement. There is a linear relationship between saccadic amplitude and both saccadic velocity and saccadic duration (between 30-100msec) (Gandhi & Katnani, 2011; Liversedge et al., 2011). The larger the distance between objects, the greater the saccadic amplitude. If a subject is asked to look alternately between two targets for a period of time the saccadic velocity should increase over time. If an individual is fatigued, distracted or under the effect of psychoactive substances the saccadic eye movements can have a reduced

velocity (Brazis, 1996). It is normal to slightly under (hypometria) or over shoot (hypermetria) a target, although this should be no greater than 10% of the saccadic amplitude (Agnes M. F. Wong, 2008).

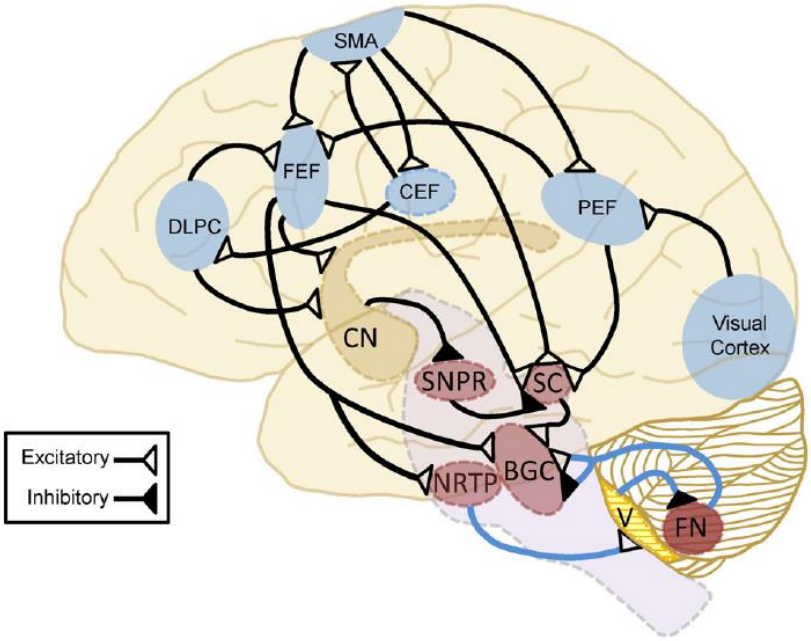
Once a stimulus appears in a person's peripheral vision it can take 150-250ms for a saccade to be generated; this is termed saccadic latency (Gandhi & Katnani, 2011; Agnes M. F. Wong, 2008). A normal saccade will move on a relatively straight pathway from its initial position to its final destination. It will initially travel slowly before speeding up and decelerating before arrival. If a person blinks during a saccade the pathway will be curved, the saccade time and the peak velocity will be slowed (Gandhi & Katnani, 2011).

A series of saccades and fixations is known as a scan-path. Whilst a saccade moves the eye, visual masking occurs to avoid blurring of vision (Liversedge et al., 2011). Visual masking is also known as saccadic suppression. While the process behind it is not fully understood, visual masking prevents blurring of vision during saccadic eye movements. It is thought that extra retinal areas such as the Lateral Geniculate Nucleus (LGN) block transmission during saccades (Castet & Masson, 2000). Saccades are generated in the brainstem but neurons in the cerebral cortex drive their initiation (Agnes M. F. Wong, 2008).

A lesion in the Frontal Eye Field (FEF) can cause hypometria on the contralateral side. Hypometria and hypermetria can be represented in Eye Tracking studies as Fixations Before (discussed in a later section). A unilateral lesion in the Parietal lobe can cause increased saccadic latency (Agnes M. F. Wong, 2008).

Figure 1.1 Cortical and subcortical pathways involved in saccade generation. (FEF – frontal eye field, PEF – parietal eye field, SC – superior colliculus, BGC – brainstem gaze centres, CEF – cingulate eye field, CN – caudate nucleus, SMA – supplementary motor area, SNPR – substantia nigra pars reticulata, DLPC –

dorsolateral prefrontal cortex, NRTP – nucleus reticularis tegmenti pontis, FN – fastigial nucleus) (Ventura et al., 2016)



The parietal eye field (PEF) instigates reflexive saccades by signalling to the ipsilateral superior colliculus (SC) and the frontal eye field (FEF). The saccadic sub region of the frontal eye field (FEFsac) acts both directly on the SC via the PEF and indirectly in an inhibitory fashion through the basal ganglia's GABA-ergic neurons. The paramedian pontine reticular formation (PPRF) is known as the horizontal gaze centre; signals transmit through the PPRF on the way to the extraocular muscles (Krebs et al., 2012). The FEFsac and SC are essential for saccade generation, if one of these structures is damaged saccades will show an increased latency. If both are impaired saccade generation will be interrupted (Agnes M. F. Wong, 2008).

Structures within the cerebellum are responsible for the size and accuracy of saccades. A lesion in either the dorsal vermis or fastigial nucleus impairs the speed and accuracy of the saccades. Damage to both of these areas will result in the phenomenon of post saccadic drift (Agnes M. F. Wong, 2008).

1.3.3 Smooth pursuit

Smooth pursuit eye movements follow slowly moving targets, such as a jet flying overhead. The pursuit system requires constant readjustment to keep the object on the fovea, and thus requires a level of attention (Barnes, 2011; Beatriz Luna, 2011; Luna & Velanova, 2011; Luna & Velanova, 2011). Smooth pursuit eye movements are driven by two separate but parallel pathways, one pathway begins in the medial superior temporal (MST) area, where the signals then travel to the pontine nuclei. The other pathway originates in the frontal eye field (FEF), signals spread to the nucleus reticularis tegmentis pontis (NRTP) (Cullen & Van Horn, 2011). Both hemispheres work together for smooth pursuit. Descending control pathways decussate within the brainstem and relay with the contralateral cerebellum (Krebs et al., 2012).

Pursuit movements and saccades work together. The brain can preferentially follow an object in a crowded landscape (Barnes, 2011). The velocity of smooth pursuit movement ranges from 0.1-70°/sec in most humans. Trained athletes can have velocities of up to 130°/sec. The time taken to initiate a smooth pursuit is between 100-130msec. The smooth pursuit movement can keep up with an object if it is predictable but it will lag behind an unpredictable target (Agnes M. F. Wong, 2008).

Pathways of the smooth pursuit system are closely linked to the optokinetic system. Visual stimuli are received by M ganglion cells in the retina; these signals transmit through the striate cortex, Brodmann areas V1, V2, V3, and then to the middle temporal V5. Projections go to the middle superior temporal V5a area, posterior parietal cortex and the visual motor area containing FEFsem and SEF.

The pathway diverges here depending on whether it is a horizontal or vertical smooth pursuit movement (Agnes M. F. Wong, 2008).

The horizontal pursuit pathway begins with retinal M ganglion cells. During the pathway for horizontal pursuit the signals cross over between hemispheres twice. This occurs first at the dorsolateral pontine nuclei (DLPN) and the second at the level of the second order vestibular neurons to the contralateral abducens nucleus (Agnes M.F. Wong, 2008). It is highlighted in the literature that this fact be taken into consideration when looking at eye movement abnormalities. A lesion in the Middle Temporal Visual Area can result in a decrease in the speed of smooth pursuit movements (Agnes M. F. Wong, 2008).

1.3.4 Maturation of eye movement through childhood

At 6 weeks post gestational age an infant should be able to fix on and follow faces and brightly coloured objects or lights. Once they are 4 months post gestational age they should be able to fix on and follow objects up to 180°. A failure to reach this developmental milestone is a cause for concern and should be investigated (Johnson, 2012). As a child progresses through adolescence into adulthood the time needed to commence appropriate eye movement diminishes. This is due to the maturation of the brain over time. The speed of transmission of signals increases as myelination occurs. Significant synaptic pruning also takes place. As the child becomes an adolescent their eye movements change from “stimulus driven” eye movements to become “voluntary, cognitively-driven eye movements”. This occurs once integrated networks of neurons are established (Luna & Velanova, 2011).

1.3.5 Attention

Attention is an important consideration in eye tracking tasks. Attention is made up of several components. One of these is the ability to disengage from one object or scene and orient to a new image. It is thought that a pathway between the eye and the superior colliculus allows this process, with input from the parietal cortex and prefrontal areas (Susan A Rose et al., 2019).

Research has shown that the speed of children's attentional disengagement is slower than adults but that it improves with age. This can be exhibited by using a gap paradigm. When measuring the gap paradigm an individual is initially shown a fixation point then asked to saccade to another object in the periphery. The saccadic latency is calculated. If the initial fixation point is made to disappear before the second object appears the individual will have already disengaged from the fixation point, the saccadic latency to the peripheral object decreases. It is proposed that the improvement over time of attentional disengagement is due to development of the frontal regions (Van der Stigchel et al., 2017).

1.4 Eye Tracking Hardware and Experimental Protocols

1.4.1 Technology

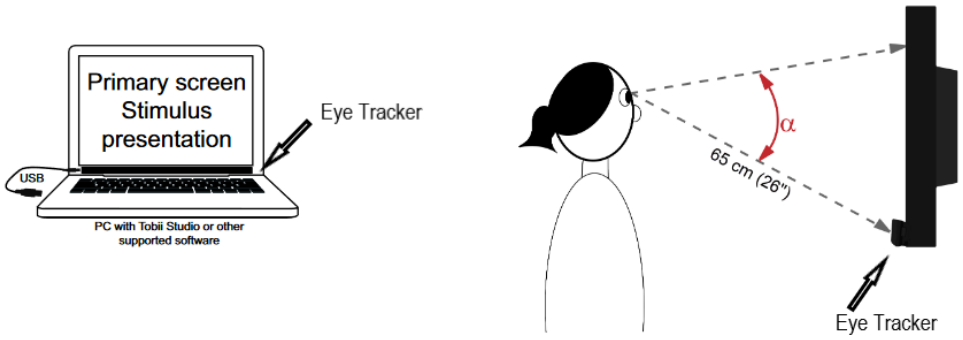
Eye tracking is used in many areas of research such as psychology and marketing. Eye tracking with an infrared camera is a method of tracking eye movement (Holmqvist, 2011). Since remote eye trackers have become more available there has been an increase in studies involving children. Remote eye trackers allow a degree of freedom of movement, there is no need for the child to be restrained (Hessels et al., 2017).

The remote infrared eye tracker works by illuminating the eye with an infrared light and measuring the resultant corneal reflection and pupil size. Eye tracking analysis software employs the combination of time stamp data and co-ordinates to express a measurement of eye movement. An algorithm determines if an eye movement has occurred. This is called an event detection. An event can be either a fixation or a saccade. Eye movements are measured in visual degrees (°) or minutes (´). 1° is equal to 60´ (Holmqvist, 2011).

Figure 1.2 Image of an infrared eye tracker. Tobii x3-120. (*Tobii Pro X3-120*, 2019)

Figure 1.3 illustrates the optimal set-up for the infrared eye tracker. The participant is fixed at a distance of 65cm from the eye tracker. At this distance the gaze angle is 36° (Studio, 2017).

Figure 1.3 Experimental set-up of X3-120 eye tracker (Studio, 2017).



Other eye tracking methods include head mounted eye trackers or tower mounted eye trackers. Head mounted eye trackers are designed for the infrared light and camera to be situated in a pair of glasses or within a hat. Tower mounted eye trackers fix the individual in place with a chin rest. This offers the advantage of less movement by the participant but this set-up could be intimidating for younger children (Holmqvist, 2011).

1.5 King-Devick Test

1.5.1 Background

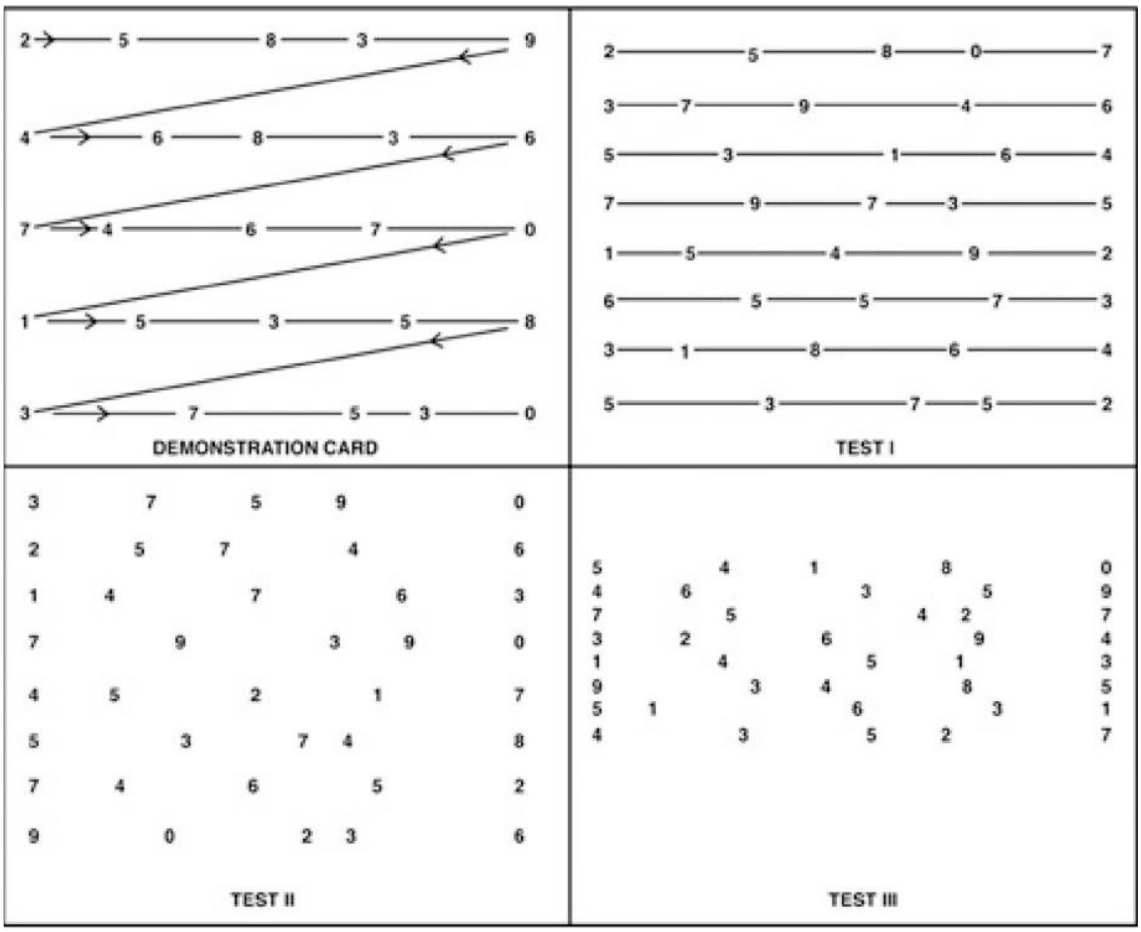
The King-Devick (K-D) test was developed in 1976 to study children with reading difficulties (Lawrence et al., 2019; K. K. Weise et al., 2017).

More recently, the K-D test has been studied as a tool for the evaluation of concussion. In this context it has been studied across a range of contact sports.

The K-D comprises a demonstration card and 3 subsequent test cards which become more difficult as the subject progresses. The cards are made up of numbers which are separated in space with increasing variability of spacing between the numbers as the cards increase in difficulty. The subject performing the test is asked to read aloud the numbers on the card, as quickly as they can. The test is performed at the beginning of the sporting season. This measurement is used as a baseline if a head injury assessment needs to take place later in the season. In studies of sports injury the K-D has been shown to have a specificity of 90% and a sensitivity of 86% for concussion (Ventura et al., 2016). The baseline test-retest reliability has an r^2 value of 0.86 (King et al., 2015). It takes between 1-2 minutes to complete the KD test. A participant may take up to 4.8 seconds longer to complete the KD after sustaining a concussion (Ventura et al., 2016).

The test is used as it involves attention, saccadic eye movements and language, by which it interrogates various pathways in the brain. It is theorised that malfunction of the DPLC could contribute to poor performance in the KD test. The DPLC contributes to short term spatial memory and generating anticipatory saccades (Ventura et al., 2016).

Figure 1.4 ***Demonstration and test cards for the K-D test adapted from Lawrence et al., 2019.***



There are standard instructions for completing the test. The examiner shows the individual the demonstration card. The participant is asked to read the numbers out loud, from left to right, as quickly as they can without any errors. The time to complete along with any errors or omissions is recorded by the examiner (Lawrence et al., 2019).

1.6 Epilepsy

Epilepsy is a neurological disorder characterised by an increased liability to seizures. A history of two unprovoked seizures separated by 24 hours is required for a diagnosis of epilepsy (Fisher et al., 2014). However, a diagnosis may be reached following a single seizure depending on the clinical context, i.e. age and use of supportive electroencephalogram (EEG) testing. A focal epilepsy is a disorder in which seizures originate in one particular brain region e.g. temporal lobe epilepsy (Panayiotopoulos, 2002).

1.6.1 Electrical status epilepticus during slow wave sleep (ESES)

ESES is a childhood epilepsy syndrome. Children with this syndrome experience seizures and experience periods of neuropsychological regression. This is associated with continuous spike and slow wave activity during non-REM sleep, a pattern which replicates the EEG appearance during prolonged epileptic seizures. The age range for this syndrome spans childhood occurring between 3-14 years. Males present more frequently than females.

Current management of children with ESES can consist of in-patient courses of intravenous immune globulin (IVIG), or involve high dose benzodiazepines combined with a maintenance dose of antiepileptic drugs such as Levetiracetam or Lamotrigine (Panayiotopoulos, 2002). ESES requires frequent EEG-studies which capture sleep. These are carried out to look for the EEG pattern of ESES and are repeated after treatment to determine if the pattern has resolved. The amount of time spent in the hospital can be disruptive to patients and their families. Children who experience ESES often need extra supports in school such as resource hours or special needs assistants.

1.6.2 Benign epilepsy with centrotemporal spikes (BECTS)

BECTS is an idiopathic childhood focal epilepsy. Children typically present between the ages of 7-10 years; males are more likely to be affected (Panayiotopoulos, 2002). According to the 2017 International League against Epilepsy classification the seizures experienced with BECTS are focal aware motor seizures. The child is unable to speak and may drool. The motor component usually affects the face and the upper limb (Robert S. Fisher, 2017). The majority of seizures occur during sleep and can last between 1-2 minutes. Children with BECTS have normal development and attend mainstream school, although some reports have shown that 15-30% of children with BECTS may experience learning or behavioural difficulties (Tedrus et al., 2009). The EEG in children with BECTS characteristically shows independent or bilateral sharp wave complexes. These can be observed during wakefulness with an increase in their frequency during drowsiness and sleep. The epileptiform discharges are observed over the central and mid-temporal regions on standard EEG montages (Panayiotopoulos, 2002).

Chapter 2 Literature Review

Eye tracking assessments in normal controls and children with neurological dysfunction.

2.1 Methods

Research using eye tracking as a measurement has increased with the availability of commercial portable eye trackers. While there does not appear to be eye tracking research specifically aimed at children with epilepsy, many other neurological conditions have been evaluated in this way. This literature review focuses on recent eye tracking studies, in particular those paediatric studies which compared an age-matched control group to a population with known neurological disease. The search was initially carried out in June 2019 and updated in December 2019. The following databases were searched through the TCD library website.

- Pubmed - www.ncbi.nlm.nih.gov/pubmed/
- Web of science - http://apps.webofknowledge.com.elib.tcd.ie
- Scopus – http://www-scopus-com.elib.tcd.ie
- Science Direct - https://www-sciencedirect-com.elib.tcd.ie/

Only papers written in English were included in the search. Publications were included if they had been published in a peer reviewed journal. The papers were evaluated for:

1. Subject age: 6-16 years
2. Study design (inclusion/exclusion criteria, sample size, eye tracking definitions, eye tracking measurement equipment, gaze event measures)

3. Methodology (detailed description enabling recreation of the study)

2.2 Results

The initial search terms, “eye tracking” and “children”, were broadened and refined by the addition of “fixation” and “saccade”. Results were narrowed by the requirement of a control group for each study and by inclusion of only those studies which used an infrared eye tracker to measure corneal reflections.

Only one paper provided details about the K-D test. This included a card by card breakdown of time to complete the test which was considered relevant to the present research study.

Table 2.1 Summary of literature search.

Search terms	PubMed (n)	Web of Science (n)	Scopus (n)	Science Direct (n)
Eye tracking children	1084	2287	1805	24,451
Fixation and saccade	41	90	240	1398
Control group	9	19	94	149
Infrared Eye Tracker used	5	4	20	2

Total number of publications after database search: 31

Total number of publications after removal of duplicates and exclusion criteria applied: 7

2.3 Discussion

Table 2.2 Summary of subject details, study design and measurement methods.

Author	Subjects	Clinical details	Stimulus	Measurement equipment
Moiroud et al (2018)	13 dyslexic children, 13 age matched children, 13 reading age matched children	All children – visual exam. Dyslexic children L2MA[1] and neuropsychological testing.	Text C of developmental eye movement test.	Eyebrain T2, 300Hz eye tracker
Sumner, E et al (2018)	23 children with DCD[2], 25 chronological age controls, 29 motor matched controls.	All had intelligence testing, MABC-2[3] and SDQ[4].	Red circle on a black background. Test number 1 in battery – fixation task	Eyelink 1000 eye tracker (SR) 5-point calibration.
Rose, S et al (2019)	31 girls with Rett syndrome and 31 age matched controls.	All children with Rett syndrome diagnosed clinically and with genetic testing.	Colourful rotating clock face followed by an animated cloud.	Tobii x2-60 eye tracker. 5-point calibration.
Yousef, A. et al (2019)	15 children with MS[5], 6 age matched controls	Neurological exam, exam by Neuro-ophthalmologist, SDMT[6], Expanded disability status scale	A video designed to test saccades.	Eye brain tracker T2. 13-point calibration.
Vagge, A et al (2015)	11 children with dyslexia, 11 paediatric controls	Dyslexia diagnosed with the DSM-IV[7]	DDDE-2[8]	Ober 2 System
Tiadi, A et al (2016)	56 paediatric controls, 26 children with dyslexia	Children with dyslexia were given L2MA[1]	Children were given a code word, they were asked to pick a corresponding picture out of a selection of 4.	Mobile Eyebrain Tracker. 13-point calibration.

(Seidman et al., 2015)	328 Adolescent controls, 9 adolescents with concussion	Adolescents with concussion had a SCAT3[9]	King Devick test pre and post season, on side-line if required	No eye tracker used. Participants were timed with a stopwatch.

L2MA[1] – A test of neurological, psychological and phonological abilities in French. (https://www.pearsonclinical.fr/l2ma-2-batterie-langage-oral-langage-ecrit-memoire-attention-2eme-edition-1) DCD2 – Developmental coordination disorder. MABC-23 – Movement assessment battery for children. SDQ4 – Strength and difficulties questionnaire. MS5 – Multiple sclerosis SDMT6 – Symbol digit modalities test DSM-IV7 - Diagnostic and Statistical Manual of Mental Disorders version four. DDDE-28 – Developmental dyslexia and dysorthographia – 2. SCAT39 – Sport concussion assessment tool – 3rd edition.

Table 2.3 Summary of aim, analysis, findings, conclusions and subjective criticism.

Author	Aim	Focus of analysis	Main findings and conclusions	Subjective criticism
Moiroud et al (2018)	That objective eye movement measurements would quantity oculomotor deficits in children with dyslexia	Number of saccades, saccadic amplitude, number of fixations, fixation duration, time to complete	Children with dyslexia had a longer time to complete and longer fixation duration. There was no difference between groups when measuring saccades.	Small sample size.
Sumner, E et al (2018)	To use eye tracking to measure eye movements and higher order processing in children with DCD.	For the fixation task, time spent on target, number of saccades and average fixation duration.	Children with DCD have a higher number of saccades and a shorter average fixation duration. Children with DCD make more anticipatory saccades, highlighting a problem with saccadic inhibition.	Visual acuity was not tested.
Rose, S et al (2019)	Further understanding of attention in people with Rett syndrome.	Number of saccades to the periphery and saccadic reaction time.	Children with Rett syndrome did poorly in comparison to their peers on both measures, the results were most pronounced in people who had objectively worse symptoms or had begun regression earlier.	Study is not easily repeatable.

Yousef, A. et al (2019)	Feasibility of eye tracking in children, specifically children with MS	Saccadic latency, anti-saccadic latency	Children in the MS group had an increased saccadic latency. No difference was found between the anti-saccadic latencies.	Small study sample size. The study is not easily repeatable without the stimulus.
Vagge, A et al (2015)	Analyse eye movement patterns while reading in children with or without dyslexia	Loss of fixation, number of saccades, reading time, number of regressions.	Children in the dyslexia group had an increased reading time, number of saccades and number of regressions.	Small sample size. Testing was not completed for co-existing conditions such as ADHD.
Tiadi, A et al (2016)	To evaluate phonological visual auditory recognition in a group of age matched children with and without dyslexia.	% of total time spent on target, Latency of the first saccade. Study used regions of interest.	Parameters of paediatric controls improved with age. Children with dyslexia had an increased saccadic latency and looked at all 4 pictures for a similar time. Normal controls fixated for longer on the target.	ADHD was not excluded in the dyslexia group.
(Seidman et al., 2015)	Assess the use of the K-D as a concussion screening tool in adolescents	Time to complete each of the cards and total time to complete.	There is a slight learning effect in normal controls. Participants with concussion were slower than their baseline when tested on the side-line but returned to baseline at the end of the season.	Some people will deliberately complete their baseline evaluation slowly. Eye tracking would add an extra dimension to their evaluation in the event of a suspected concussion.

(Moiroud, 2018; Susan A Rose et al., 2019; Seidman et al., 2015; Sumner et al., 2018; Tiadi et al., 2016; Aldo Vagge et al., 2015; Andrew Yousef et al., 2019)

2.4 Conclusion

This study aims to quantitatively study fixations, and eye-movements in healthy adult and paediatric control cohorts, using remote eye tracker technology and to compare these measurements between children with focal epilepsy and healthy controls. Seven papers were identified in the literature review. Epilepsy was not a focus in any of the studies although one paper by Rose et al studied children with Rett Syndrome, which is associated with epilepsy in association with a profound developmental disorder. The studies identified were focused on disorders of Childhood Development such as Developmental Coordination disorder or on multiple sclerosis.

Chapter 3 - Research Questions and Hypothesis

3.1 Healthy control

3.1.1 King-Devick Test

i. That the Time to Completion for the King-Devick test will decrease with increasing age and then reach a plateau.
ii. That the number of Fixations and Saccades will be proportional to the time to completion of the King-Devick.

3.1.2 Number Naming Video Task

i. That adults and children without neurological disease will be able to correctly detect and name each of the five numbers.

3.1.3 Spot the Difference Task

i. That the Time to Complete for the task will decrease with increasing age and then reach a plateau.
ii. That there may be a difference in time to completion for people who play video games when compared with people who do not.

3.2 Children with focal epilepsy

3.2.1 King-Devick Test

i. Children with focal epilepsy will take a longer time to complete the task than their age matched controls.
ii. Children with focal epilepsy will fixate for longer and have a greater number of fixations.

3.2.2 Number Naming Video Task

i. Children with focal epilepsy may not see all the numbers in the time allotted to watch the video.
ii. They may have a greater number of Fixations.
iii. They may have a greater number of Visits and Revisits to each target when compared with age matched controls.

3.2.3 Spot the Difference Task

i. Children with focal epilepsy will take longer to complete the task.
ii. Children with focal epilepsy will have a greater number of Visits and Revisits to each object.

Chapter 4 - Methods

4.1 Subjects

4.1.1 Normal controls

Adult control subjects were recruited from the staff members of the Departments of Clinical Neuroscience in Children's Health Ireland at Crumlin along with family and friends. Paediatric controls were recruited from patients and families who attended the Department. Participants were also recruited from a primary school, Our Lady of Lourdes girls national school, Ballinlough in Cork where children from 4th, 5th and 6th class, aged 9-13 years were tested.

4.1.2 Children with epilepsy

Children with epilepsy were recruited through the Department of Paediatric Neurology and through the Departments of Clinical Neurophysiology in both CHI at Crumlin and CHI at Tallaght. Electroencephalogram (EEG) was recorded in all children within this group which helped to classify their epilepsy syndrome. All EEGs were carried out by Clinical Physiologists using the standard 10-20 electrode placement system. All EEGs were recorded after sleep deprivation and captured the waking, drowsy and non-REM stage I-III (N1-N3) sleeping states. Children were recruited if they had a focal epilepsy such as benign partial epilepsy of childhood with centrotemporal spikes (BECTS) or electrical status epilepticus during slow wave sleep (ESES). Children with psychiatric presentations or with intellectual vulnerability were not recruited.

4.2 Acquisition

4.2.1 Ethical approval

Ethical approval for the study was obtained from the Medical Research Ethics Committee of Our Lady's Children's Hospital, Crumlin (OLCHC), now known as Children's Health Ireland at Crumlin. A pilot study was approved permitting recruitment within the hospital only. Follow-up permission was extended to permit testing in the community which included schools and sports clubs. Correspondence from the Ethics Committee is contained in appendix 10.5.

4.2.2 Enrolment

Information leaflets were provided to both the parents/guardians and the participants. Both parent/guardian consent and participant assent forms were completed before the test was performed. All people participating in the study were given a unique identifier and then de-identified, any data obtained from the study is being kept securely within the Department of Clinical Neurophysiology in CHI at Crumlin. A copy of all information leaflets, consent forms and assent forms can be found in Chapter 10 Appendices 10.2 and 10.3.

4.3 Experimental Set-up

4.3.1 Equipment

The eye tracking equipment employed was a Tobii X3-120 infrared eye tracker. Tobii Studio Software is the companion software for eye movement data acquisition. The eye tracker records at a frequency of 120Hz. The eye tracker has an accuracy of 0.4º and a precision of 0.24º ("Tobii studio analysis software," 2011).

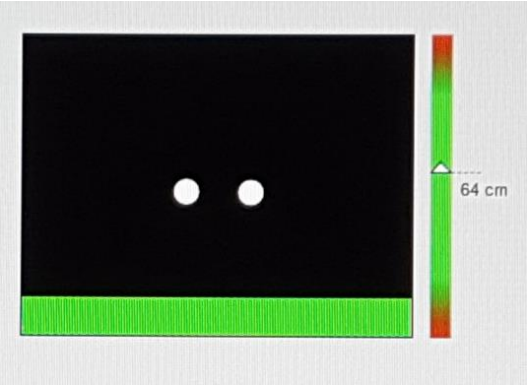
4.3.2 Participant positioning

Subjects undergoing testing were asked to sit in a chair with stable legs facing the computer. If wearing glasses, they were cleaned beforehand. Participants were instructed to keep their eyes open and to keep as still as possible during calibration and recording.

4.3.3 Calibration

Before each portion of the test was carried out a calibration process was undertaken. For optimal calibration the subject was positioned 60-65cm from the laptop screen and eye tracker. Before the calibration, positioning of the subject was determined using the Tobii software calibration tool, Track Status.

Figure 5.1 Track status tool showing a green colour bar indicating optimal positioning for a participant. ("Tobii studio analysis software," 2011)



The ideal status was signalled by the appearance of two white dots which represent each eye and a colour bar which turns from red to orange to green to indicate correct positioning of the subject relative to the tracker. The participant was encouraged to sit still. To facilitate this a stationary chair with backrest was placed in front of a desk and height-adjusted for the subject. If the colour bar was not green for the test it would lead to poor quality data.

4.4 Eye Tracking Stimuli

4.4.1 King-Devick Test Card II

The King-Devick Test is a rapid number naming task (Katherine K. Weise et al., 2017). As outlined in chapter 3.1 the hypothesis is that the time to complete this task will decrease as age increases until it reaches a plateau in late childhood or early adulthood.

Figure 4.2 King Devick Test Card II (adapted from Weise, et al. 2017)

Each participant was shown this card first and instructed to read the numbers out loud, left to right from the top, as fast as they could. Subjects were told that if they made a mistake they could correct it. After the pilot study the instruction “ready, set, go” was added. The test was stopped after the participant named the last number. The card was imported into the Tobii Studio Software in PDF form.

4.4.2 Number Naming Video Task

The eye movement systems being elicited by this task relate to the saccadic, fixation and smooth pursuit systems. This task is a time limited at 10s, the hypothesis is that individuals without neurological disease will correctly identify all appearing numbers.

Figure 4.3 Screenshot of number naming task

This video was originally developed in Microsoft® PowerPoint. The numbers were placed on each slide, then the animation function was used to make them appear in sequence. There was a total of 300 frames over the 10 second video. The video was imported into Tobii Studio as a Microsoft® Windows Media video file. ("Tobii studio analysis software," 2011)

Table 4.1 Sequence of appearance of numbers in video

Object	Frame at which they appear	Time at which they appear (Sec)
Cross	0-1	0
Green 2	16	0.5
Grey 8	60	2.03
Orange 3	120	4.03
Blue 1	169	5.6
Maroon 4	239	8.02

Before the video started, participants were instructed that “numbers are going to pop up on the screen, and to call the numbers out when you see them”. The Green 2, Grey 8 and Maroon 4 all appeared spontaneously. The Orange 3 flew onto the screen from the right side. The Blue 1 appeared rotating on the spot, gradually becoming darker before stopping. The video automatically ended after 10 seconds, regardless of whether the participant had correctly identified all of the numbers.

4.4.3 Spot the difference task

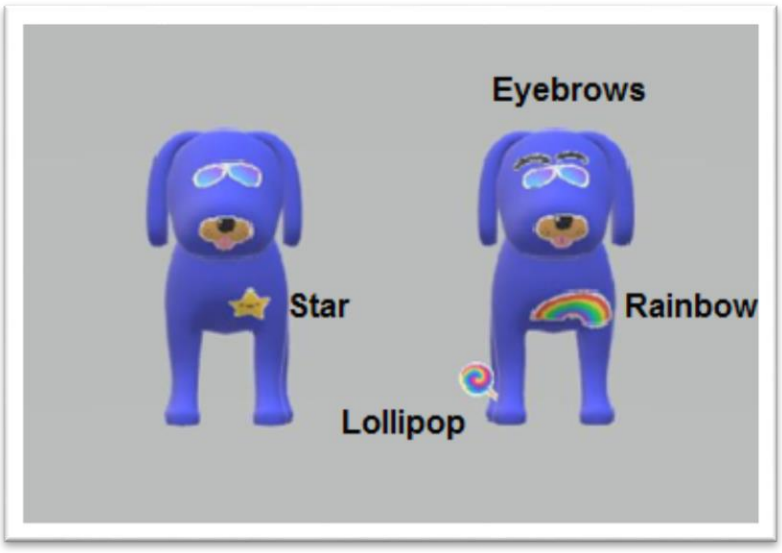
The hypothesis of this task, as outlined in Chapter 3.3 is that the time to complete it would decrease as children increase in age before reaching a plateau. It is also hypothesised that individuals who play on video game-consoles will be faster and more accurate at completing the task when compared with their peers.

This task comprised 2 separate pictures. The images were created in Microsoft® Paint 3D. The picture was added as a PDF to Tobii Studio. Before the test was started, participants were asked to identify all of the differences in the pictures as

quickly as possible. Switching from the first to the second picture and ending of the task was carried out manually by the experimenter once the participant correctly identified all of the differences. It has been shown that children pay more attention to stimuli that are eye catching when compared to plain targets such as dots of only one colour (Irving et al., 2011).

Figure 4.4 Spot the difference picture number 1 “Faces”

Figure 4.5 Spot the difference picture number 2 "Dogs"



4.5 Pilot study

4.5.1 Pilot testing of the full experimental protocol

Pilot testing was carried out in a group of adult volunteers, all of whom were postgraduate students or staff of TCD. Eight tasks, executed as one sequence in Tobii Studio, took 12 minutes to run. It quickly became apparent that this was too long. In order to ensure high quality data, it is important that the participant stays still and maintains their eyes in an optimal position. Twelve minutes to run a test is a very long time to sit still, especially since the study was primarily designed for children.

4.5.2 Changes to the test protocol following the pilot study

After the pilot study, each element of the test was separated into its own task as opposed to being run consecutively as one lengthy test protocol. This ensured that a calibration could be performed before each element of the test. It allowed participants to have a break in between each task, and to correctly reposition themselves before beginning the next task. Separating the tasks lengthened the protocol to 20 minutes per participant, but this was compensated by an opportunity for breaks between test elements.

4.5.3 Changes made to the format of the protocol

Originally the Spot the Difference Task was imported into Tobii Studio as a Windows Media video. Each picture was shown for 10 seconds; the time to complete each picture was noted manually. However, after 1 participant struggled to name any of the objects in the time allotted, the format was changed to a PDF. This allowed the test to be stopped only after the participant had

correctly identified all of the objects. The Tobii Studio software was then time locked to the task being terminated.

4.5.4 Changes made to the length of the protocol

Originally there were eight components to the test. After pilot analysis it was felt that some of the tasks were duplicative. The decision was made to keep three tasks. The total testing time was thus compressed to less than 10 minutes. This was helpful for restless participants. Some data was acquired for the other tasks which can be revisited in the future.

4.6 Data analysis

4.6.1 Data export for all studies

Before data could be interpreted it was necessary to sort it into participant groups. Independent categorical variables that were collected for each participant, (see table 1 below,) were entered through the Manage Participants Tab in Tobii Studio. A velocity chart was created and exported. The velocity chart plotted angular velocity of the eyes along with gaze co-ordinates ("Tobii studio analysis software," 2011). There was a delay between manually triggering a task to begin and the eye tracker presenting the stimulus, this delay was not the same duration for each study so it was necessary to observe each sample individually post collection. Each test was edited into segments and each segment was labelled by participant group. This allowed any time not actually involved in eye tracking to be removed from analysis. The raw data was then exported through the Export Tab for each segment.

Table 4.2 Independent variables

Age (years)	6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20-29, 30-39, 40-49, 50-59, 60-69
Brain surgery	No, Yes
Concussion	No, Yes
Elapsed time (since concussion)	N/A, <3 hours, <24 hours, <7 days, <14 days, <21 days, >21 days
Epilepsy	No, ESES, Focal, Generalised
Eye colour	Blue, Non-blue
Eye history	Nil, Surgery, Patching
Formally sleep deprived	No, Yes
Gender	Female, Male, Other
Included for analysis*	Adult control, Paediatric control, Epilepsy, Post-TBI, Post-ICU, Not included for analysis
Medication	Nil, Anti-epileptic drug
Participant Group	Adult control, Paediatric control, Epilepsy, Post-TBI, Post-ICU
Previous concussions	N/A, Yes 1, Yes 2, Yes 3
Refracted	No, Yes
Video game	Unknown, Screen, PlayStation®/Xbox, No

4.6.2 Data export for spot the difference task

Areas of Interest (AOI) are defined areas on an image. Specific data are collected whenever the participant fixates within the AOI. AOIs allow measurement of: the time between appearance of an image and the moment the participant first fixates on the defined area, the total time spent on the AOI and the number of fixations on the AOI. AOIs can be known as “Regions of Interest” or “Interest Areas”. AOI are best utilised when there is a large space between different visual targets, for this reason they were not used in the K-D Task as the numbers are too close together (Holmqvist et al., 2015). The AOIs used in the Spot the Difference task were static AOIs. The AOIs are placed manually by the experimenter once the stimulus has been imported into Tobii Studio ("Tobii studio analysis software," 2011). Each AOI measured 16140-16260 pixels or approximately 1-1.32% of the frame. Figure below demonstrates the use of a static AOI for the Spot the Difference task “faces”.

Figure 4.6 Spot the Difference "Faces" with an AOI placed over the "sad" face

4.6.3 Data export for Saccadic Numbers Task utilising dynamic areas of interest

The Saccadic Numbers Task used dynamic areas of interest (AOI). Dynamic AOI's are used when the stimulus is a video ("Tobii studio analysis software," 2011). As this task was a video in which objects appeared it was necessary that the areas of interest only began detecting events once the object had become visible to the participant. The Saccadic Numbers Task had AOIs measuring between 20200-20600 pixels or approximately 1% of the frame. The Saccadic Numbers Task was a video. The video had to be broken up into a segment and then into five separate scenes for each of the five appearing objects. Dynamic AOIs were then placed on the objects in the scenes in which they appear. Measurements regarding each individual AOI were made for each scene, each scene lasted from the frame in which the number appeared until the end of the video. Once the test had been segmented and fragmented into scenes the data was exported from the Statistics Tab. This included information such as Time to First Fixation (TTFF) and visit information.

4.6.4 Data quality

In an ideal situation each participant would keep perfectly still with their eyes wide open with no obstructions present. Using Tobii studio software there are two ways to measure data quality. The first is to observe calibration. A poor quality study will show "long error vectors" as green lines spreading out from the calibration points or the participant may fail calibration entirely. If this happens the participant can be coached to remain still and keep focused on the target ("Tobii studio analysis software," 2011).

The second measure of data quality is to look at the gaze sample (GS) percentage and the weighted gaze sample (WGS) percentage.

Equation 4.1 Calculation of gaze samples

$$Gaze\ sample = \frac{Number\ of\ usable\ eye\ tracking\ samples\ correctly\ identified}{Number\ of\ attempts}$$

Weighted gaze samples take into account if both eyes were detected. A low GS or WGS can result from a participant looking away from the screen or if their eyes were obscured. This occurred during the study, it was caused by bifocal glasses, thick eyelashes, and mascara on eyelashes or drooping eyelids ("Tobii studio analysis software," 2011). Data which was deemed to be poor was excluded from analysis. In other studies, testing paediatrics it was found that the GS and WGS averaged about 75% (Pel et al., 2010).

When a person's eyes are difficult to accurately measure the eye tracker can misidentify events. For this reason, each data set was screened for measurements that did not make sense in the context. Saccadic velocities measuring over 700º/s were excluded. Saccadic velocities accelerate to a peak and then decelerate. Very high velocities appearing on their own are unlikely to be genuine eye movement recordings. These can occur when a participant moves their head and the corneal reflection is mistakenly recorded ("Tobii studio analysis software," 2011).

4.7 Statistics

Data from Tobii Studio were exported to Microsoft Excel. Information gathered from AOI was exported through Notepad and then to Microsoft Excel. The data from Tobii Velocity Chart was exported to Microsoft Excel in the format 97-2003.

Statistical analysis was carried out on JMP Statistical Discovery software version 14. Nonparametric statistical analysis was utilised. The data was plotted into histograms, the data appeared to not fall within a normal distribution. Therefore when comparing the Paediatric Control Group and Focal Epilepsy Group, nonparametric comparisons for each pair were made using the Wilcoxon Method.

Chapter 5 Results – Normal Control Group

5.1 Statistical analysis

All analyses were carried out using JMP Statistical Discovery, version 14.

The distribution of all data were plotted and inspected for normality and the presence of outliers using the Tukey and Median Absolute Deviation (MADe) methods. These distributions are available for inspection in the Appendix.

For the statistics included below, α level was set at 0.05. One of the statistics included is a measure of the variation of the response, this is represented in the text as an r^2 value. R^2 is expressed as percentage between 0.0-1.0. The term adjusted r^2 is also used in this chapter; an adjusted r^2 reflects the sample size measured. If an *adjusted* r^2 is much smaller than an unadjusted r^2 value the result is less robust. A negative adjusted r^2 value indicates that the sample size is too small to perform the analysis. This method is susceptible to outliers. Prior studies have noted that young children can perform variably and become more consistent as they grow older (Katherine K. Weise et al., 2017). A wider variation can be expected for performance at a younger age.

5.2 Demographics

Over the course of the study 113 individuals were recruited as normal Controls. The participants were assigned to either an Adult or Paediatric Control Group. Six individuals were not included in analysis for any task. Four of the excluded individuals were unable to complete calibration. Two participants had extremely low quality data, as defined by criteria described in Chapter 4 Methods.

The study cohort comprised more females (n=102) than males (n=11). Almost all of the Paediatric Control Group were recruited from a Girls National School, Our Lady of Lourdes Girls National School, Cork. Each individual was asked at the Time of testing if they played a video game console i.e. Sony PlayStation® or Microsoft X-Box.

5.2.1 Demographics for King-Devick Test

A Total of 95/113 individuals were included for analysis after completing the K-D test. Individuals were excluded if they had followed the instructions incorrectly or in a way that would make the task more difficult or if the data gathered was not of sufficient quality (n=18). For example, some children were excluded after they read lines of the K-D in the wrong direction. This is demonstrated in figure 5.1, the gaze plot on the right is an example of a child who read from top to bottom rather than from left to right, the gaze plot on the left shows the correct order for reading the K-D Test.

Figure 6.1 Example of gaze plots from 2 volunteer children

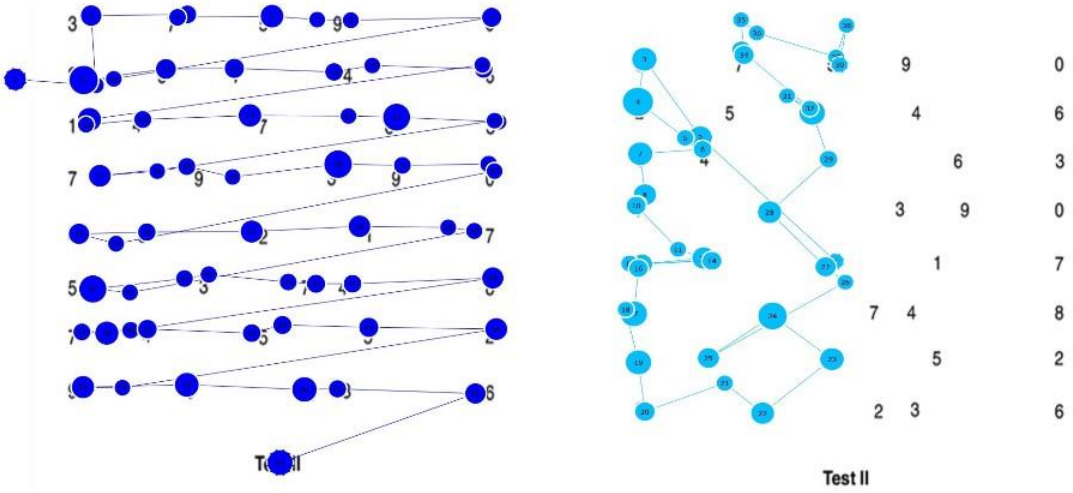


Table 5.1 summarises age and sex of participants for the K-D Test.

Table 5.1 Demographics for K-D Test.

N=95	Adult Control Group	Paediatric Control Group
Total (n)	26	69
Age Range (y)	21-49	8-13
Sex (Female/Male)	19/7	67/2

The Adult Control Group were characterised by age profile: 20-29, 30-39 and 40-49 years.

Table 5.2 Demographics of the Adult Control Group for K-D Test

	20-29 (years)	30-39 (years)	40-49 (years)
Total (n=26)	13	10	3
Sex (Female/Male)	11/2	6/4	1/2
Plays Video Games (n)	1	1	1

Across all three Groups a Total of 18 people played a video game console regularly.

Table 5.3 Demographics of Paediatric Control Group for K-D Test

	8 (years)	9 (years)	10 (years)	11 (years)	12 (years)	13 (years)
Total (n=69)	2	2	17	23	24	1
Sex (Female/Male)	1/1	1/1	17/0	23/0	24/0	1/0
Plays Video Games (n)	1	1	4	1	2	1

5.2.2 Number Naming Video Task

After exclusion criteria were applied 95/113 Normal Controls were analysed for the Number Naming Video (NNV) Task. Eighteen participants were excluded as their Eye Tracking data was of insufficient quality, the GS and WGS were below 75%, as discussed in Chapter 4 Methods.

Table 5.4 Demographics for Adult Control Group in the NNV Task.

	20-29 (years)	30-39 (years)	40-49 (years)
Total (n=22)	9	11	2
Sex (Female/Male)	7/2	7/4	1/1
Plays Video Games (n)	1	1	1

Table 5.5 Demographics for Paediatric Control Group for NNV Task

Age	8 (years)	9 (years)	10 (years)	11 (years)	12 (years)	13 (years)
Total (n=69)	1	1	21	23	26	1
Sex (Female/Male)	1/0	1/0	21/0	23/0	26/0	1/0
Plays Video Games (n)	0	0	5	1	1	1

5.2.3 Spot the Difference Task

The Total number available for the Spot the Difference Task (SDT) is 80.

Table 5.6 Demographics for Spot the Difference Task.

	Adult	Children
Total (n)	16	64
Age Range (y)	21-49	5-13
Sex (Female/Male)	10/6	60/4

There were fewer younger children available for this task. The bulk of the Group was made up of eleven and twelve year olds.

Table 5.7 Demographics for Adult Control Group in SDT

Age (Years)	20-29	30-39	40-49
Total (n=16)	8	6	2
Sex (Female/Male)	6/2	3/3	1/1
Plays Video Games (n)	1	0	1

Seventeen of the Paediatric Control Group played video games.

Table 5.8 Demographics for Paediatric Control Group for SDT

Age (Years)	5	8	9	10	11	12	13
Total (n=64)	2	2	2	9	25	23	1
Sex (Female/Male)	0/2	1/0	1/0	9/0	25/0	23/0	1/0
Plays Video Games (n)	2	1	1	8	2	2	1

5.3 King-Devick Test

5.3.1 Adult Controls

Twenty-six Adult volunteers were included for analysis.

5.3.1.1 Time to Complete task

The K-D is a rapid number naming task. It was selected to be a part of this study as it is a validated measure for assessment of reading ability and oculomotor function (Katherine K. Weise et al., 2017).

The Velocity Chart and Gaze Plot show an example of excellent eye tracking quality, WGS of 99% in a participant who took 12s to complete the K-D test.

Figure 5.2 Gaze Plot for K-D Test – Adult Participant. On the Gaze Plot the red circles represent Fixations, the straight lines represent Saccades.

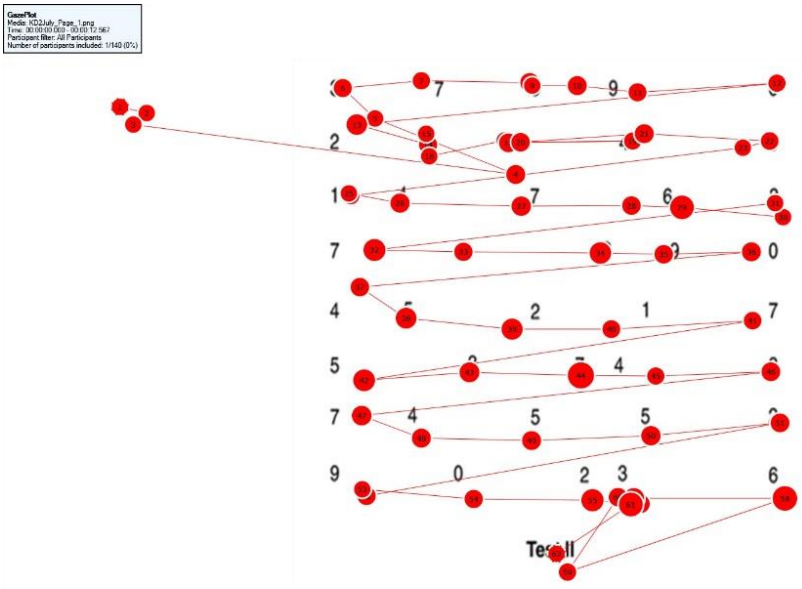
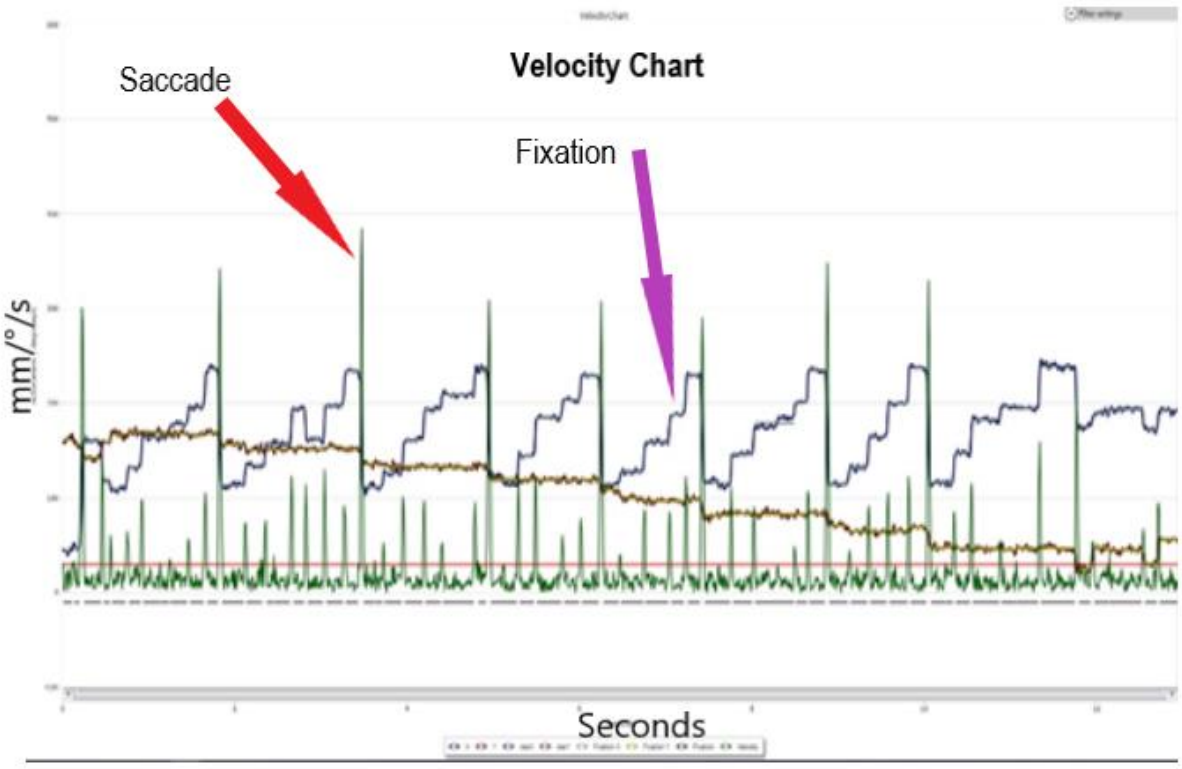


Figure 5.3 Velocity chart for K-D Test - Adult Participant. On the Velocity Chart the red arrow points to the Saccadic Velocity in º/s. The purple arrow points to a Fixation.



The First measure of the K-D test is Time to Complete.

Table 5.9 Median and range for Time to Complete (s) for each age bracket

	20-29 (n=13)	30-39 (n=10)	40-49 (n=3)	Group (n=26)
Median (s)	14.2	16.7	14.6	14.5
Range (s)	11.8-19.7	12.5-29.4	14.1-20.0	11.8-29.4

Table 5.10 Median and range for Time to Complete for each sex (p value 0.06 when measured by

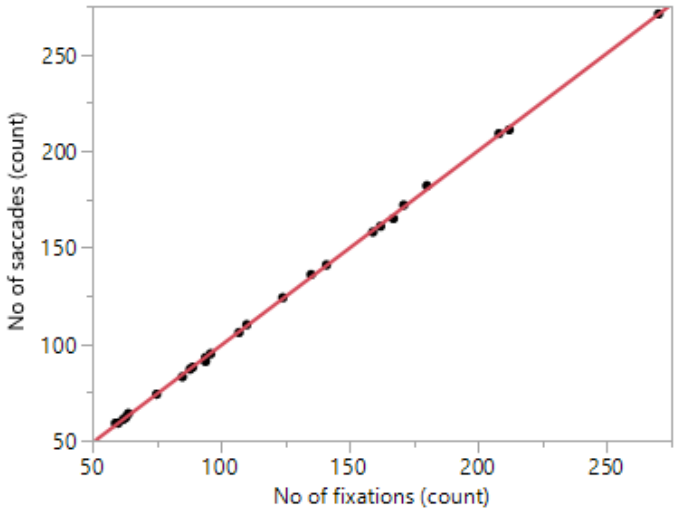
	Female (n=19)	Male (n=7)
Median (s)	16.4	13.9
Range (s)	11.8-29.4	12.5-14.8

Only three individuals from the Adult Control Group played with video games consoles, all three were male. The mean values of the console based video game players are 3s faster than the non-playing Group. The r^2 value was 0.06 with an adjusted r^2 value of 0.02, the lower adjusted r^2 suggests that the sample size is too small for meaningful comparison.

5.3.1.2 Number of Fixations and Duration of Fixations during K-D Task

The first Eye Tracking measure of interest is the number of Fixations over the course of the task. Fixations are classified by the Fixation filter settings in the Gaze Export Tab (Studio, 2017). In the majority of cases the number of Fixations is directly correlated with the number of saccades recorded by the Eye Tracker, as seen in figure 1 below. Going forward only the number of Fixations will be used.

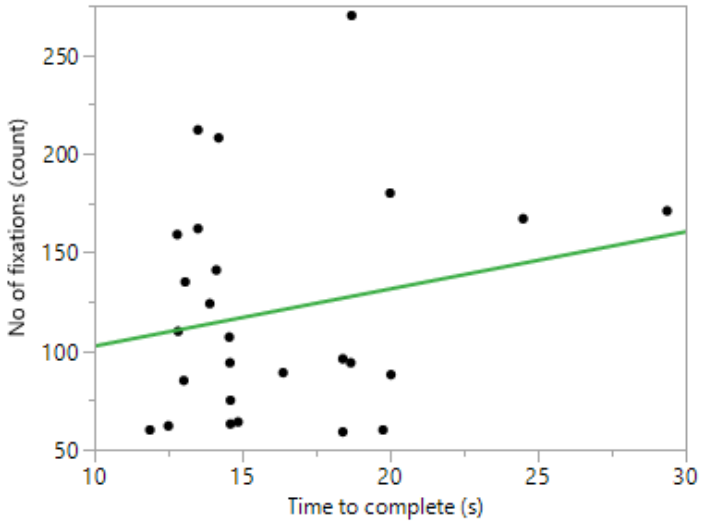
Figure 5.4 Bivariate fit of number of Fixations (n) vs number of saccades (n) during K-D Test for the Adult Control Group. R^2 value = 0.99



The number of Fixations ranged from 59-270 with a mean of 120 and a median of 101. The distribution of this data is available in Appendix 10.8. There was no difference between age Groups, sex or video game use in the number of

Fixations. The Time to Complete the K-D did not correlate with the number of Fixations, as seen below in figure 2. The adjusted r^2 value was 0.04.

Figure 5.5 Bivariate fit Time to Complete K-D Test vs Number of Fixations (n) in the Adult Control Group. R^2 value = 0.04



A further Eye Tracking measure for this test is Fixation Duration, the distribution of this data is available in Appendix 10.9.

Table 5.11 Median and range of Maximum Fixation Duration for Adults completing K-D Test

	Fixation Duration (s)
Median (s)	0.5
Range (s)	0.3-1.3

There was no difference between the sexes or with computer gamer groups for Fixation Duration.

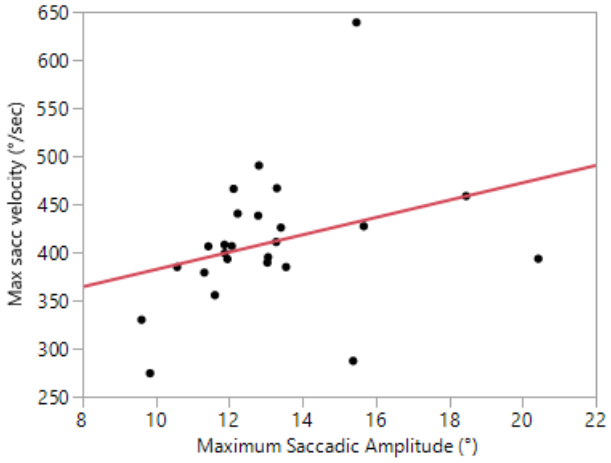
5.3.1.3 Saccadic Velocity and Saccadic Amplitude during K-D Test

The distributions for both saccadic amplitude and saccadic velocity are available in appendix 10.10 and 10.11.

Table 5.12 Median and range of Maximum Saccadic Amplitude and Maximum Saccadic Velocity for Adults who Completed the K-D Test

	Saccadic Amplitude (°)	Saccadic Velocity (°/s)
Median	12.5	399
Range	9.6-20.4	274-490

Figure 5.6 Bivariate fit of Maximum Saccadic Amplitude vs Maximum Saccadic Velocity. R^2 value 0.10



5.3.2 Analysis of Paediatric Controls on K-D Test

Sixty-nine individuals were included for analysis after completing the King-Devick Test. All individuals in this Group attended mainstream school and had no known neurological disease.

5.3.2.1 Time to Complete Measure

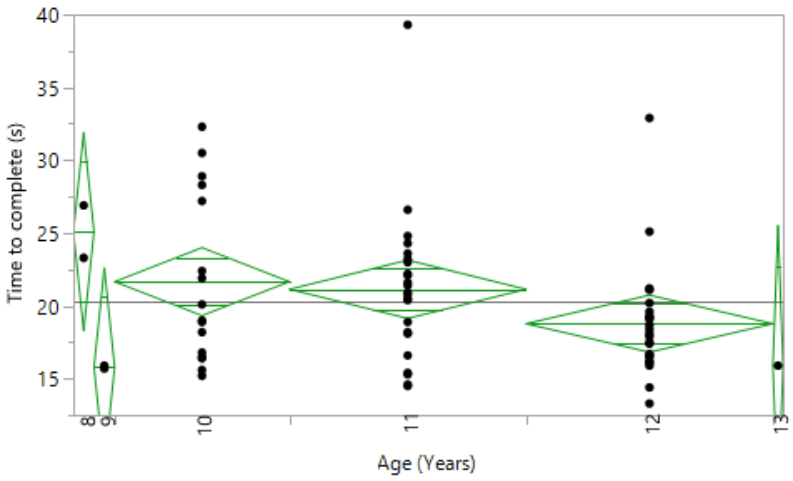
The range of the Time to Complete measure in the children's Control Group is broader than that in Adults, 13.3-39.3s.

Table 5.13 Median and range of Time to Complete K-D Test by Age (years)

Age	8 (n=2)	9 (n=2)	10 (n=17)	11 (n=23)	12 (n=24)	13 (n=1)
Median(s)	25.1	15.8	20.1	20.9	18.25	15.9
Range(s)	23.3-26.9	15.7-15.9	15.2-32.3	14.5-39.3	13.3-32.9	15.9

As the age of the children increases the Time taken to complete the K-D Test decreases.

Figure 5.7 One-way analysis (ANOVA) of Time to Complete vs age. n=69 r2 = 0.12, adjusted r^2 value 0.05



There are only two boys in this cohort so the sexes cannot be compared. There is no difference between the ten children who reported playing video games and the children who did not.

5.3.2.2 Number of Fixations and Duration of Fixations during K-D Task

The number of Fixations in the Paediatric Control Group ranged from 49-236 with a mean of 108 and a median of 88.

Table 5.14 Median and range of number of Fixations during K-D Test

	8 (n=2)	9 (n=2)	10 (n=17)	11 (n=23)	12 (n=24)	13 (n=1)
Median(n)	114	65.8	89	103	82.5	74
Range(n)	110-118	58-79	49-226	67-236	56-231	74

One-way ANOVA testing between different paediatric age groups did not suggest any effect of age on Number of Fixations during the KD.

Figure 5.8 Bivariate fit of Time to Complete K-D vs number of Fixations. r^2 value of 0.24. r^2 adjusted 0.23. p value <0.0001

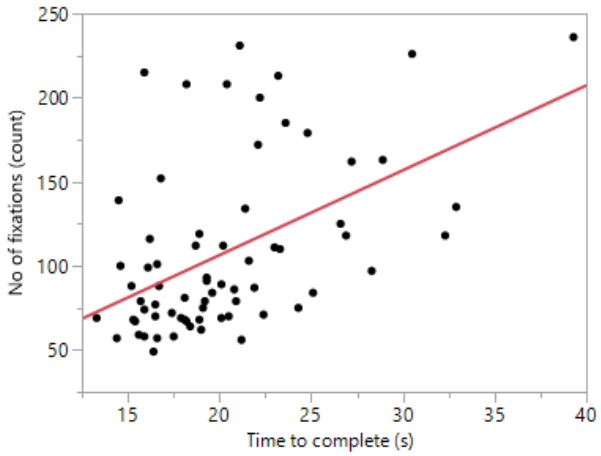


Table 5.15 Median and range of Maximum Fixation Duration for each age

	8 (n=2)	9 (n=2)	10 (n=17)	11 (n=23)	12 (n=24)	13 (n=1)
Median(s)	0.9	0.5	0.7	0.63	0.64	0.67
Range(s)	0.8-1.0	0.4-0.59	0.4-1.2	0.5-1.2	0.4-1.1	0.67

There was no significant effect of age on Maximum Fixation Duration (MFD) among the paediatric control group although the mean of the MFD was longer in children (0.7s) than in the adult control group where the value was 0.5s.

5.3.2.3 Saccadic Velocity and Saccadic Amplitude during K-D Test

The median Maximum Saccadic Velocity was 401°/s. The median Maximum Saccadic Amplitude was 13° with a range of 8-28°.

5.4 Number Naming Video Task

The number of individuals included in the analysis for this task was ninety-five. The Group comprised of 22 Adults and 73 children. Unlike the KD and SDT, the Number Naming Video Task (NNVT) had a fixed duration of 10s to complete and therefore there were no performance time measurements. The other experimental difference is that this task ends regardless of whether the individual has identified all five targets. Therefore there was a possibility of incomplete performance of this task.

5.4.1 Number of Fixations and Fixation Duration for Adult Control Group

During the 10s video there was a median of 70 Fixations, with a range of 27-187. The distribution of the number of fixations is shown in appendix 10.12. The median Maximum Fixation Duration was 0.69s with a range of 0.17-1.6s.

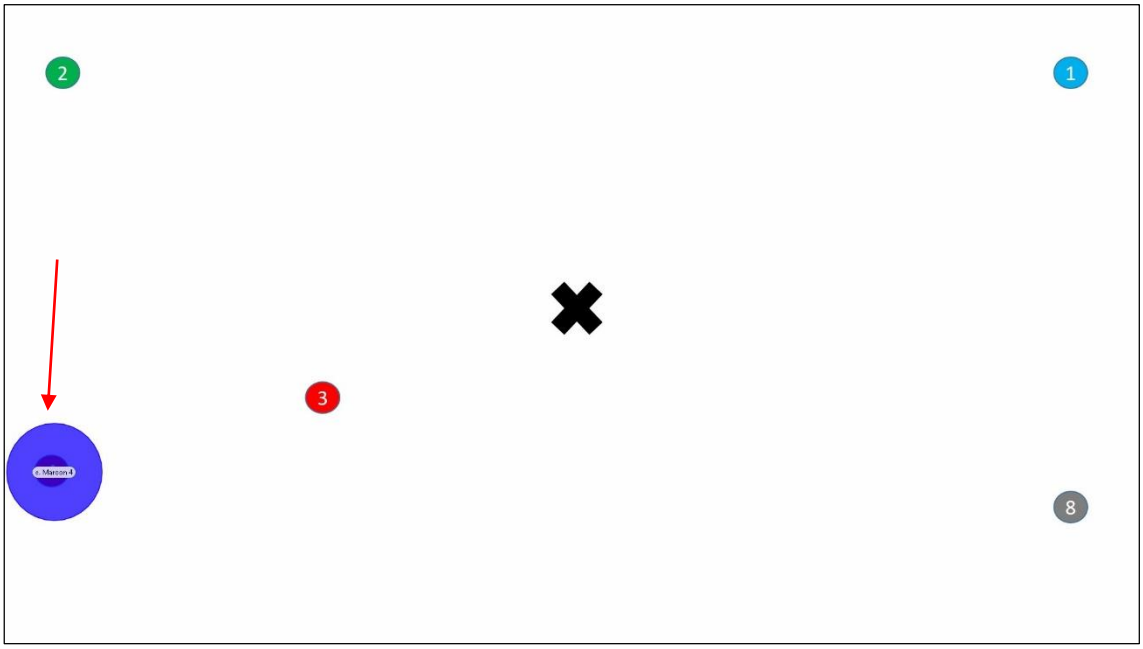
5.4.2 Saccadic Velocity and Saccadic Amplitude Data for Adult Control Group

Maximum Saccadic Amplitude ranged from 14-40° with a median of 24.9°. The median Maximum Saccadic Velocity was 554°/s, with a range of 298-664°/s.

5.4.3 Area of Interest Results for Adult Control Group

Each appearing object is labelled by its colour and number. Subjects were asked to call out the numbers as they detected them. Figure 5.10 shows an example of a large Blue circular AOI placed over the last appearing stimulus “Maroon 4”.

Figure 5.9 An AOI placed over Maroon 4 to record data. The red arrow points to Maroon 4.



Time to First Fixation (TTFF) is a measure of the time between appearance of the stimulus and an individual's Fixation on it for the first Time (Studio, 2017). Table 5.11 demonstrates the values for the Adult Control Group.

Table 5.16 Breakdown of Time to First Fixation for Adult Control Group.

Stimulus	Median (s)	Range (s)
Green 2	0.53	0.26-1.5
Grey 8	0.88	0.16-5.92
Orange 3*	0.16	0.04-0.36
Blue 1	0.48	0.14-1.52
Maroon 4	0.33	0.21-0.55

Two of the participants fixated on the Grey 8 stimulus at 5.9s, much later than the rest of the Group. One individual never fixated on two of the stimuli, Green 2 or Orange 3. There was no statistically significant difference in the TTFF measure

between the sexes. The cohort of three console video game players was too small to compare with the rest of the Group.

The Total Fixation Duration is the combined Time for all Fixations within an Area of Interest (Studio, 2017). This does not differentiate between initial Fixations and Fixations on the same stimulus later on in the task.

Table 5.17 Median and range for Total Fixation Duration within each AOI for the Adult Control Group.

Stimulus	Median (s)	Range (s)
Green 2	0.68	0.23-1.3
Grey 8	0.45	0.14-1.15
Orange 3	1.06	0.11-2.68
Blue 1	0.82	0.35-2.1
Maroon 4	0.3	0.02-1.32

The longest Total Fixation Duration was for the Orange 3 stimulus compared to the shortest which was the Maroon 4 stimulus.

Visit Count is defined as “the time interval between the first fixation on the active AOI and the end of the last fixation within the same active AOI where there have been no fixations outside the AOI” (Studio, 2017). Using the Visit Count, the number of return visits to an AOI can be calculated. The amount of times an individual has fixated before coming to rest on an AOI can also be measured. This is referred to as Fixations Before (Studio, 2017). Table 5.18 details the Fixations Before, Visit Count and Revisit Count for the Number Naming Video

Task. There is an outlier in the Fixations Before category, this high value corresponds to the data shown earlier where 2 participants were very late to fixate on the “Grey 8” target.

Table 5.18 Median and range for Fixations Before, Visit Count and Revisit Count for the Adult Control Group.

Stimulus	Median (Range) Fixations Before (n)	Median (Range) Visit Count (n)	Median (Range) Revisit Count (n)
Green 2	3 (1-17)	1 (1-6)	0 (0-5)
Grey 8	3.5 (1-188)	1 (1-3)	0 (0-2)
Orange 3	2 (0-6)	2 (1-5)	1 (0-4)
Blue 1	3.5 (1-8)	1 (1-7)	0 (0-6)
Maroon 4	2.5 (1-6)	1 (1-2)	0 (0-1)

5.4.4 Number of Fixations and Fixation Duration for the Paediatric Control Group

The median number of Fixations for the Paediatric Control Group was 52, with a range of 24-156.

Table 5.19 Number of Fixations by Age for NNV Task

	8 (n=1)	9 (n=1)	10 (n=21)	11 (n=23)	12 (n=26)	13 (n=1)
Median(n)	42	64	55	52	49.5	42
Range(n)	42	64	29-104	24-129	26-156	42

5.4.5 Saccadic Amplitude and Saccadic Velocity for Paediatric Control Group

Median Maximum Saccadic Amplitude was 25.8°, the range was 15-34°. The median Maximum Saccadic Velocity was 575°/s.

5.4.6 Areas of Interest Results for Paediatric Control Group

The Gaze Plot and Velocity Chart is taken from a paediatric volunteer. The Gaze Plot illustrates that they fixated on all of the targets, longer fixations are represented by larger red circles. These longer fixations can be also seen on the Velocity Chart as horizontal lines, marked by an arrow.

Figure 5.10 NNVT Gaze Plot - Paediatric Participant

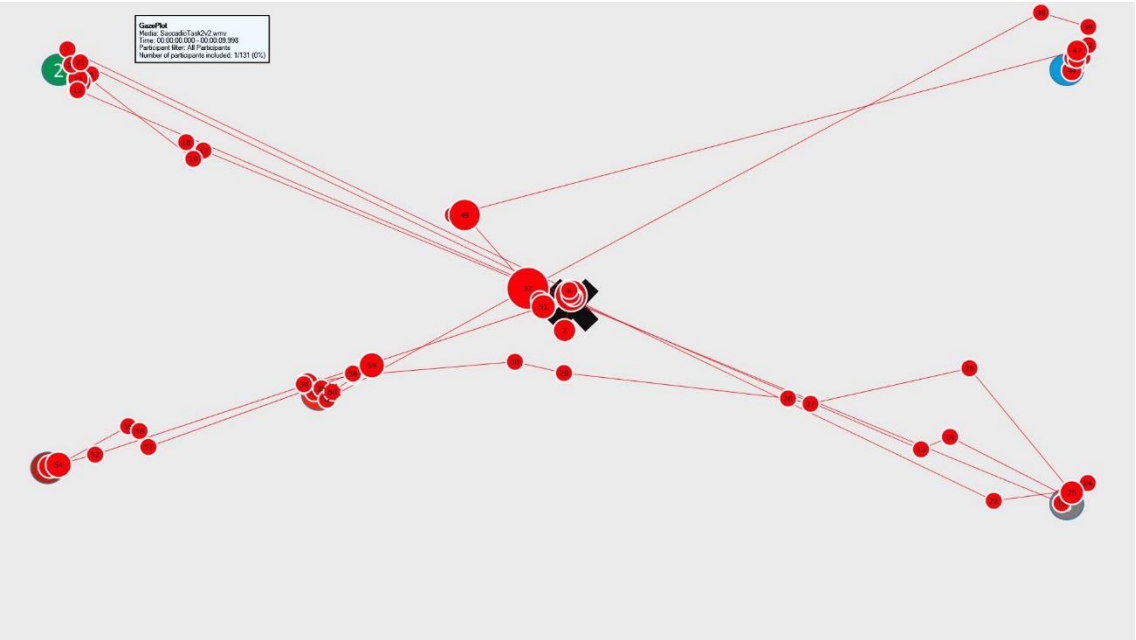


Figure 5.11 NNVT Velocity Chart - Paediatric Participant

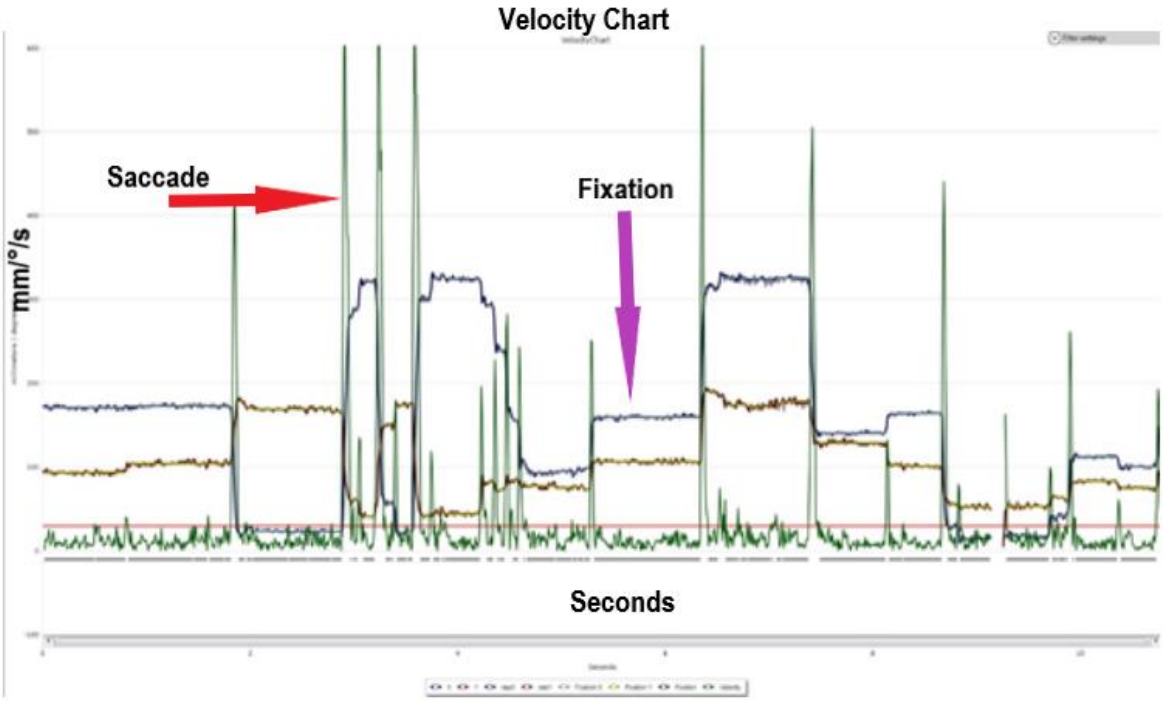


Table 5.20 below outlines the median TTFF and the range of TTFF for the Paediatric Control Group.

Table 5.20 Median and Range of Time to First Fixation for the Paediatric Control Group

Stimulus	Median (s)	Range (s)
Green 2	0.39	0.19-7.25
Grey 8	0.47	0.23-0.98
Orange 3	0.16	0.02-0.8
Blue 1	0.46	0.34-1.8
Maroon 4	0.33	0.02-1.62

One participant never fixated on the Green 2 stimulus. TTFF does not decrease with age within this Group, age range 8-13 years. There is no significant difference between video gamers and non-video gamers.

Table 5.21 Median and Range of Total Fixation Duration within each AOI for the Paediatric Control Group.

Stimulus	Median (s)	Range (s)
Green 2	0.98	0.08-1.59
Grey 8	0.47	0.19-1.24
Orange 3	1.07	0.11-2.61
Blue 1	0.84	0.07-1.66
Maroon 4	0.5	0.23-1.56

Table below outlines the AOI information for Fixations before, visit count and revisit counts.

Table 5.22 Summary of Fixations before, Visit Count and Revisit count for the Paediatric Control Group.

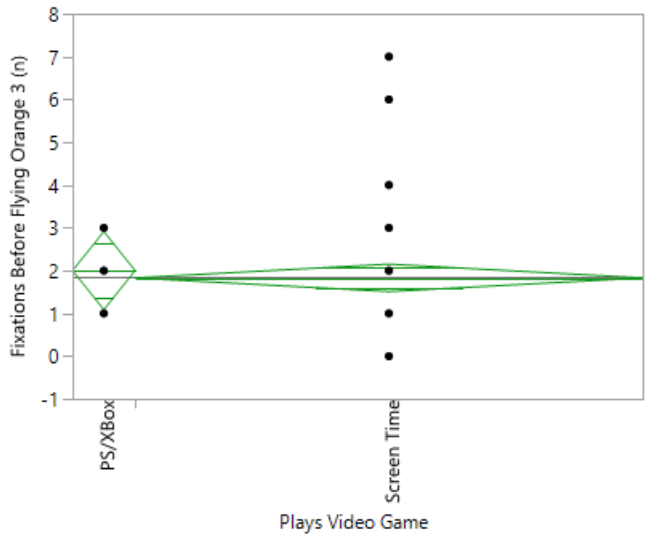
Stimulus	Median (Range) Fixations Before (n)	Median (Range) Visit Count (n)	Median (Range) Revisit Count (n)
Green 2	2 (1-31)	2 (1-6)	1 (0-5)
Grey 8	3 (1-11)	1 (1-4)	0 (0-3)
Orange 3	2 (0-7)	3 (1-7)	2 (0-6)
Blue 1	3 (0-10)	1 (1-7)	0 (0-6)
Maroon 4	2 (0-10)	1 (0-5)	0 (0-4)

One participant did not fixate on “Green 2” until the end of the task, this extended the range of Fixation Before count to 31. The lowest number of Fixations before is for the “Orange 3”. This is the most eye catching object, appearing from the

right side, flying in before stopping. This finding in the Paediatric Group is similar the Adult Control Group.

There was no significant difference in the mean values between the eight individuals who played video games and the rest of the Group for Fixations before or visit count.

Figure 5.12 One-way analysis (ANOVA) of Fixations Before comparing console video game player's vs non-players. r^2 value 0.00, r^2 adjusted value -0.01



5.5 Spot the Difference Task

This task consisted of two pictures. The second picture was displayed only after the difference in the first picture was identified. In this section I considered them together before examining them separately.

The size of the Paediatric Control Group for this task was 64 individuals, ranging in age from 5-13 years. The age groups with the largest numbers were ages 10, 11 and 12 years.

5.5.1 Time to Complete Spot the Difference Task Adult Control Group

Time to Complete the entire task in at the Adult Control Group ranged from 5-32.5s. The median Time to Complete was 13.7s. The total number in this Group was 16. This number is too small to measure if there is an age effect on the Time to Complete. This conclusion is based on the negative adjusted r^2 value when a one way AVOVA test was carried out.

Table 5.23 Median and range of Time to Complete comparing sex for SDT overall

	Female (n=10)	Male (n=6)
Median (s)	13.7	12.8
Range (s)	5.1-31.1	8.8-32.5

Only two Adults in this Group played video games, the sample size is too small for meaningful measurement.

5.5.2 Time to Complete Spot the Difference Task Paediatric Control Group

The sample number in the Paediatric Control Group is 64. The range is broader for the Paediatric Group 7.8-46.5s when compared to the Adult Control Group,

but the median is similar at 15.6s. In this Group there is an age effect such that time to complete the test reduces with increasing age.

Figure 5.13 One-way ANOVA of Time to Complete vs Age SDT Task r^2 value = 0.28

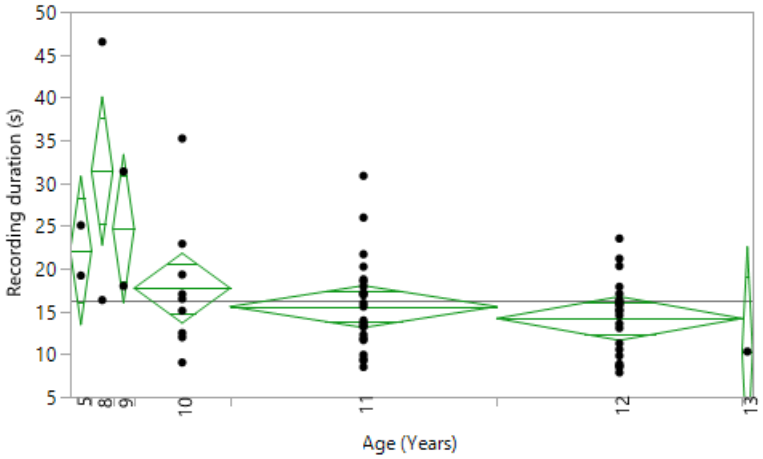


Table 5.24 Time to Complete SDT for the Paediatric Control Group

	5 (n=2)	8 (n=2)	9 (n=2)	10 (n=9)	11 (n=25)	12 (n=23)	13 (n=1)
Median(s)	22.1	31.4	24.6	16.5	15.6	15.0	10.3
Range(s)	19.2-25.1	16.3-46.5	17.9-31.3	9.0-35.2	8.5-30.8	7.8-23.5	10.3

5.6 Spot the Difference Task “Faces”

The object of the Spot the Difference Task “Faces” was to correctly identify the sad face in the bottom right corner. An area of interest (AOI) was placed over the sad face, Fixations made within the AOI were detected by Tobii Studio Software and exported through the Statistics Tab (detailed in Chapter 4 Methods). The AOI is demonstrated below in figure 9.

Figure 5.14 Spot the Difference Task "Faces" AOI "sad face"

5.6.1 Time to Complete for Adult Control Group

There were 16 Adults in the Control Group. The median Time to Complete for this element of the task was 3.3s with a range from 1.9-7.1s.

5.6.2 Saccadic Amplitude, Saccadic Velocity and Number of Fixations for Adult Control Group

The median Maximum Saccadic Velocity was 377°/s and the median Maximum Saccadic Amplitude was 11.9°. Adults had a median of 26.5 Fixations with a range of 8-67.

5.6.3 Area of Interest Results for Adult Control Group

The median Time to First Fixation on the “sad face” AOI was 0.95s, the range was 0.5-1.5s. The Time to First Fixation correlates to the Time to Complete, with an adjusted r^2 value of 0.25. Sex or a history of playing video games did not affect Time to First Fixation.

Figure 5.15 Bivariate fit of Time to Complete "Face" vs TTFF. r^2 value 0.3, r^2 adjusted value 0.25

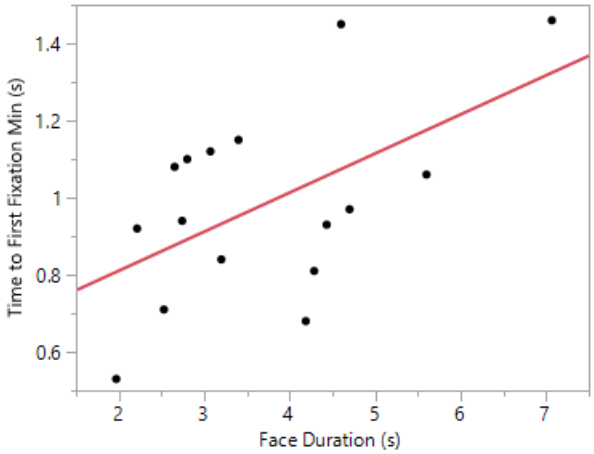


Table 5.25 Median and range temporal data for "Sad face" AOI for Adult Control Group

	Median	Range
TTFF (s)	0.95	0.53-1.46
First Fixation Duration (s)	0.10	0.01-3.17
Total Fixation Duration (s)	0.9	0.18-3.17

A visit can be made up of a number of Fixations within the AOI. Seventy-five percent of the Group revisited the “sad face” AOI.

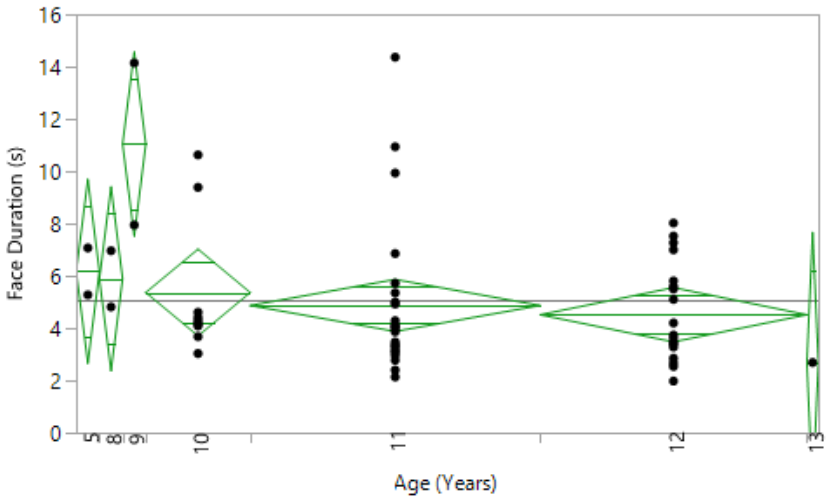
Table 5.26 Median and range for AOI Data "Sad face" AOI for Adult Control Group

	Median	Range
Fixations Before (n)	7	3-20
Fixations (n)	7.5	1-35
Visits (n)	2	1-5
Revisits (n)	1	0-4

5.6.4 Time to Complete for Paediatric Control Group

There were 64 children included in this Group. The median Time to Complete this portion of the task was 4.2s, it ranged between 1.9-14.1s. As age increased the Time to Complete decreased.

Figure 5.16 One-way analysis (ANOVA) of Time to Complete vs Age. r^2 value = 0.20, r^2 adjusted 0.11



The Paediatric Control Group median at 4.2s is slightly longer than the Adult Group of 3.3s, but not significantly.

Table 5.27 Median and range of Time to Complete "Faces" for each age

	5 (n=2)	8 (n=2)	9 (n=2)	10 (n=9)	11 (n=25)	12 (n=23)	13 (n=1)
Median(s)	6.2	5.9	11.0	4.3	4.0	3.7	2.7
Range(s)	5.3-7.1	4.8-6.9	7.9-14.1	3.0-10.6	2.1-14.3	1.9-8.0	2.7

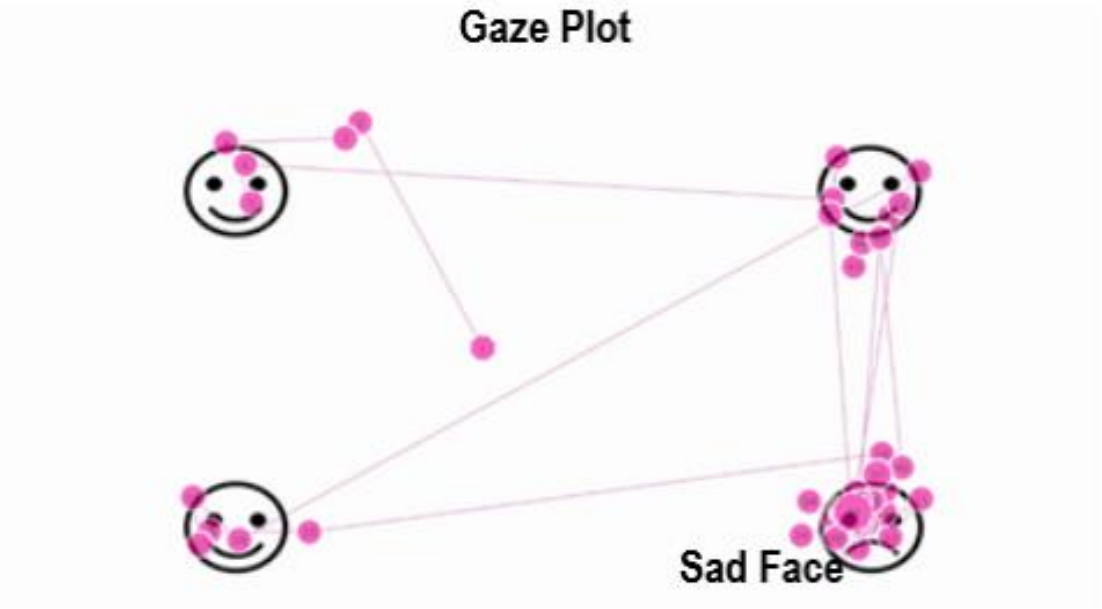
5.6.5 Saccadic Amplitude, Saccadic Velocity and Number of Fixations for Adult Control Group

The median Maximum Saccadic Velocity was 424°/s and the median Saccadic Amplitude was 13.3°. Saccadic Amplitude does not vary with age. The median number of Fixations was 26, range of 10-102.

5.6.6 Area of Interest Results for Paediatric Control Group

The figure shows a Gaze Plot for a Child in the Paediatric Control Group, she took 4.9s to complete the task and had a total of 48 Fixations.

Figure 5.17 Gaze Plot Paediatric participant SDT "Faces"



The mean Time to First Fixation on the "sad face" AOI was 1.0s, with a range of 0.4-4.5s. There was no difference between the Adult and Paediatric Control Groups when measuring Time to First Fixation.

Table 5.28 Median and range temporal data for "Sad Face" AOI

	Median	Range
TTFF (s)	0.94	0.3-4.5
First Fixation Duration (s)	0.14	0.01-0.52
Total Fixation Duration (s)	1.05	0.4-6.1

The children did not differ from the Adult Control Group for either First Fixation Duration or Total Fixation Duration. Age did not have an effect on any measure recorded by an AOI. All of the children revisited the AOI.

Table 5.29 Median and range "Sad face" AOI data for Paediatric Control

	Median	Range
Fixations Before (n)	6	1-21
Fixations (n)	6.5	2-26
Visits (n)	3	2-6
Revisits (n)	2	1-5

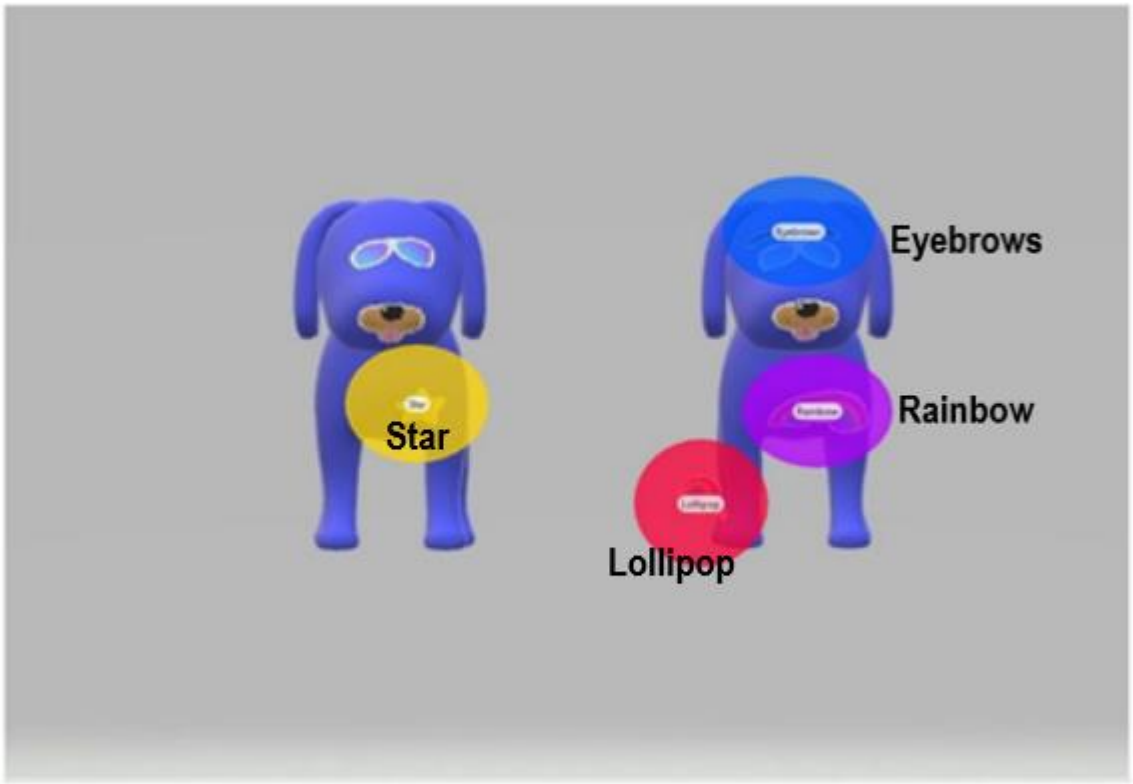
In summary, children looked at the “sad face” slightly more times than the Adults.

This is the only measure that differs between the two Control Groups.

5.7 Spot the Difference Task “Dogs”

Spot the Difference “Dogs” was a more complex task as it involved four differences. The individuals were asked to identify the differences as quickly as they could. Areas of interest were placed over the four objects as demonstrated below in figure 5.19.

Figure 5.18 Areas of Interest placed over objects in the Spot the Difference Task "Dogs"



5.7.1 Time to Complete for Adult Control Group

The median Time to Complete for this segment of the task was 7.1s, range of 2.4-27.7s. Sex did not have an effect on Time to Complete.

Table 5.30 Median and range for Time to Complete "Dogs" SDT comparing sex

	Female (n=10)	Male (n=6)
Median (s)	7.1	8.7
Range (s)	2.4-27.7	5.4-25.9

The number of individuals who played video games was too few to have a meaningful comparison in this Group.

5.7.2 Saccadic Amplitude, Saccadic Velocity and Number of Fixations for Adult Control Group

Adults had a median of 52 Fixations over the Time taken to Complete the task, the range was broad at 6-368 Fixations. The median Maximum Saccadic Velocity was 277°/s and the median Maximum Saccadic Amplitude was 8.2°.

5.7.3 Area of Interest Results for Adult Control Group

The analysis for this picture is more complex than for the “faces” picture as there are four AOI in comparison compared to just one. I have chosen to present the data for each AOI in table format for ease of reading.

Table 5.31 Summary of Time to First Fixation data for each AOI on “Dogs” for the Adult Control Group.

AOI	Median (s)	Range (s)
Eyebrows	2.6	0.4-5.7
Lollipop	1.9	0.03-7.7
Rainbow	1.0	0.75-4.1
Star	0.6	0.25-1.2

It appears from examining the TTFF data that the Adults looked at the Star initially, closely followed by the Rainbow. The TTFF for the Eyebrows and the Lollipop are very similar. The trend is similar when we examine Fixations Before.

Table 5.32 Summary of Fixations before for each AOI for the Adult Control Group.

AOI	Median (n)	Range (n)
Eyebrows	17.5	2-84
Lollipop	20.5	0-76
Rainbow	6.5	4-69
Star	4	0-14

While women and men took the same amount of time to look at the Rainbow and the Lollipop, the 10 women were quicker on average to fixate on the Eyebrows and the Star, when compared with the 6 men. There was no difference in the time taken to complete the task. Women fixated on the Lollipop and the Star AOI less than men with a mean of 7 Fixations, compared to the men's average of 20 Fixations. The total number of Fixations for all combined AOI is double for the men at 65, compared to women's 32.

Table 5.33 Summary of number of Fixations within an AOI for Spot the Difference "Dogs"

AOI	Median (n)	Range (n)
Eyebrows	7.5	1-66
Lollipop	6	1-68
Rainbow	6.5	1-43
Star	7.5	1-46

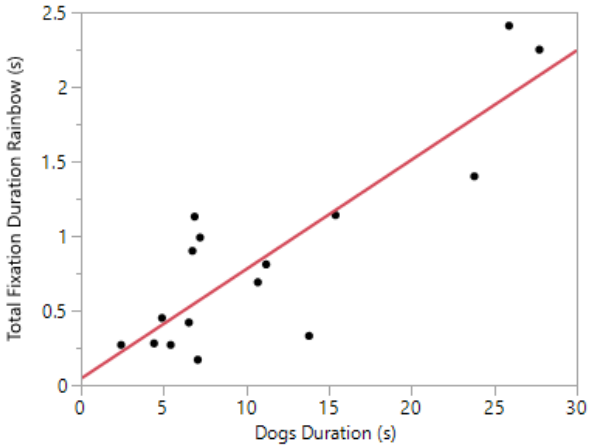
The median and range for First Fixation Duration and the Total Fixation Duration for each AOI is outlined below. Adults looked within the Star AOI briefly at the beginning, they looked at the Rainbow for the least amount of Time overall.

Table 5.34 Median (Range) First Fixation Duration and Total Fixation Duration in the Adult Control Group.

AOI	First Fixation Duration (s)	Total Fixation Duration (s)
Eyebrows	0.1 (0.01-0.87)	0.9 (0.02-3.67)
Lollipop	0.14 (0.01-1.22)	1.0 (0.32-6.16)
Rainbow	0.13 (0.01-0.9)	0.75 (0.17-2.41)
Star	0.13 (0.01-0.3)	1.12 (0.3-2.5)

The Total Fixation Duration within each AOI closely correlates with time to completion of the task, with an adjusted r^2 value of between 0.77-0.87. This is demonstrated for the Rainbow AOI.

Figure 5.19 One-way analysis of Time to Complete (s) vs Total Fixation Duration for the Rainbow AOI (s). r^2 value = 0.74



The number of visits an individual makes to an AOI is measured by the Eye Tracker. A visit can be made up of one or more Fixations. The number of visits

can be subtracted by 1 to determine the number of revisits to an AOI. % revisited refers to the number of individuals who revisited an AOI.

Table 5.35 Median (range) Visit and Revisit data for Adult Control Group

AOI	Visits (n)	Revisits (n)	% Revisited
Eyebrows	3 (1-19)	2 (1-18)	81
Lollipop	3 (1-12)	2 (0-11)	75
Rainbow	3 (1-14)	2 (0-13)	81
Star	4.5 (1-16)	3.5 (0-15)	94

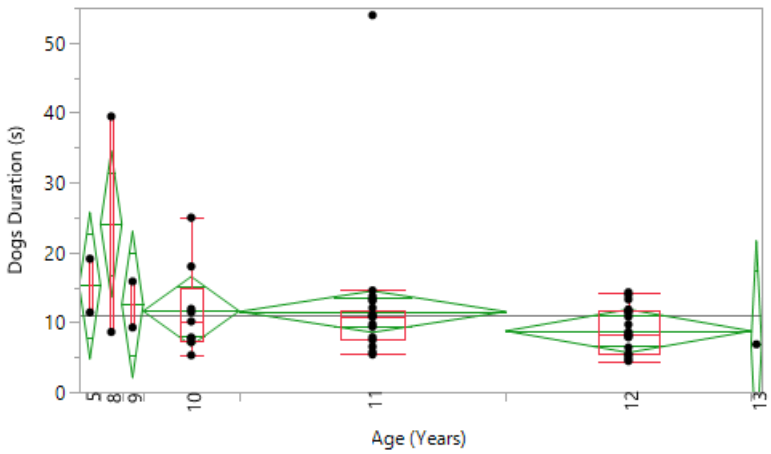
5.7.4 Time to Complete for Paediatric Control Group

The median Time to Complete for Spot the Difference "Dogs" was 9.7s, the range was 4.4-53.9s. This is slightly longer than the Adult Control Group median of 7.1s. Age again has an effect on Time to Complete. As age increases the range of Time taken to Complete becomes narrower. There is one outlier in the age 11 group at 53.9 seconds.

Table 5.36 Summary of Time to Complete "Dogs" SDT for a range of ages

	5 (n=2)	8 (n=2)	9 (n=2)	10 (n=9)	11 (n=25)	12 (n=23)	13 (n=1)
Median(s)	15.2	24.0	12.5	10.1	10.7	8.3	6.8
Range(s)	11.4-19.1	8.6-39.4	9.2-15.8	5.3-24.9	5.4-53.9	4.4-14.3	6.8

Figure 5.20 One-way analysis (ANOVA) age vs Time to Complete "Dogs" for Paediatric Control Group. r^2 value 0.14, r^2 adjusted value 0.11



5.7.5 Number of Fixations, Saccadic Amplitude and Saccadic Velocity for Paediatric Control Group

The Paediatric Control Group made an average of 42 Fixations across the task, this ranged from 18-225. This was less than the Adult Control Group but not significantly. The number of Fixations and saccades recorded did not vary with age. The median Maximum Saccadic Velocity was 286°/s and the median Maximum Saccadic Amplitude was 8.5°.

5.7.6 Area of Interest Results for Paediatric Control Group

The results from the Paediatric Control Group suggest that the children fixated on the objects in this order: Rainbow, Star, Lollipop and finally Eyebrows. Figure 5.22 shows a Gaze Plot for a paediatric participant who took just 2.5s to complete the task with a total of 16 Fixations over this time. Fixations are denoted by circles; Saccades are represented by straight lines.

Figure 5.21 SDT Gaze Plot - Paediatric Participant

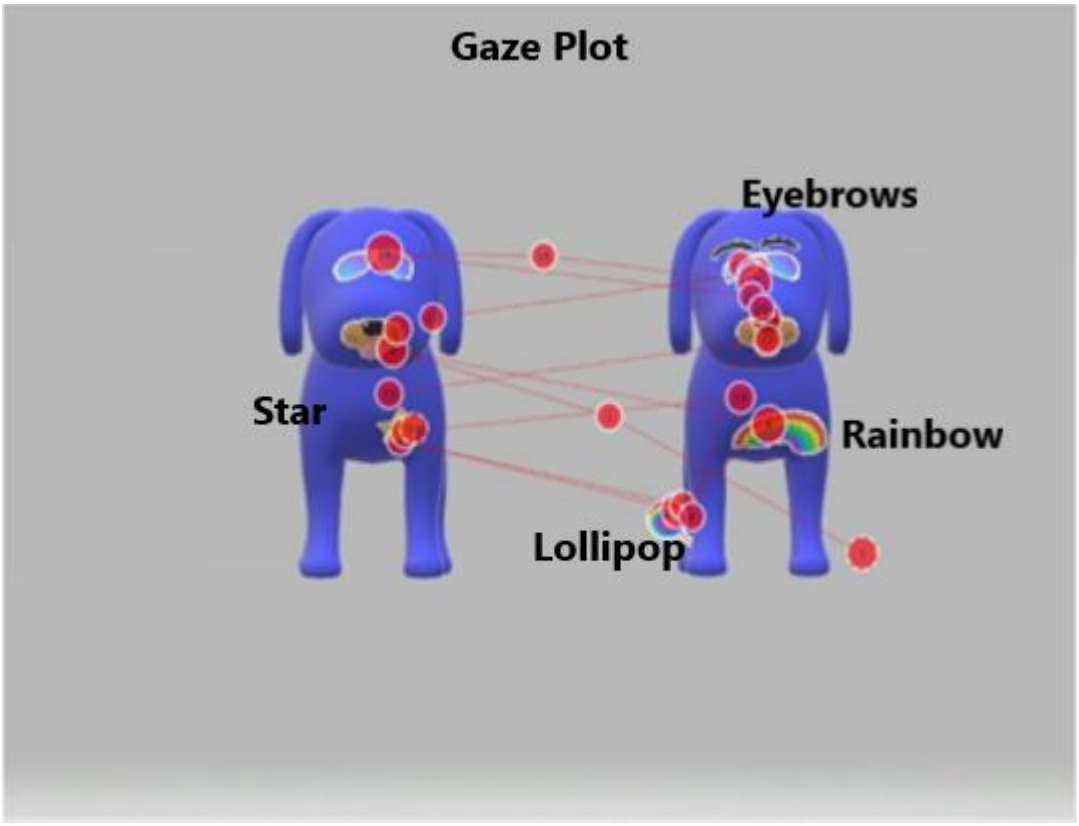


Table 5.37 Summary of Time to First Fixation for each AOI for the Paediatric Control Group.

AOI	Median (s)	Range (s)
Eyebrows	2.3	0.3-9.5
Lollipop	1.3	0.01-12.5
Rainbow	0.9	0.06-3.3
Star	1.0	0.16-6.65

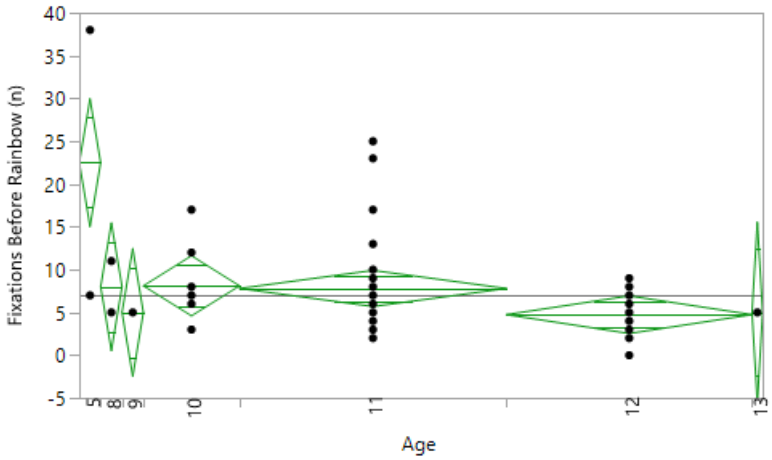
There is no significant difference between the Adult and Paediatric Control Groups for the measure Fixations Before.

Table 5.38 Summary of Fixations Before for the Paediatric Control Group.

AOI	Mean (n)	Range (n)
Eyebrows	12	1-53
Lollipop	8	0-90
Rainbow	6	0-38
Star	6	2-44

Age had an effect on 'Fixations Before' for the Star, Rainbow and Lollipop AOI, the strongest age effect was seen with the Rainbow AOI. The r^2 value was .28, for the other AOI Star and Rainbow the adjusted r^2 value was .14-.16.

Figure 5.21 One-way analysis (ANOVA) of Age vs Fixations Before Rainbow. r^2 value 0.29, r^2 adjusted value 0.21



A history of playing video games did not affect how many Fixations were made before a Fixation within an AOI. There is no difference between the Paediatric and Adult Control Groups. There is an observed reduction in Fixation count as

the age increases, the mean at age 10 years was 10 Fixations and the mean at age 12 years was 6 Fixations, but this difference is not statistically significant.

Table 5.39 Summary of Fixation count for each AOI.

AOI	Median (n)	Range (n)
Eyebrows	6.5	1-42
Lollipop	3	1-29
Rainbow	5	2-24
Star	5	1-41

Age did not have a significant effect on either First Fixation Duration or Total Fixation Duration.

Table 5.40 Summary of First Fixation Duration and Total Fixation Duration for the Paediatric Control Group.

AOI	First Fixation Duration (s)	Total Fixation Duration (s)
Eyebrows	0.14 (0.01-0.8)	1.4 (0.14-0.87)
Lollipop	0.2 (0.01-1.36)	1.2 (0.32-4.2)
Rainbow	0.13 (0.01-0.58)	0.9 (0.28-3.4)
Star	0.17 (0.01-0.69)	1.1 (0.13-5.22)

The visit and revisit data does not differ significantly from the Adult Control Group.

Table 5.41 Median (range) of visit and revisit data for the Paediatric Control Group.

AOI	Visits (n)	Revisits (n)	% Revisited
Eyebrows	4 (1-13)	3 (0-12)	97
Lollipop	3 (1-16)	2 (0-15)	89
Rainbow	3.5 (1-11)	2.5 (0-10)	99
Star	4 (1-12)	3 (0-11)	91

Chapter 6 Results - Focal Epilepsy Group

This section details results from the eleven children in the focal epilepsy combined Group, nine males and two females.

6.1 Focal Epilepsy Classification

Two of the children have a diagnosis of Focal Epilepsy with electrical status epilepticus during slow wave sleep (ESES), four have a diagnosis of Benign epilepsy with centrotemporal spikes (BECTS) and the remaining five have an Other Focal Epilepsy (OFE).

6.2 Statistical Analysis

The sample size for this Group is smaller than the sample available for the Paediatric Control Group. The results are not normally distributed. The distributions for selected results are displayed in the appendices. Due to the distribution of the data nonparametric statistical analysis was utilised in this chapter. Specifically, nonparametric comparisons for each pair using Wilcoxon Method. Significance levels were set at 0.05. Just as in the previous results chapter all outliers were included in analysis. The aim of the study was to determine if there was a difference present between the focal epilepsy group and the normal control group.

6.3 King-Devick Test

Nine children were available for analysis in this task. Two of the eleven children who attempted the KD were not included in analysis as they failed to correctly complete the test.

The Velocity Chart and Gaze Plot below demonstrate Eye Tracking data with a WGS sample of 85%. This participant was one of the 2 children with ESES, he took 39s to complete the K-D test. In contrast to the example displayed in the previous results chapter, there are a greater number of Fixations of different durations, occurring in clusters over some numbers. Longer Fixation Durations are denoted by larger circles.

Figure 6.1 Gaze Plot - Participant with ESES completing the K-D Test. Circles denote fixations, straight lines denote saccades.

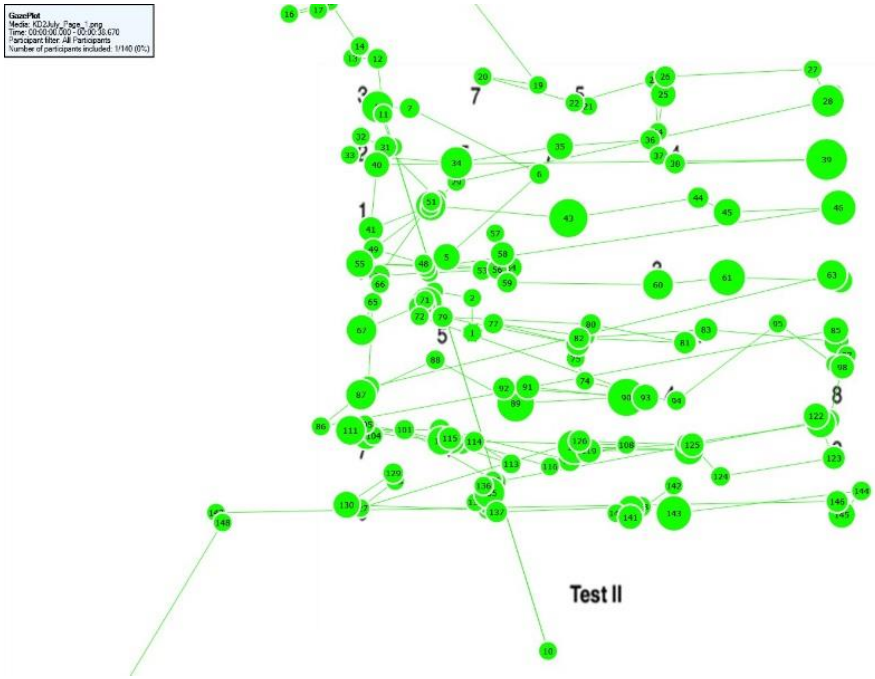
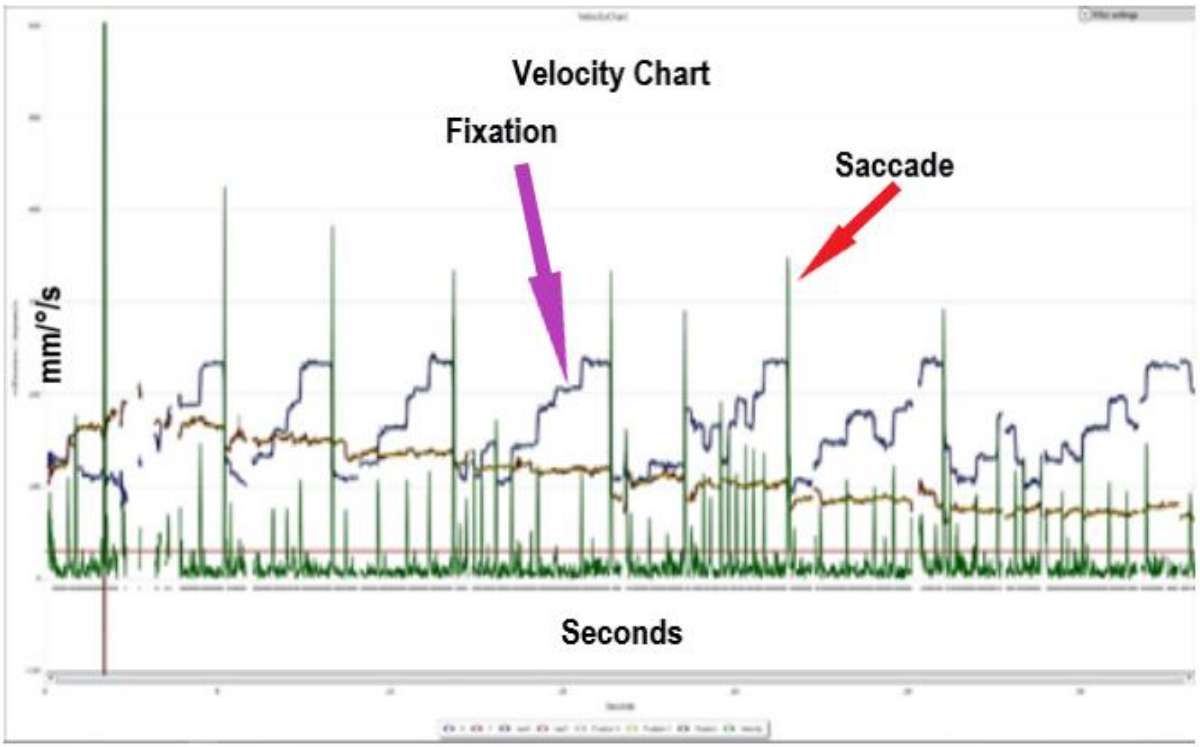


Figure 6.2 Velocity Chart - Participant with ESES performing the K-D test. The velocity chart shows a snapshot of 30 seconds.



6.3.1 King-Devick Test Time to Complete

The range of Time to Complete for the overall Focal Epilepsy Group is 16.9-67.0s. A histogram detailing the distribution is available in Appendix 10.6. There is no difference between paediatric controls and children with epilepsy, considered together. However, the times to complete for children with OFE and ESES were markedly longer. The median for the ESES subgroup is 34s longer than the Paediatric Control Group.

Table 6.1 Summary of data for the K-D Test for each group

	Epilepsy (n=9)	BECTS (n=4)	OFE (n=3)	ESES (n=2)	Control (n=69)
Time (s)	21.6 (16.9-67.8)	19.4 (17.3-21.6)	31.7 (16.9-40.9)	53.2 (38.7-67.8)	19.2 (13.3-39.3)
Fixations (n)	139 (73-288)	87 (73-163)	139 (129-194)	219 (150-288)	88 (49-236)
Fixation Duration(s)	0.9 (0.7-2.1)	0.8 (0.7-0.9)	1.4 (0.8-1.7)	1.5 (0.8-2.1)	0.7 (0.3-1.2)
Saccadic Amplitude(°)	16.3 (12.3-34.3)	15.2 (12.6-22.7)	12.4 (12.3-16.3)	28.8 (21.9-34.3)	12.9 (8.2-28.7)
Saccadic Velocity(°/s)	486 (363-532)	510 (425-532)	486 (382-501)	395 (363-427)	401 (143-542)

6.3.2 Eye tracking data for the K-D test

The number of Fixations was measured for each participant, the distribution is displayed in appendix 10.8. Similar to the time to complete, the OFE and ESES subgroups both demonstrate a larger Maximum Fixation Duration when

compared to the Paediatric Control Group. The small sample size of the epilepsy subgroups impacts on the relevance of statistical analysis for this task.

6.4 Number Naming Video Task

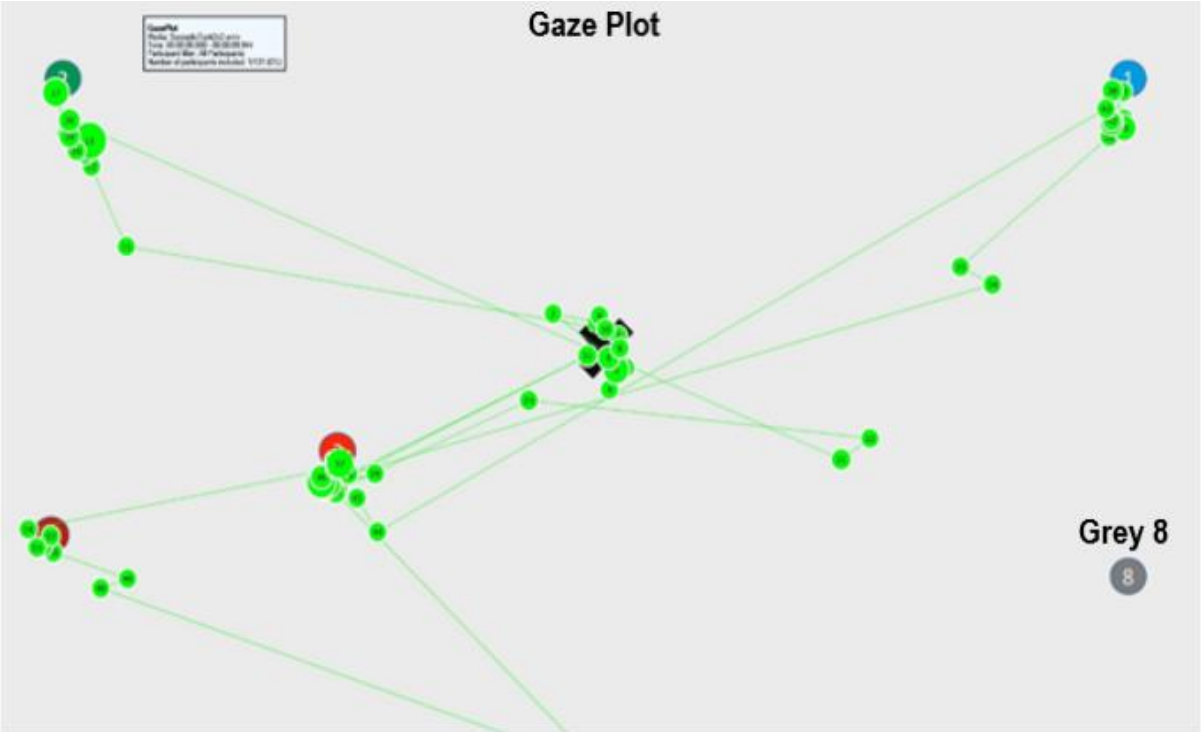
All eleven children from the Focal Epilepsy Group participated in the Number Naming Video Task (NNVT). Their ages range from 7-16 years.

6.4.1 Eye tracking data for NNV Task

As detailed in Chapter 5 Methods this is a fixed time task, Time to Complete was not a factor as it is in the other two tasks.

Three of the participants in this Group failed to fixate on one of the targets, both participants in the ESES Group missed one target each. The target missed was different for each of the three patients (Grey 8, Blue 1 and Maroon 4). The Gaze Plot is displayed below for the Child with ESES who never fixated on the Grey 8 target.

Figure 6.3 NNVT Gaze Plot - Participant with ESES. Fixations are denoted by circles, straight lines indicate a saccade.



The total number of Fixations recorded during the task does not differ significantly for the epilepsy Group.

Table 6.2 Median (range) for Fixations during NNVT for each subgroup

	Epilepsy (n=9)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=73)
Fixations (n)	57 (28-119)	50 (39-87)	64 (28-119)	80 (57-103)	52 (25-156)
Saccadic Amplitude(°)	32 (17-36)	28 (16-35)	33 (19-35)	31 (28-34)	26 (15-35)

When Maximum Saccadic Amplitude is examined there is one significant difference present. The median Maximum Saccadic Amplitude of the OFE Group is higher than the Paediatric Control Group.

6.4.3. Area of Interest Results for NNV Task

The Area of Interest (AOI) data is very helpful in this task. The initial measurement is Time to First Fixation (TTFF). Table 6.8 below provides a breakdown for TTFF within this Group.

Table 6.3 Median (range) of TTFF for NNV Task for each subgroup

Stimulus	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=73)
Green 2	0.4 (0.3-2.4)	0.5 (0.3-1.6)	0.4 (0.3-0.8)	1.4 (0.4-2.4)	0.4 (0.2-7.2)
Grey 8	0.6 (0.4-1.5)	0.5 (0.4-0.6)	0.7 (0.4-1.5)	0.8 (0.8-0.8)	0.5 (0.2-0.9)
Orange 3	0.3 (0.0-0.3)	0.2 (0-0.3)	0.2 (0.1-0.3)	0.3 (0.2-0.3)	0.1 (0.02-0.8)
Blue 1	0.6 (0.3-2.6)	0.4 (0.3-0.6)	0.6 (0.4-0.9)	1.7 (0.9-2.6)	0.5 (0-1.2)
Maroon 4	0.5 (0.2-0.9)	0.4 (0.2-0.5)	0.5 (0.2-0.9)	0.7 (0.7-0.7)	0.3 (0.1-1.6)

Participants in the OFE Group took a longer time to fixate on the Grey 8 stimulus than the Paediatric Control Group. Participants in the ESES subgroup were slower to fixate on the moving Orange 3 stimulus when compared to the Paediatric Control Group.

Total Fixation Duration is the time spent fixating on each AOI.

Table 6.4 Median (range) of Total Fixation Duration within each AOI for the NNV Task

Stimulus	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=73)
Green 2	1.0 (0.2-2.1)	0.8 (0.4-1.3)	1.6 (0.8-2.1)	0.4 (0.2-0.6)	0.9 (0.1-1.6)
Grey 8	0.5 (0-1.1)	0.3 (0.2-0.5)	0.9 (0.3-1.0)	0.5 (0.0-1.1)	0.5 (0.2-1.2)
Orange 3	1.1 (0.2-2.3)	0.4 (0.2-0.8)	1.5 (0.4-2.3)	1.6 (1.1-2.2)	1.1 (0.1-2.6)
Blue 1	0.7 (0-1.0)	0.7 (0-0.8)	0.8 (0.3-1.0)	0.9 (0.7-0.9)	0.8 (0.1-1.6)
Maroon 4	0.4 (0-0.6)	0.3 (0.2-0.6)	0.5 (0.4-0.6)	0.5 (0-0.3)	0.5 (0-1.6)

The total Fixation Duration is different for the Grey 8 stimuli, participants in the OFE Group fixate for nearly twice as long than the Paediatric Control Group. The next comparison available is for the AOI measures: Fixations Before, Visit Count and Revisit Count.

Table 6.5 Median (range) of Fixations Before for NNV Task for each subgroup

Stimulus	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=73)
Green 2	3 (1-18)	3 (2-18)	3 (1-4)	6.5 (1-12)	2 (1-31)
Grey 8	4 (3-13)	4 (3-7)	4 (3-6)	13 (13-13)	3 (1-11)
Orange 3	2 (0-5)	2 (0-3)	1 (1-5)	1.5 (1-2)	2 (0-7)
Blue 1	2 (0-30)	2 (0-6)	2 (1-7)	17.5 (5-30)	3 (0-10)
Maroon 4	3 (1-14)	2.5 (1-4)	3 (1-14)	3 (3-3)	2 (1-10)

There was no significant difference present between the individuals who play video games and those who do not.

Table 6.6 Median (range) Visit Count for NNV Task for each Group

Stimulus	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=73)
Green 2	2 (1-5)	2.5 (1-5)	2 (1-4)	2.5 (2-3)	2 (1-6)
Grey 8	1 (0-3)	1 (1-3)	2 (1-2)	1 (0-2)	1 (1-4)
Orange 3	2 (1-6)	3 (1-3)	2 (1-5)	5 (4-6)	3 (1-7)
Blue 1	1 (0-10)	1.5 (0-4)	1 (1-10)	1.5 (1-2)	1 (1-7)
Maroon 4	1 (0-2)	1 (1-2)	1 (1-1)	0.5 (0-1)	1 (0-5)

The Revisit Count is calculated by subtracting one from the Visit Count. The sample size is lower as not every participant Revisits an AOI.

Table 6.7 Median (range) for Revisits to AOIs for NNV Task for each subgroup

Stimulus	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=73)
Green 2	1 (0-4)	1.5 (0-4)	1 (0-3)	1.5 (1-2)	1 (0-5)
Grey 8	0 (0-2)	0 (0-2)	1 (0-1)	0.5 (0-1)	0 (0-3)
Orange 3	1 (0-5)	1 (0-2)	1 (0-4)	4 (3-5)	2 (0-6)
Blue 1	0 (0-9)	0.5 (0-3)	0 (0-9)	0.5 (0-1)	0 (0-6)
Maroon 4	0 (0-1)	0 (0-1)	0 (0)	0 (0)	0 (0-4)
Total	4 (0-11)	4 (2-8)	5 (0-11)	6 (4-8)	4 (0-15)

6.5 Spot the Difference Task

All 11 of the participants tested were included for analysis for Spot the Difference Task (SDT).

6.5.1 Time to Complete SDT

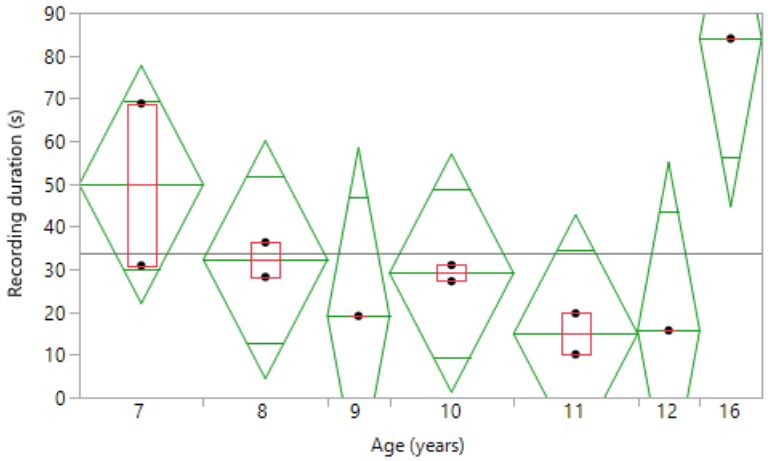
Histograms are available in Appendix 10.7 for the distribution of total Time to Complete for each subgroup. Playing video games did not offer an advantage in this task.

Table 6.8 Median (range) total Time to Complete SDT for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Time (s)	28.3 (10.1-84.0)	17.3 (10.1-27.2)	31 (19.7-84.0)	33.6 (30.9-36.3)	15.6 (7.8-46.5)

Children in the Focal Epilepsy Group ranged from 7-16 years. Time to Complete the SDT correlated with age (r^2=0.84). A one-way ANOVA test demonstrates an adjusted r^2 value of 0.6, this adjustment is made as the sample size is small.

Figure 6.4 One-way analysis (ANOVA) of Age vs Time to Complete (s). r^2 value 0.84, r^2 adjusted value 0.61



6.6 Spot the Difference Task “Faces”

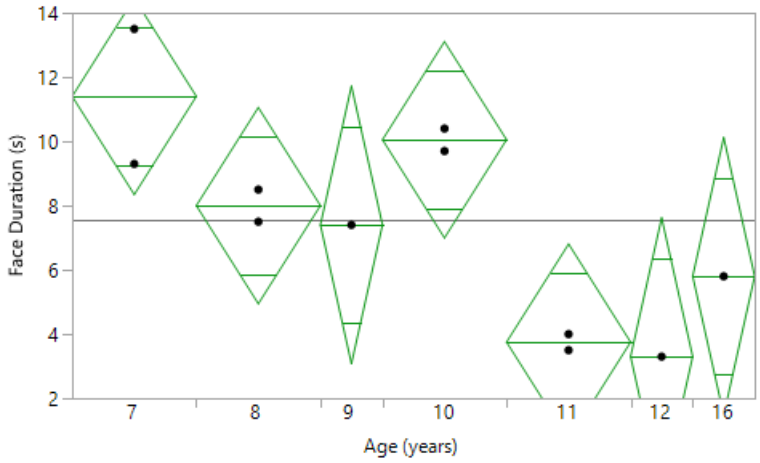
6.6.1 Time to Complete for SDT “Faces”

Table 6.9 Median (range) Time to Complete SDT "Faces" for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Time (s)	7.5 (3.3-13.5)	5.7 (3.3-9.7)	7.5 (3.5-10.4)	10.9 (8.8-13.5)	4.2 (1.9-14.3)

The children with focal epilepsy take almost twice as long to complete this task as the Paediatric Control Group. As with the Paediatric Control Group, age was correlated with Time to Complete (r^2=0.9), adjusted r^2 is 0.76.

Figure 6.5 One-way analysis (ANOVA) of Time to Complete SDT "faces" (s) by age (years). r^2 value 0.90, r^2 adjusted value 0.76



6.6.2 Saccadic Amplitude, Saccadic Velocity and Number of Fixations for SDT "Faces"

Table 6.10 Median (range) Maximum Saccadic Amplitude and Maximum Saccadic Velocity during SDT "Faces" for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Saccadic Amplitude(°)	15 (12-25)	15 (12-21)	14 (12-25)	17 (16-17)	13 (10-18)
Saccadic Velocity(°/s)	423 (34-506)	443 (413-506)	387 (34-457)	414 (374-455)	424 (304-547)

Table 6.11 Median (range) number of Fixations during SDT "faces" for each subgroup

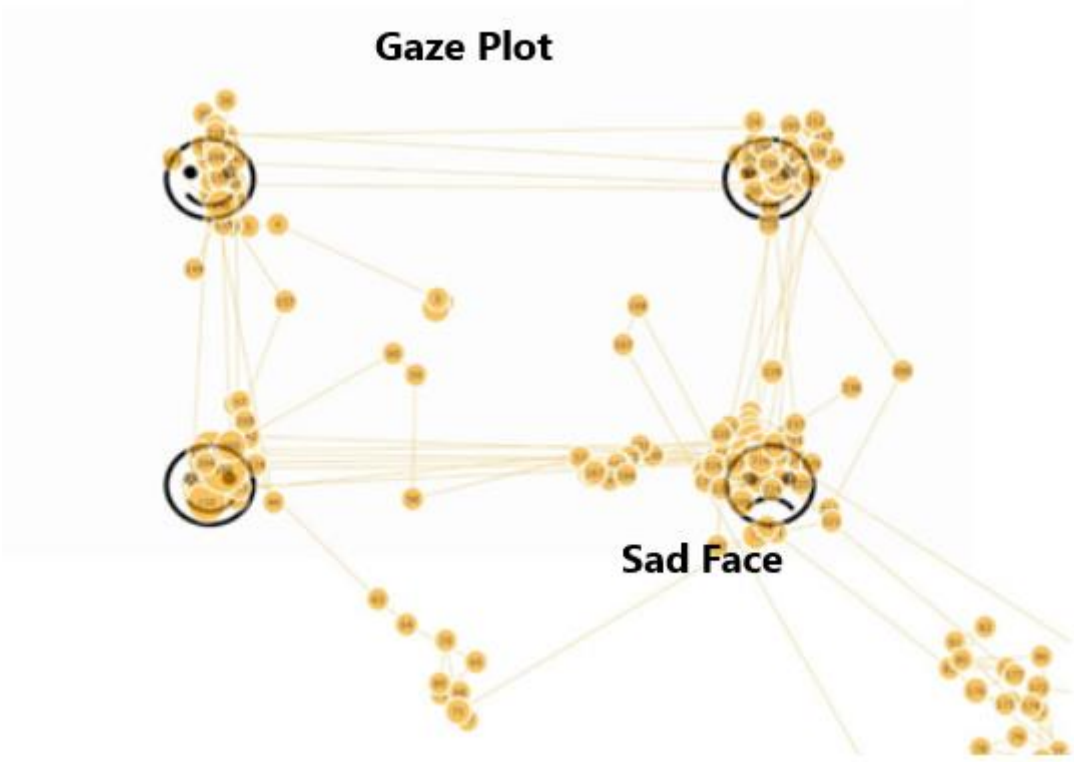
	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Fixations (n)	47 (11-99)	33.5 (16-54)	25 (11-97)	94 (89-99)	26 (10-102)

As observed in the table above, ESES subgroup had 3 times the number of Fixations than the Paediatric Control Group.

6.6.2 Area of Interest Results for SDT “Faces”

The figure shows a Gaze Plot for one of the Children with ESES, he took 13.5s to complete this part of the task and had a total of 99 Fixations in this time.

Figure 6.6 SDT Faces Gaze Plot - participant with ESES



The time to first Fixation (TTFF) for the BECTs and Control subgroups was similar, the overall TTFF for the Epilepsy Group is prolonged when compared to the Paediatric Control Group.

The total Fixation Duration and the first Fixation Duration are similar when comparing the Paediatric Control Group and Focal Epilepsy Group. The children of the ESES Group had twice the amount of Fixations Before, compared to the Paediatric Control Group.

Table 6.12 Median (range) temporal data for "Sad" AOI in SDT

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
TTFF (s)	1.3 (0.9-1.9)	1.1 (0.9-1.4)	1.4 (0.9-1.9)	1.4 (1.3-1.4)	0.9 (0.3-4.5)
First Fixation Duration (s)	0.2 (0.02-0.4)	0.2 (0.1-0.3)	0.1 (0.03-0.4)	0.1 (0.02-0.2)	0.1 (0.01-0.5)
Fixation Duration(s)	1.8 (0.9-1.9)	0.2 (0.1-0.3)	0.13 (0.03-0.4)	0.2 (0.02-0.2)	1.0 (0.4-6.1)

Table 6.13 Median (range) Fixations Before for "Sad" AOI in SDT for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Fixations Before (n)	6 (3-18)	5.5 (4-10)	5 (3-17)	12.5 (7-18)	6 (1-21)
Fixations (n)	16 (2-34)	9 (2-17)	16 (4-27)	31.5 (29-34)	6.5 (2-26)
Visits (n)	4 (1-10)	4 (1-7)	2 (2-10)	4.5 (4-5)	3 (2-6)
Revisits (n)	3 (0-9)	3 (0-6)	1 (1-9)	3.5 (3-4)	2 (1-5)

There is no significant difference between any of the subgroups for either Visit Count or Revisit Count. The number of Fixations within an AOI can be measured

and is referred to as Fixation Count. Each visit is made up of one or more Fixations. The ESES subgroup had a greater number of Fixations within the “Sad” AOI than the Paediatric Control Group, when comparing median values ESES Group fixated 5 times more than the Paediatric Control Group.

6.7 Spot the Difference Task “Dogs”

6.7.1 Time to Complete SDT “Dogs”

The OFE subgroup and ESES subgroup take over twice as long to complete this part of the task when compared to the Paediatric Control Group.

Table 6.14 Median (range) Time to Complete SDT “Dogs” for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Time (s)	16.6 (5.2-77.2)	11.1 (5.2-16.5)	19.7 (15.3-77.2)	21.8 (16.6-27.0)	9.8 (4.5-53.9)

6.7.2 Number of Fixations, Saccadic Amplitude and Saccadic Velocity for SDT “Dogs”

The table below summarises the median and range for Fixations during the task.

Table 6.15 Median (range) number of Fixations SDT “Dogs” for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Fixations (n)	87 (29-340)	56 (29-82)	90 (52-340)	192 (119-266)	42 (18-225)

6.7.3 Area of Interest Results for SDT “Dogs”

While there are some differences across the Groups for time to first Fixation (TTFF) they are not statistically significant.

Table 6.16 Median (range) of TTFF for each AOI for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Eyebrows(s)	2.4 (0.5-12.0)	2.1 (0.9-3.1)	2.8 (0.5-4.2)	6.3 (0.6-12.0)	2.3 (0.3-9.5)
Lollipop (s)	1.8 (0.9-6.4)	1.6 (1.1-5.6)	1.8 (0.9-3.8)	3.9 (1.4-6.4)	1.3 (0.0-12.5)
Rainbow (s)	1.4 (0.7-4.3)	1.4 (0.7-4.3)	1.4 (0.7-3.3)	1.2 (1.0-1.4)	0.9 (0.1-3.3)
Star (s)	1.2 (0.4-2.4)	0.6 (0.4-2.4)	1.2 (0.4-2.1)	2.1 (1.9-2.2)	0.9 (0.2-6.6)

ESES subgroup has a greater number of Fixations Before than the Paediatric Control Group for the Rainbow and Star AOI.

Table 6.17 Median (range) Fixations Before for AOI SDT "Dogs" for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Eyebrows (n)	12 (4-131)	11.5 (4-16)	12 (4-20)	69.5 (8-131)	12 (1-53)
Lollipop (n)	12 (5-48)	11 (6-19)	12 (5-27)	33.5 (19-48)	8 (0-90)
Rainbow (n)	9 (3-18)	6.5 (3-14)	9 (4-15)	15 (12-18)	6 (0-38)
Star (n)	7 (2-28)	2.5 (2-10)	7 (2-13)	22.5 (17-28)	6 (2-44)

Total Fixation Duration was longer for OFE subgroup, between 3-4 times greater than the Paediatric Control Group.

Table 6.18 Median (range) Total Fixation Duration AOI in SDT "Dogs" for each subgroup

	Epilepsy	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Eyebrows(s)	2.4 (0.2-15.4)	1.3 (0.2-2.4)	4.8 (1.1-15.4)	2.7 (1.6-3.8)	1.4 (0.1-8.2)
Lollipop (s)	2.7 (0.4-7.4)	0.9 (0.4-2.9)	2.9 (2.7-7.4)	1.8 (1.4-2.4)	1.2 (0.3-4.2)
Rainbow (s)	1.4 (0.5-14.2)	1.1 (0.5-1.6)	3.2 (1.1-14.2)	0.8 (0.6-0.9)	0.9 (0.3-3.4)
Star (s)	1.5 (0.6-5.4)	1.1 (0.6-1.7)	3.4 (1.0-5.4)	2.2 (1.5-2.8)	1.1 (0.1-5.2)

The Gaze Plot for one of the participants with ESES shows many short Fixations, the participant in this example Fixated 266 times and took 63s to complete the task.

Figure 6.7 SDT dogs Gaze Plot - Participant with ESES

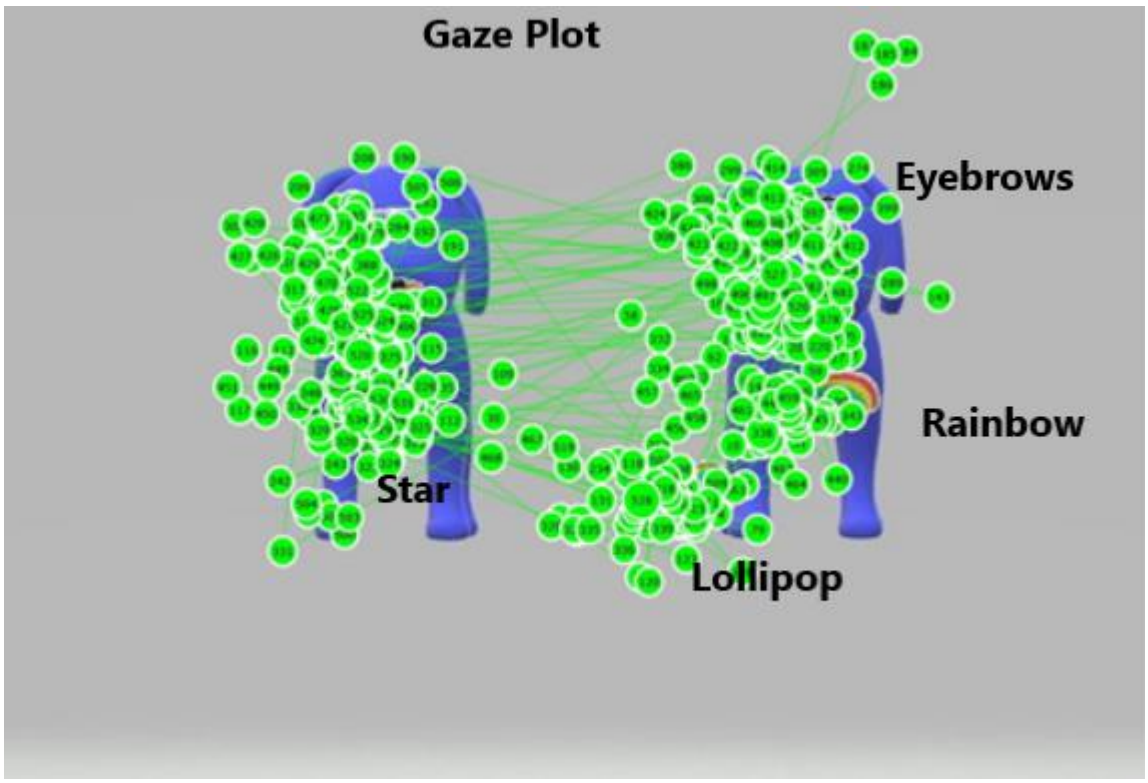


Table 6.19 Median (range) Visit Count AOI SDT "Dogs" for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Eyebrows (n)	6 (1-22)	4 (1-6)	10 (4-22)	7.5 (6-9)	4 (1-13)
Lollipop (n)	5 (1-11)	3 (1-5)	9 (4-11)	7 (7-7)	3 (1-16)
Rainbow (n)	6 (2-21)	5.5 (2-7)	7 (4-21)	6 (6-6)	3.5 (1-11)
Star (n)	5 (2-17)	4.5 (2-6)	5 (4-17)	12 (10-14)	4 (1-12)

Revisit Count for each AOI demonstrates a similar pattern. Children in the Epilepsy Group revisited each AOI more times than the Paediatric Control Group.

Table 6.20 Median (range) Revisit Count each AOI SDT "Dogs" for each subgroup

	Epilepsy (n=11)	BECTS (n=4)	OFE (n=5)	ESES (n=2)	Control (n=64)
Eyebrows (n)	5 (0-21)	3 (0-5)	9 (3-21)	6.5 (5-8)	3 (0-12)
Lollipop (n)	4 (0-10)	2 (0-4)	8 (3-10)	6 (6-6)	2 (0-15)
Rainbow (n)	5 (1-20)	4.5 (1-6)	6 (3-20)	5 (5-5)	2.5 (0-10)
Star (n)	4 (1-16)	3.5 (1-5)	4 (3-16)	11 (9-13)	3 (0-11)

Chapter 7 - Discussion

7.1 King-Devick Test

7.1.1 Adult Control Group

Currently in clinical practice, the K-D Test is used primarily as a concussion screening tool in adults (Ventura et al., 2016). The results of this study indicate that male participants were faster to complete the task when compared with female participants, although interestingly there were no differences between the sexes for any of the Eye Tracking measures, such as number of Fixations. The observed difference may be an effect of smaller numbers of adult male controls and would ideally require some additional data to verify.

Our results for Adult performance for the measure Time to Complete, saccadic amplitude and saccadic velocity in the KD replicated those published by Rizzo et al (Rizzo et al., 2016).

7.1.2 King Devick Test Paediatric Controls Group

One aim of the present study was to assess the effect of age on performance in the K-D Test. In the Paediatric Control Group the Time to Complete decreased as age increased. When compared to Adults, Children take a longer Time to Complete the task and have a longer mean Fixation Duration, although both measures were seen to shorten with increasing age. Previous studies have shown improved consistence of performance as individuals increase in age (Katherine K. Weise et al., 2017).

7.1.3 King-Devick Test Focal Epilepsy Group

While the overall Time to Complete of the Focal Epilepsy Group for the K-D Test (21.6s) does not differ significantly from the Paediatric Control Group (19.2s), children in the Focal Epilepsy Group had a much higher number of fixations within that time. Using this eye tracking measure, children with focal epilepsy can be distinguished from their peers. When children with epilepsy were separated into subgroups based on their Epilepsy classification some significant performance differences emerge. Children with ESES take over twice as long as their peers to complete the K-D Test Card II, with a median of 53.2s. Children in the OFE group also take longer to complete the test although the difference is not as dramatic (31.7s). It is proposed that malfunction of the Dorsolateral Prefrontal cortex (DLPC) may contribute to poor performance in the KD test. The DLPC contributes to short term spatial memory and generating anticipatory saccades (Ventura et al., 2016).

This is a larger difference than is seen in the literature detailing children and adolescents following a concussion or mild traumatic brain injury. In a study carried out by Seidman et al., there was an increase in Time to Complete of 5-6s compared to normal Controls (Seidman et al., 2015).

The children in the OFE and ESES subgroups had a higher number of Fixations and also Fixated for a greater amount of time, when compared to the Paediatric Control Group. The two children in the ESES subgroup had the most pronounced difference, they had 2.5 times the Number of Fixations and Fixated for twice as long. This is a marked finding which raises the possibility that the KD with eye tracking could be a tool that permits identification or evaluation of children with

ESES. However, the small number of such patients who actually recruited into the study was small and therefore further testing is required to confirm the practical impact of these findings.

The K-D Test is primarily used for assessing head trauma (Moran & Covassin, 2018). Children with Epilepsy have not been investigated previously using the K-D Test, and therefore there is no available literature to make direct comparisons. Children with other Neurological Diseases such as Multiple Sclerosis (MS) have been evaluated using Eye Tracking. Children with MS assessed in an eye tracking study were found to have longer saccadic latencies when compared to age matched controls (Andrew Yousef et al., 2019). The prolonged saccadic and inter-saccadic latencies were observed even in Children who were not showing clinical signs of MS at the time of testing (A. Yousef et al., 2019). A group which have been extensively researched for reading tasks are Children with a diagnosis of Dyslexia. An Eye Tracking study comparing Children with and without a diagnosis of Dyslexia reported that Children with a diagnosis of Dyslexia had a longer mean Fixation Duration and shorter Saccadic Amplitudes in between targets (Nilsson Benfatto et al., 2016).

7.2 Number Naming Video Task

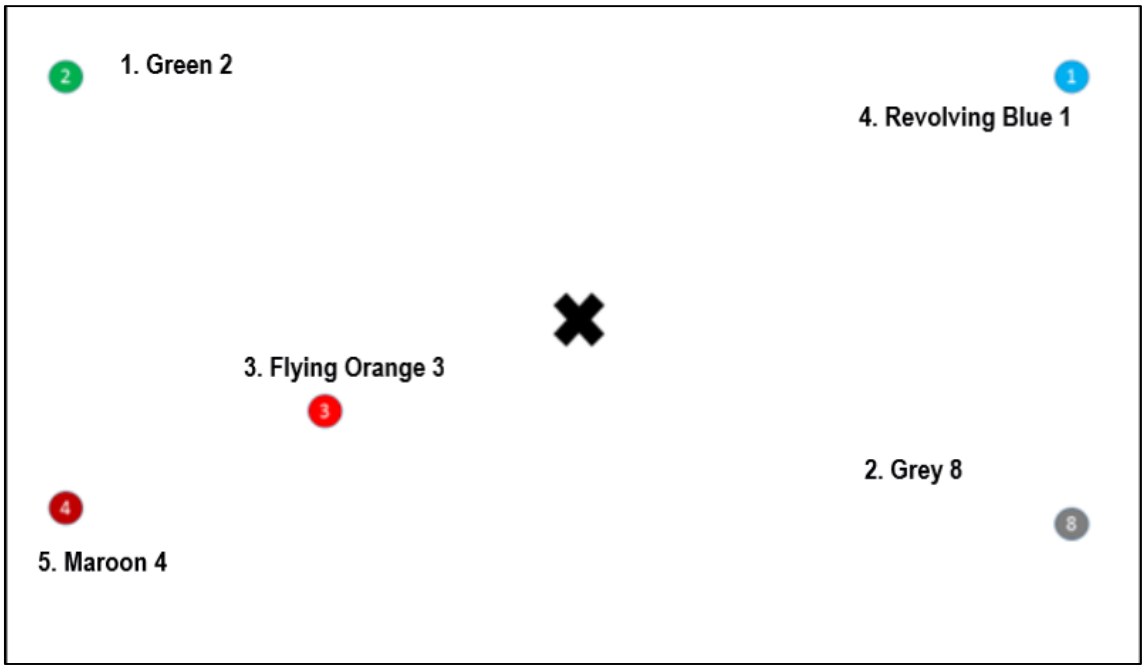
7.2.1 Adult Control Group

The most interesting finding from the NNVT was that the type of stimulus effected the Eye Tracking measurements.

The mean Maximum Fixation Duration was 0.75s, this is longer than the mean Maximum Fixation Duration for the K-D Test by 0.25s. The mean Maximum Saccadic Velocity was 554°/s, this is faster than the same value obtained in the K-D Test. This might reflect the greater distance between on-screen targets or the structure of the video, which involved movement of target stimuli in some instances.

The Area of Interest contributed a lot of data for this task. The measure Time to First Fixation (TTFF) is discussed below.

Figure 7.1 Number Naming Video Task with all stimuli displayed



The stimulus Orange 3 flew in from the right side, this attracted the attention of the individuals and contributed to a much faster TTFF. The Blue 1 stimulus appeared revolving in the upper right corner of the screen. This began as a faint colour and became darker before settling to a stop. The movement may have drawn attention to the stimulus, resulting in a shorter TTFF. The Maroon 4 stimulus appeared at eight minutes into the video, individuals had less than 2s to fixate on the stimulus before it disappeared. The two targets which have the longest TTFF are also the targets that some individuals missed entirely. A possible explanation for this might be that they are easier to miss in the corners of the screen or that they are less eye catching because they appeared without any additional animation.

When adults have been assessed with Eye Tracking they tended to have hypometric saccades, they would fixate near the target rather than landing directly on it (Fioravanti et al., 1995). In our study this would translate as Fixations Before. Adults had between 2-3.5 Fixations Before each target. Young adults, under the age of 35 years have been found to have the shortest saccadic latency to a target. This ability peaks in young adulthood but declines in middle age (Irving & Lillakas, 2019).

7.2.2 Paediatric Control Group

An initial objective of this experiment was to determine if children without a history of neurological disease would correctly fixate on and correctly identify all of the objects in the NNVT. With the exception of 1/73 participants this was a success. While the Paediatric Control Group had a lower overall Number of Fixations when compared to the Adult Control Group, they were noted to have a longer Fixation

Duration. Interestingly there is no age affect present when measuring the total number of Fixations within the Paediatric Control Group.

Children were faster than the Adult Control Group when measuring TTFF for Green 2 and Grey 8.

Compared to the Adult Control Group, the Paediatric Control Group had less Fixations Before but they had more Visits and Revisits. An increased number of Visits and Revisits correlates with the longer Fixation Duration. Prior studies have noted the importance of the distance between the targets as to whether children undershot (hypometric) or overshot (hypermetric) a stimulus. Children between ages 5-15 years were hypometric for stimuli placed far away but hypermetric for stimuli located closely together (Fioravanti et al., 1995).

7.2.3 Focal Epilepsy Group

The most important clinically relevant finding from this group was that the eye tracking measure TTFF is prolonged in the Focal Epilepsy Group, allowing children in this group to be distinguished from their peers. It is interesting to note that 3/11 of the children failed to fixate on one of the targets.

Children in the ESES subgroup had a much higher number of Fixations and Fixations Before. However, caution must be applied as the sample size is small, consisting of only 2 children.

These results reflect those of Raud et al (2015) who found that children with Focal Epilepsy performed well on visuospatial tasks when compared with their age matched peers (Raud et al., 2015). Children with Generalised Epilepsy who

completed the same study were found to have more difficulties across many Neuropsychological tests (Raud et al., 2015).

7.3 Spot the Difference Task

7.3.1 Adult Control Group

It was hypothesised that participants with a history of playing video games would be faster in completing this task, or that they were more efficient with a reduced number of Fixations. The number of participants who have a history of playing video games is small but no differences were found between gamers and non-gamers.

In contrast to the findings in the K-D Test, there was no difference between the sexes when examining Time to Complete. Although women were faster to fixate on two of the targets in SDT “Dogs”, Eyebrows and Lollipop, it did not offer them a clear advantage in finishing the task quicker. Men registered twice the number of Fixations over the task as women. In the Adult Control Group there was a strong correlation between Time to Complete and Maximum Fixation Duration within an AOI.

The most Visited and Revisited AOI was the Star which was a solitary AOI on one dog. Men on average returned to each AOI more than women, again this did not affect the overall Time to Complete.

Attention was not measured in this study. Some individuals appeared more motivated to complete the task than others, leading them to hurry to complete. A study by Jazbec et al, compared Adults and Adolescents accuracy and peak velocity of Saccadic eye movements. Adults were found to be more accurate but

when offered an incentive the Adolescent group were able to replicate the Adults accuracy (Jazbec et al., 2006).

7.3.2 Paediatric Control Group

This study set out with the aim of assessing the importance of age as a factor in Time to Complete. Our study found that as children grow older the mean Time to Complete and the range of time taken to complete reduces. Not enough males were recruited into this Group to measure a difference between the sexes. There was no significant difference found between the video gamers and non-video gamers.

When examining the SDT “Faces” specifically every child Revisited the “Sad Face” AOI, this is different to the Adult Control Group where only 75% of Adults recorded a Revisit.

Focusing on the SDT “Dogs” children tended to Fixate in the order of Rainbow, Star, Lollipop and finally Eyebrows. There is a difference present between the Control Groups, the Adult Group fixated on the Star initially and seemed to fixate on the Lollipop last. The Eyebrows are the least colourful object contained in the task. A paper by Irving et.al found that Children are quicker to respond to objects that are of interest to them, this was not found to be the case with the adults in the study (Irving et al., 2011) The children Visited and Revisited each AOI slightly more than the Adult Control Group. A higher proportion of Children revisited all targets when compared to the Adult Control Group.

7.3.3 Focal Epilepsy Group

One of the questions in this study sought to determine if Children with Focal Epilepsy would take longer to complete the Spot The Difference task. This was found to be the case such that their median Time to Complete was twice as long as the Paediatric Control Group. Subsequent to that question was that Children with Focal Epilepsy would have a greater number of Fixations, contained within a greater number of Visits and Revisits to each AOI. What stands out from the results is that children in the Focal Epilepsy Group fixated twice as much as their peers, this occurred in both sections of the task.

The current study found that Children with OFE and ESES take longer than their peers to complete each element of the task. When examined in isolation children with BECTS do not differ statistically from the Paediatric Control Group with regards to the median Time to Complete.

Children in the OFE and ESES subgroups took almost twice as long as the Paediatric Control Group to complete SDT Faces, the ESES subgroup demonstrates the most pronounced difference. All of the Children in the Focal Epilepsy Group had a longer TTFF when compared to the Paediatric Control Group. Children in the ESES subgroup had 3 times the amount of overall Fixations during the task and 5 times the number of Fixations within the “Sad Face” AOI compared to the Paediatric Control Group.

While a number of measures are similar to the Paediatric Control Group some differences are evident. The ESES subgroup takes longer to complete this task. Subjects in this group fixated on the object of interest more times than healthy control children.

There is no literature available for Eye Tracking specifically related to ESES. Eye Tracking studies involving Children with Rett Syndrome, as performed by Rose et al, 2019, report that Children with Rett Syndrome are slower to disengage with an initial stimulus and move onto the next (Susan A. Rose et al., 2019). Children with Rett Syndrome are typically non-verbal and Eye Tracking has provided an opportunity for research with this group (Susan A. Rose et al., 2019).

The most obvious finding to emerge from this research is the pronounced difference exhibited by the OFE and ESES subgroups, they took twice as long as the Paediatric Control group to identify all 4 objects. The Focal Epilepsy Group fixated twice as many times as the Paediatric Control Group, ESES subgroup fixated five times more than the Paediatric Control Group.

The Focal Epilepsy Group had a longer TTFF for each AOI compared to the Paediatric Control Group. This difference was most marked for the ESES subgroup, Children in the ESES subgroup took 3 times as long to Fixate on Eyebrows AOI. The ESES subgroup also had a much greater number of Fixations Before for the Eyebrows AOI.

OFE subgroup visited Eyebrows and Rainbow twice as many times as Paediatric Control Group, visited Lollipop three times more than Paediatric Control Group. The ESES subgroup had twice the amount of Visits and Revisits compared to the Paediatric Control Group.

Eye Tracking studies examining Children with Focal Epilepsy is not currently available for comparison. Eye Tracking research investigating Children with Dyslexia have found that their saccadic eye movements can be less organised than their peers (A. Vagge et al., 2015).

7.4 Focal Epilepsy Group Summary

The Focal Epilepsy Group can be distinguished from the Paediatric Control Group on a number of measures across the tasks. The Children with BECTS performed as well as Paediatric Control Group for the majority of the tasks. These Children were all in main stream school. None of them were taking an Anti-epileptic drug at the time of testing.

The Children in the ESES subgroups are on anti-epileptic medications and require frequent monitoring and admission to hospital for treatment. Their parents and carers can identify a deterioration in their speech and school ability, which prompts intervention from the Neurology team. The results included for analysis in this study are baseline measurements. Each of these Children have had follow-up studies to access the effect of medication on cognitive ability. When developing a hypothesis for this study we thought that this group would have difficulty performing some of these tasks. It was proposed that they would take longer to perform the tasks and that their eye movements would reflect that. The Eye Tracker can tell us that the Children in the Focal Epilepsy Group Visit and Revisit targets more times than their peers and that they Fixate on the objects for a greater length of time.

Chapter 8 – Conclusion

8.1 Summary of Aims

The aim of this study was to devise an Eye Tracking protocol that could be used for clinical evaluation of children. We wished to establish normal control values for children and to explore factors, such as age, which might influence eye tracking. Finally, we sought to examine whether our eye tracking protocol could differentiate between healthy children and children with a neurological disorder. Specifically, we focused on children with a focal epilepsy.

8.2 King-Devick Test

The K-D test is an established psychometric test (Katherine K. Weise et al., 2017). We recruited healthy adults and children and hypothesised that the time to complete the test would fall with increasing age in childhood and then plateau. Our study confirmed this hypothesis albeit that the range of ages for children in our study was not broad.

Our study has found that Children with Focal Epilepsy, OFE and ESES take longer to complete the KD Test and have a greater number of Fixations when compared to healthy controls. Notwithstanding the small sample size for this subgroup, this work offers valuable insights into the difficulties which children with ESES may experience with school work. Furthermore, the finding raises the possibility that Eye Tracking and the KD Test could play a quick and non-invasive role in screening for children with suspected epilepsy. Although much further work is necessary before this might be established.

8.3 Number Naming Video Task

The NNVT was designed to elicit both saccadic and smooth pursuit eye movements. From an Eye Tracking perspective children and adults perform similarly on this test. It does not differ with age as the K-D Test does. Furthermore, this test does not differentiate between Focal Epilepsy and healthy controls.

8.4 Spot the Difference Task

This was the most successful of the 3 tasks. It had good engagement from all of the groups. It was the most user friendly of the 3 tasks. The test successfully differentiated adults from children and established differences between children with epilepsy and paediatric controls. The findings, in particular those from the OFE and ESES subgroups will be of interest to Paediatric Neurologists. Eye Tracking was able to differentiate such Children from their healthy peers using a quick, readily accessible and non-invasive protocol.

8.5 Limitations of the study

The major limitation of this study was recruitment. When recruiting for normal controls it was only possible to test children aged 9-13 years in a Girls National School. It would have been preferable to test older adolescents also, the available literature reports that measures such as Time to Complete should improve as age increases. Going forward it would be a priority to recruit a wider age range of participants if possible. It is unfortunate that the normal control group did not include many male participants, as the Focal Epilepsy Group was predominantly male.

8.6 Further Research

This study has proven that simple Eye Tracking paradigms can potentially differentiate children with epilepsy from healthy controls. The mechanisms underlying these differences are not clear and further work should explore whether these may result from the effects of anti-epileptic drug use or from the epilepsies themselves. A natural progression of this work is to combine eye tracking results with EEG, neuroimaging and neuropsychology testing in order to comprehensively evaluate each participant.

Further prospective studies in an epilepsy cohort would also be interesting which would include other epilepsies, including the genetic generalised groups.

8.7 Clinical Application

Provision of Eye Tracking as a service could enhance the care of Children living with Epilepsy. One possible clinical application would be to measure the eye movements of Children with a history of ESES each time that they present to clinic, as well as before and after the administration of IV steroid treatment. The quick analysis of these results could offer Paediatric Neurologists timely feedback on the improvement or deterioration of patient state.

Chapter 9 Bibliography

Anderson, T. J., & MacAskill, M. R. (2013). Eye movements in patients with neurodegenerative disorders. *Nat Rev Neurol*, *9*(2), 74-85. https://doi.org/10.1038/nrneurol.2012.273

Barnes, G. R. (2011). Ocular pursuit movements. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The oxford handbook of eye movements* (pp. 116-129). Oxford University Press.

Beatriz Luna, K. V. (2011). Development from reflexive to controlled eye movements. In *The Oxford Handbook of Eye Movements* (pp. 621-636).

Brazis, P. W., Masdeu, J. C., & Biller, J. (1996). *Localization in clinical neurology*. Little Brown.

Castet, E., & Masson, G. S. (2000). Motion perception during saccadic eye movements. *Nature Neuroscience*, 177-183.

Cullen, K. E., & Van Horn, M. R. (2011). Brainstem pathways and premotor control. In *Oxford Handbook of Eye Movements* (pp. 152-172). Oxford University Press.

Ebenholtz, S. M. (2001). *Oculomotor systems and perception*. Cambridge University Press.

Fioravanti, F., Inchingolo, P., Pensiero, S., & Spanio, M. (1995). Saccadic eye movement conjugation in children. *Vision Res*, *35*(23-24), 3217-3228. https://doi.org/10.1016/0042-6989(95)00152-5

Fisher, R. S., Acevedo, C., Arzimanoglou, A., Bogacz, A., Cross, J. H., Elger, C. E., Engel, J., Forsgren, L., French, J. A., Glynn, M., Hesdorffer, D. C., Lee, B. I., Mathern, G. W., Moshé, S. L., Perucca, E., Scheffer, I. E., Tomson, T., Watanabe, M., & Wiebe, S. (2014). ILAE official report: a practical clinical definition of epilepsy. *Epilepsia*, *55*(4), 475-482. https://doi.org/10.1111/epi.12550

Fitzgerald, M. J. T., Gruener, G., & Mtui, E. (2012). *Clinical neuroanatomy and neuroscience* (6th ed.). Saunders/Elsevier.

Gandhi, N. J., & Katnani, H. A. (2011). Interactions of eye and eylid movements. In *The Oxford Handbook of eye movements* (pp. 323-335). Oxford University Press.

Hecimovich, M., King, D., Dempsey, A., Gittins, M., & Murphy, M. (2019). In situ use of the King-Devick eye tracking test and changes seen with sport-related concussion: saccadic and blinks counts. *The Physician and Sportsmedicine*, *47*(1), 78-84.

Hessels, R. S., Andersson, R., Hooge, I. T. C., Nystrom, M., & Kemner, C. (2015). Consequences of Eye Colour, Positioning and Head Movement for Eye-Tracking Data Quality in Infant Research. *Infancy*, 601-633.

Hessels, R. S. N., Diederick C, Kemner, C., & Hooge, I. T. C. (2017). Noise-robust fixation detection in eye movement data: Identification by two-means clustering (I2MC). *Behaviour research methods*, *49*(5), 1802-1823.

Holmqvist, K. (2011). *Eye tracking : a comprehensive guide to methods and measures*. Oxford University Press.

Holmqvist, K., Nystrom, M., Andersson, R., Dewhurst, R., Jarodzka, H., & van de Weijer, J. (2015). *Eye Tracking A Comprehensive Guide to Methods and Measures*. Oxford University Press.

Irving , E. L., Gonzalez, E. J., Lillakas, L., Wareham , J., & McCarthy, T. (2011). Effect of stimulus type on eye movements of Children. *Investigative Ophthalmology & Visual Science*, 658-664.

Irving, E. L., & Lillakas, L. (2019). Difference between vertical and horizontal saccades across the human lifespan. *Exp Eye Res*, *183*, 38-45. https://doi.org/10.1016/j.exer.2018.08.020

Jazbec, S., Hardin, M. G., Schroth, E., McClure, E., Pine, D. S., & Ernst, M. (2006). Age-related influence of contingencies on a saccade task. *Exp Brain Res*, *174*(4), 754-762. https://doi.org/10.1007/s00221-006-0520-9

Johnson, S. (2012). *A clinical handbook on child development paediatrics*. Churchill Livingstone Australia.

King, D., Hume, P., Gissane, C., & Clark, T. (2015). Use of the King-Devick test for sideline concussion screening in junior rugby league. *J Neurol Sci*, *357*(1-2), 75-79. https://doi.org/10.1016/j.jns.2015.06.069

Krebs, C., Weinberg, J., & Akesson, E. (2012). *Neuroscience*. Wolters Kluwer/Lippincott Williams & Wilkins Health.

Lawrence, J. B., Haider, M. N., Leddy, J. J., Hinds, A., Miecznikowski, J. C., & Willer, B. S. (2019). The King-Devick test in an outpatient concussion clinic: Assessing the diagnostic and prognostic value of a vision test in conjunction with exercise testing among acutely concussed adolescents. *J Neurol Sci*, *398*, 91-97. https://doi.org/10.1016/j.jns.2018.12.020

Leigh, R. J., & Zee, D. S. (2015). *The neurology of eye movements* (5th ed.). Oxford ; New York : Oxford University Press, [2015].

Liversedge, S. P., Gilchrist, I. D., & Everling, S. (2011). *The Oxford handbook of eye movements*. Oxford University Press.

Luna, B., & Velanova, K. (2011). Development from reflexive to controlled eye movements. In *The Oxford Handbook of Eye Movements* (pp. 621-636).

Luna , B., & Velanova, K. (2011). Development from reflexive to controlled eye movements. In *Oxford Handbook of Eye Movements* (pp. 621-636).

Martini, F., & Nath, J. (2009). *Fundamentals of Anatomy & Physiology*. Pearson.

Moiroud, L., Gerard, Christophe Loic, Peyre, Hugo, Pia Bucci, Maria. (2018). Decelopmental eye movement test and dyslexic children: A pilot study with eye movement recordings.

Moran, R. N., & Covassin, T. (2018). King-Devick test normative reference values and internal consistency in youth football and soccer athletes. *Scand J Med Sci Sports*, *28*(12), 2686-2690. https://doi.org/10.1111/sms.13286

Nilsson Benfatto, M., Öqvist Seimyr, G., Ygge, J., Pansell, T., Rydberg, A., & Jacobson, C. (2016). Screening for Dyslexia Using Eye Tracking during Reading. *PLoS One*, *11*(12), e0165508. https://doi.org/10.1371/journal.pone.0165508

Panayiotopoulos, C. P. (2002). *A clinical Guide to Epilepstic syndromes and their treatment*. Bladon Medical Publishing.

Pel, J. J., Manders, J. C., & van der Steen, J. (2010). Assessment of visual orienting behaviour in young children using remote eye tracking: methodology and reliability. *Neuroscience Methods*, *189*(2), 252-256.

Raud, T., Kaldoja, M. L., & Kolk, A. (2015). Relationship between social competence and neurocognitive performance in children with epilepsy. *Epilepsy Behav*, *52*(Pt A), 93-101. https://doi.org/10.1016/j.yebeh.2015.08.028

Rizzo, J. R., Hudson, T. E., Dai, W., Desai, N., Yousefi, A., Palsana, D., Selesnick, I., Balcer, L. J., Galetta, S. L., & Rucker, J. C. (2016). Objectifying eye movements during rapid number naming: Methodology for assessment of normative data for the King-Devick test. *J Neurol Sci*, *362*, 232-239. https://doi.org/10.1016/j.jns.2016.01.045

Robert S. Fisher, J. H. C., ‡Jacqueline A. French, §Norimichi Higurashi, ¶Edouard Hirsch, #Floor E. Jansen, **Lieven Lagae, ††Solomon L. Moshe, ‡‡Jukka Peltola, §§Eliane Roulet Perez, ¶¶Ingrid E. Scheffer, and ##***Sameer M. Zuberi. (2017). Operational classification of seizure types by the International League Against Epilepsy: Position Paper of the ILAE Commission for Classification and Terminology *Epilepsia*, *4*(58), 522–530.

Rose, S. A., Jankowski, J. J., Wass, S., & Feldman, J. F. (2019). Attentional Shifting and Disengagement in Rett Syndrome. *Neuropsychology*, 335-342.

Rose, S. A., Wass, S., Jankowski, J. J., Feldman, J. F., & Djukic, A. (2019). Attentional Shifting and Disengagement in Rett Syndrome. *Neuropsychology*, *33*(3), 335-342. https://doi.org/10.1037/neu0000515

Schapira, A. H. V., & Byrne, E. (2007). *Neurology and clinical neuroscience*. Mosby Elsevier.

Seidman, D. H., Burlingame, J., Yousif, L. R., Donahue, X. P., Krier, J., Rayes, L. J., Young, R., Lilla, M., Mazurek, R., Hittle, K., McCloskey, C., Misra, S., & Shaw, M. K. (2015). Evaluation of the King-Devick test as a concussion screening tool in high school football players. *J Neurol Sci*, *356*(1-2), 97-101. https://doi.org/10.1016/j.jns.2015.06.021

Studio, T. (2017). Tobii Studio User's manual v3.4.8. In *Tobii Studio User's manual v3.4.8*. Sweden.

Sumner, E., Hutton, S. B., Kuhn, G., & Hill, E. L. (2018). Oculomotor atypicalities in developmental coordination disorder. *Developmental science*, *21*(1).

Tedrus, G. M. A. S., Fonseca, L. C., Melo, E. M. V., & Ximenes, V. L. (2009). Educational problems related to quantitative EEG changes in benign childhood epilepsy with centrotemporal spikes. *Epilepsy & Behavior*, 486-490.

Tiadi, A., Seassau, M., Gerard, C. L., & Bucci, M. P. (2016). Differences between dyslexic and non-dyslexic children in the performance of phonological vidual-auditory recognition tasks: An eye tracking study. *PLoS One*, e0159190.

Tobii Pro X3-120. (2019). https://www.tobiipro.com/product-listing/tobii-pro-x3-120/

Tobii studio analysis software. (2011). In.

Vagge, A., Cavanna, M., Traverso, C. E., & Iester, M. (2015). Evaluation of ocular movements in patients with dyslexia. *Ann Dyslexia*, *65*(1), 24-32. https://doi.org/10.1007/s11881-015-0098-7

Vagge, A., Cavanna, M., Traverso, C. E., & Iester, M. (2015). Evolution of ocular movements in patients with dyslexia. *Ann of dyslexia*, 24-32.

Van der Stigchel, S., Hessels, R., van Elst, J. C., & Kemer, C. (2017). The disengagement of visual attention in the gap paradigm across adolescence. *Experimental Brain Research*, 3585-3592.

Ventura, R. E., Balcer, L. J., Galetta, S. L., & Rucker, J. C. (2016). Ocular motor assessment in concussion: Current status and future directions. *J Neurol Sci*, *361*, 79-86. https://doi.org/10.1016/j.jns.2015.12.010

Weise, K. K., Swanson, M., Penix, K., Heath Hale, M., & Ferguson, D. (2017). King-Devick and Pre-season Visual Function in Adolescent Athletes. *Optom Vis Sci.*, 89–95.

Weise, K. K., Swanson, M. W., Penix, K., Hale, M. H., & Ferguson, D. (2017). King-Devick and Pre-season Visual Function in Adolescent Athletes. *Optom Vis Sci*, *94*(1), 89-95. https://doi.org/10.1097/OPX.0000000000000938

Wong, A. M. F. (2008). *Eye Movement Disorders*. Oxford University Press.

Wong, A. M. F. (2008). *Eye movement disorders*. Oxford University Press.

Yousef, A., Devereux, M., Gourraud, P.-A., Jonzzon, S., Suleiman, L., Waubant, E., Green, A., & Graves, J. S. (2019). Subclinical saccadic eye movement dysfunction in pediatric multiple sclerosis. *Child Neurology*, *34*(1), 38-43.

Yousef, A., Devereux, M., Gourraud, P. A., Jonzzon, S., Suleiman, L., Waubant, E., Green, A., & Graves, J. S. (2019). Subclinical Saccadic Eye Movement Dysfunction in Pediatric Multiple Sclerosis. *J Child Neurol*, *34*(1), 38-43. https://doi.org/10.1177/0883073818807787

Chapter 10 Appendices

10.1 Funding letter

HUMAN RESOURCES DEPARTMENT
General & Nursing
Telephone: 01- 4096479 / 01- 4096590
Medical Division
Telephone: 01- 4096314 / 01- 4096187
Website: www.olchc.ie

Ospidéal Mhuire na Leanaí, Cromghlinn
Our Lady's Children's Hospital, Crumlin

Strictly Personal & Confidential:

Ms Eileen O'Flaherty
81 Simmonstown Manor,
Celbridge,
Co.Kildare.

6th September 2016

Re: OLCHC Bursary Fund

Dear Eileen,

Congratulations again and on behalf of the OLCHC Board of Management I would like to wish you well in your studies following being awarded one of the ten OLCHC Bursaries in 2016/17.

As outlined in the Bursary Fund terms and conditions, the hospital will sponsor you in respect of course tuition fees and exam fees (first sitting only) of up to €5000 per academic year, for up to three academic years.

May I request that you submit your college receipts / invoices to Ms Louise Whelan, Human Resources Department for processing payment. If you have any queries in relation to this, please contact Louise on ext. 6196.

Study leave of 5 working days per academic year will be granted and Exam leave of up to 5 x ½ working days per academic year will be granted provided the exams fall within the working day (exam timetable to be submitted to HR in advance and exam results to be submitted also).

On completion of your exams, please submit a transcript for your HR File.

Yours sincerely,

Joan Troy
Deputy Director of Human Resources

cc. Ms Ailish Colfer, Neurophysiology Measurement Physiologist, Neurology/EEG, OLCHC

....where children's health comes first

50 YEARS 1956-2006

10.2 Consent and Assent Forms

10.2.1 Adult Consent Form

Eye Tracking Study

I understand that participation in this study is entirely voluntary and that I may withdraw at any time. ☐

I understand that my identity will remain confidential at all times. ☐

I …… give informed consent to participate in this research study lead by the Neurosciences Department.

Signed……

Date……

To be completed by Investigator

I the undersigned have taken the time to fully explain to the above participant, the nature of the study. I have answered any queries or questions that they had prior to the study.

Signed..…… Date…….

10.2.2 Children's Assent Form

Children's Assent Form

Eye Tracking Study

We would like you to read the information booklet given to you. If you would like to take part in our project, please sign your name below. You do not have to take part in this project if you do not want to. If so, we will not use any of your information for our project. We always try to make the test as enjoyable and easy for you as possible. Your parents (Mum and Dad) /guardians have been told about our study and have agreed that you may take part in it, if you are happy to do so.

I _____ have read about the study from the information booklet given to me and would like to take part in the project during my test today.

Signature of child

_____

Date:

Questions are welcome!

10.3 Information Leaflets

10.3.1 Recruitment letter for parents

Dear Parent/Guardian,

Your child is being asked to participate in a research project within the Neurosciences department. If you agree to let your child participate I can perform the test on the same day as your outpatient appointment or at a time that suits your family. The test should take between 10-20 minutes.

About the study

We would like to better understand the parts of the brain involved in eye movement. For this study we would like to observe and measure children's eye movement. We will do this while they read text and/or observe objects on a screen. The study is painless; we try to make the test as enjoyable as possible for your child. With the information from the study we hope to provide more detailed testing for our patients in the future.

What will the study tell us?

On arrival to the department on the day of your appointment you will be asked to sign a written consent form. Your child will be asked sit in front of a computer, an infrared camera will measure their eye movements. The camera does not take any pictures of your child. The tasks involve a variety of reading numbers and observing pictures.

Are there any risks Involved?

There are no risks arising from your child's participation in the study.

What are my rights if I take part?

If you decide to take part, you may withdraw from the study at any time and all the data collected will not be used. Note: If your child wears glasses when reading please bring them with you to the department. *If you have any queries about the test or any questions about this research study, please call the Neurophysiology department on 01-4096632 and ask to speak to Eileen. I can also answer any questions you may have when you attend for the study. I have included an information leaflet for your child with this letter.*

Best wishes,

Eileen O'Flaherty

Senior Clinical Physiologist (Neurophysiology)

Children's Health Ireland (CHI) at Crumlin

Crumlin, D12 N512, Ireland

T + 353 (0) 1 4096632

E eileen.oflaherty@olchc.ie | www.olchc.ie

10.3.2 Participant Information Leaflet

Will the outcomes of the research be published?

It is hoped that this study will be published however all identifying data will remain confidential.

Confidentiality Issues

Only the clinical physiologists and Consultant Neurophysiologist are able to access the data. The data collected for the study is coded and is only accessible to the consultant neurophysiologist.

Your Participation counts

Taking part in this study is your own choice.

We hope that you can support us in our work and we would like to thank you for your help

If you have any queries about the test or any questions about this research study please call the Neurophysiology department.

Department of Clinical Neurophysiology,
Children's Health Ireland at Crumlin,
Crumlin, Dublin 12

Phone: 01-4096632

Department of Clinical Neurophysiology,
Children's Health Ireland at Crumlin,
Crumlin, Dublin 12

Phone: 014096632

Email: eileen.oflaherty@olchc.ie

Children's Health Ireland at Crumlin

Participant Information Leaflet

Children's Health Ireland at Crumlin

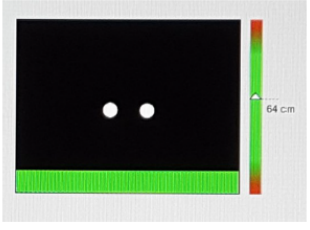
Eye Tracking Study

Participant Information Leaflet

We would like to invite you to participate in a research project which is being run by the Neurophysiology department. We would like to tell you a little bit about our project so that you can decide if you would like to take part.

About the study

We would like to better understand the parts of the brain involved in eye movement. For this study we would like to observe and measure children's eye movement. We will do this while you read some numbers and/or observe objects on a screen. The study is painless, we try to make the test as fun as possible for you.

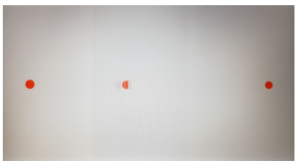


What will the study tell us?

We hope to collect and analyze a variety of eye movements across age groups using different techniques. With the information from the study we hope to provide more detailed testing for our patients in the future.

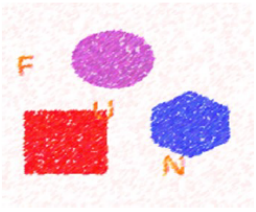
What would I have to do?

We will ask you to sit in front of a laptop computer, there will be a small camera underneath the screen. The camera is designed to only take pictures of your eyes.



Before beginning each part of the test we will ask you to follow a red dot around the screen. This helps us to ensure that the test is accurate.

We will ask you to read some numbers and letters, then show you some pictures.



The time needed to take part in the study will take about 10-15 minutes.

What are my rights if I take part?

If you decide to take part you may withdraw from the study at any time and all the data collected will not be used.

Taking part in this study is entirely voluntary.

What if I choose not to take part?

If you do not wish to take part, then the test will be not be carried out. Thank you for taking the time to read about the study.

Who are the study Researchers?

The study researchers are the clinical measurement physiologists who perform the test along with the consultant Neurophysiologist.

How long will the study last?

We plan to run the study for 2 years. Your involvement in the project will only be on the day of testing.

Note: If you wear glasses when reading please bring them with you to the department.

10.3.3 Parent Information Leaflet

Parent Information Leaflet

We are asking your child to participate in a simple research project within the Neurosciences department. You should read the following information carefully before deciding if you would like to take part. Your child will need to be able to read numbers and letters to participate in the study.

About the study

We move our eyes throughout our waking and sleeping lives. We would like to better understand the parts of the brain involved in eye movement as it might help us to recognize problems in children with different brain illness. For this study we would like to observe and measure children's eye movement. We will do this while they read text and/or look at objects on a computer screen. The study is painless; we try to make the test as enjoyable as possible for your child. Your child will need to be able to read numbers and letters to participate in the study.

What will the study tell us? We hope to collect information about eye movements across a range of age groups. With the information from the study we hope to provide more detailed testing for our patients in the future.

What happens if my child takes part? **Note:** If your child wears glasses when reading please bring them with you to the department.

Test: On arrival to the department on the day of your appointment you will be asked to sign a written consent form. We will ask your child to sit in front of a screen. You will be able to accompany your child at all times. We will ask your child to read a combination of numbers and letters from the screen. A discrete eye tracker will be situated at the base of the screen. This measures your child's eye movements as they carry out the reading tasks in a non-invasive manner. The test will take between 10-15 minutes.

Are there any risks Involved? There are no risks arising from your child's participation in the study.

What are my rights if I take part? If you decide to take part, you may withdraw from the study at any time and all the data collected will not be used. Taking part in this study is entirely voluntary.

What if I choose not to take part? If your child does not wish to take part, then the test will be not be carried out. Thank you for taking the time to read about the study.

How long will the study last? We plan to run the study for 1 year. Your child s involvement in the project will only be on the day of testing.

Who are the study Researchers? The study researchers are the clinical

measurement physiologists who perform the test along with the consultant Neurophysiologist.

Will the outcomes of the research be published? It is hoped that this study will be published however all data is confidential.

Confidentiality Issues Only the clinical measurement physiologists and Consultant Neurophysiologist are able to access the data. The data collected for the study is anonymous and is only accessible to the consultant neurophysiologist.

Your Participation counts Taking part in this study is voluntary. We hope that you can support us in our work and we would like to thank you for your help.

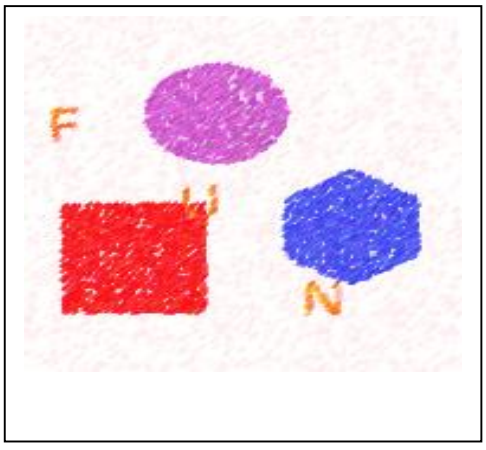
If you have any queries about the test or any questions about this research study please Please contact the neurosciences department on 01-4096632, or email eileen.oflaherty@olchc.ie. We can also answer any questions you may have when you attend for the study.

Children Information Leaflet (<12 years)

We are carrying out a project in our hospital to look at eye movement. We would like to tell you a little bit about our project so that you can decide if you would like to take part.

About the study

When you read or look around you, many parts of your brain are working together to guide your eye movements.



What would I have to do?

We will ask you to sit in front of a screen. We will ask you to read some numbers and letters, then show you some pictures. A very small camera sitting below the screen will record your eye movements. The time needed to take part in the study will only take 10-15 minutes, your mum or dad can stay with you as you take part.

Do I have to take part in the project?

You do not have to take part if you would not like to. Thank you for reading about our project.

10.4 Study Material

Children's Health Ireland at Crumlin

Eye Tracking Demographics

Age: _____

Gender: _____

Eye colour: Blue / Non-Blue/ Green

Wears glasses: Yes/No If yes.

Wearing glasses for study: Yes/No

Date:
Time:
Identifier:

Medication: _____

Relevant History: _____

_____

Have you ever had a head injury which required you to attend a doctor? Yes/No

Do you play sport? Yes/No If yes, which sports? _____

_____

Do you play computer games? If yes, PlayStation/Xbox/PC

To be filled in by the Physiologist performing the test:

Calibration 9 5 3

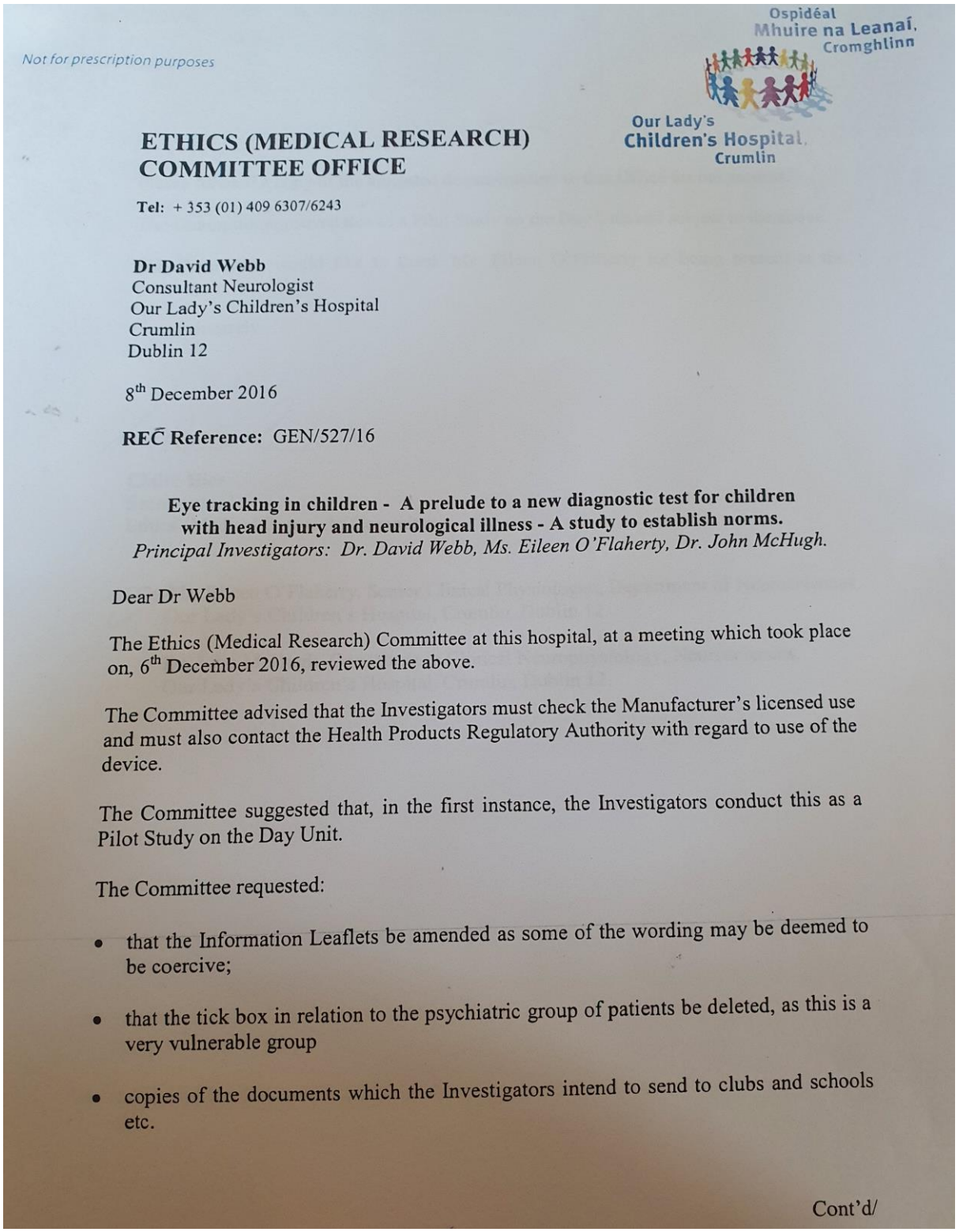
King-Devick _____

Number Naming Video _____

Spot the difference _____

10.5 OLCHC Ethics (Medical Research) Committee Correspondence

10.5.1 Letter from Ethics (Medical Research) Committee OLCHC 2016



Not for prescription purposes

Ospidéal Mhuire na Leanaí, Cromghlinn
Our Lady's Children's Hospital, Crumlin

ETHICS (MEDICAL RESEARCH) COMMITTEE OFFICE

Tel: + 353 (01) 409 6307/6243

Dr David Webb
Consultant Neurologist
Our Lady's Children's Hospital
Crumlin
Dublin 12

8th December 2016

REC Reference: GEN/527/16

Eye tracking in children - A prelude to a new diagnostic test for children with head injury and neurological illness - A study to establish norms.
Principal Investigators: Dr. David Webb, Ms. Eileen O'Flaherty, Dr. John McHugh.

Dear Dr Webb

The Ethics (Medical Research) Committee at this hospital, at a meeting which took place on, 6th December 2016, reviewed the above.

The Committee advised that the Investigators must check the Manufacturer's licensed use and must also contact the Health Products Regulatory Authority with regard to use of the device.

The Committee suggested that, in the first instance, the Investigators conduct this as a Pilot Study on the Day Unit.

The Committee requested:

- that the Information Leaflets be amended as some of the wording may be deemed to be coercive;
- that the tick box in relation to the psychiatric group of patients be deleted, as this is a very vulnerable group
- copies of the documents which the Investigators intend to send to clubs and schools etc.

Cont'd/

Please forward a copy of the amended documentation to this Office for our records.

The Committee approved this as a Pilot Study on the Day Unit and subject to the above.

The Committee would like to thank Ms. Eileen O'Flaherty for being present at the meeting.

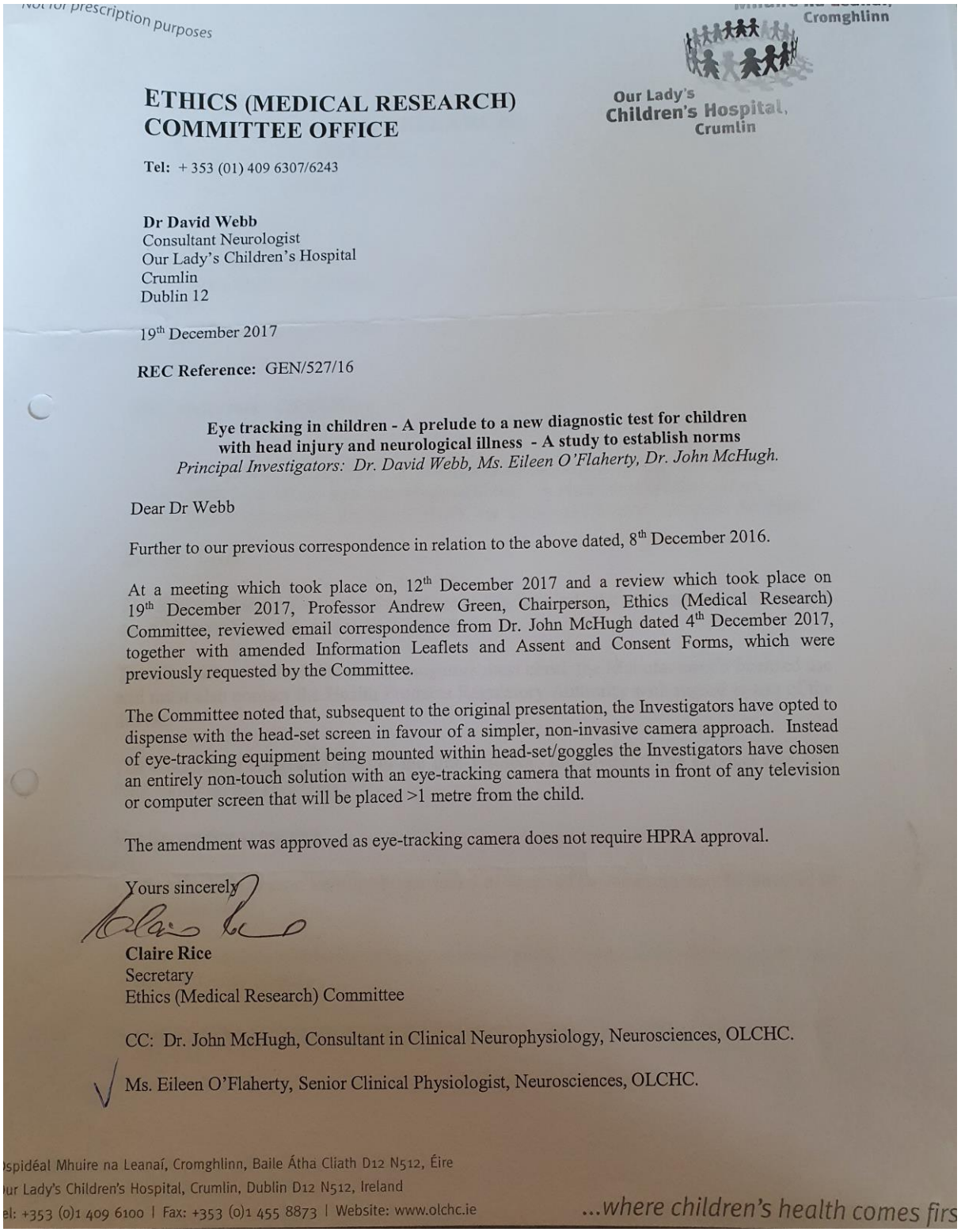
Yours sincerely

Claire Rice
Secretary
Ethics (Medical Research) Committee

CC: Ms. Eileen O'Flaherty, Senior Clinical Physiologist, Department of Neurosciences, Our Lady's Children's Hospital, Crumlin, Dublin 12.

Dr. John McHugh, Consultant in Clinical Neurophysiology, Neurosciences, Our Lady's Children's Hospital, Crumlin, Dublin 12.

10.5.2 Approval letter form Ethics (Medical Research) Committee OLCHC 2017



Not for prescription purposes

Cromghlinn

Our Lady's Children's Hospital, Crumlin

ETHICS (MEDICAL RESEARCH) COMMITTEE OFFICE

Tel: + 353 (01) 409 6307/6243

Dr David Webb
Consultant Neurologist
Our Lady's Children's Hospital
Crumlin
Dublin 12

19th December 2017

REC Reference: GEN/527/16

Eye tracking in children - A prelude to a new diagnostic test for children with head injury and neurological illness - A study to establish norms
Principal Investigators: Dr. David Webb, Ms. Eileen O'Flaherty, Dr. John McHugh.

Dear Dr Webb

Further to our previous correspondence in relation to the above dated, 8th December 2016.

At a meeting which took place on, 12th December 2017 and a review which took place on 19th December 2017, Professor Andrew Green, Chairperson, Ethics (Medical Research) Committee, reviewed email correspondence from Dr. John McHugh dated 4th December 2017, together with amended Information Leaflets and Assent and Consent Forms, which were previously requested by the Committee.

The Committee noted that, subsequent to the original presentation, the Investigators have opted to dispense with the head-set screen in favour of a simpler, non-invasive camera approach. Instead of eye-tracking equipment being mounted within head-set/goggles the Investigators have chosen an entirely non-touch solution with an eye-tracking camera that mounts in front of any television or computer screen that will be placed >1 metre from the child.

The amendment was approved as eye-tracking camera does not require HPRA approval.

Yours sincerely

Claire Rice
Secretary
Ethics (Medical Research) Committee

CC: Dr. John McHugh, Consultant in Clinical Neurophysiology, Neurosciences, OLCHC.

Ms. Eileen O'Flaherty, Senior Clinical Physiologist, Neurosciences, OLCHC.

Ospidéal Mhuire na Leanaí, Cromghlinn, Baile Átha Cliath D12 N512, Éire
Our Lady's Children's Hospital, Crumlin, Dublin D12 N512, Ireland
Tel: +353 (0)1 409 6100 | Fax: +353 (0)1 455 8873 | Website: www.olchc.ie

...where children's health comes firs

Not for prescription purposes

Ospidéal Mhuire na Leanaí, Cromghlinn
Our Lady's Children's Hospital Crumlin

ETHICS (MEDICAL RESEARCH) COMMITTEE OFFICE
Tel: + 353 (01) 409 6307/6243

Dr John McHugh
Consultant in Clinical Neurophysiology
Our Lady's Children's Hospital
Crumlin
Dublin 12 N512

31st December 2018

REC Reference: GEN/699/18

Eye tracking in children. A prelude to a new diagnostic test for children with head injury and neurological illness
Principal Investigator: Dr. John McHugh, Professor David Webb, Ms. Eileen O'Flaherty.

Dear Dr McHugh

The Ethics (Medical Research) Committee at this hospital, at a meeting that took place on 11th December 2018, reviewed the above study.

1. The Committee advised that Parents be should asked for their permission to contact their General Practitioner should any abnormality be discovered in the participant during the Study - this request should be included in the Consent Form.

2. The Committee recommended that contact should be made, in the first instance, with Schools that have a connection with this hospital (this information will be available from the Chief Executive/Communications Offices).

3. In Section E2.11 (a) '*Will any of the study data collected consist of photographs/video recordings?* The answer should read '*No*'.

The Study was approved subject to the above alterations.

The Committee would like to thank you and Ms. Sinead Monaghan for being present at the meeting and for speaking to this item.

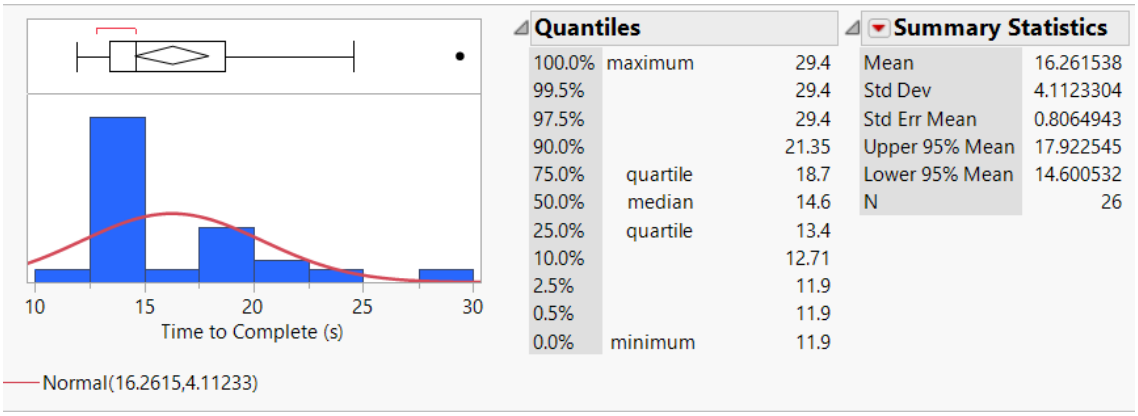
Yours sincerely

Claire Rice
Secretary
Ethics (Medical Research) Committee

CC: Professor David Webb, Consultant Paediatric Neurologist, OLCHC.
Ms. Sinead Monaghan, Senior Speech and Language Therapist, OLCHC.

10.6 Distribution Histograms of Time to Complete the King-Devick Test

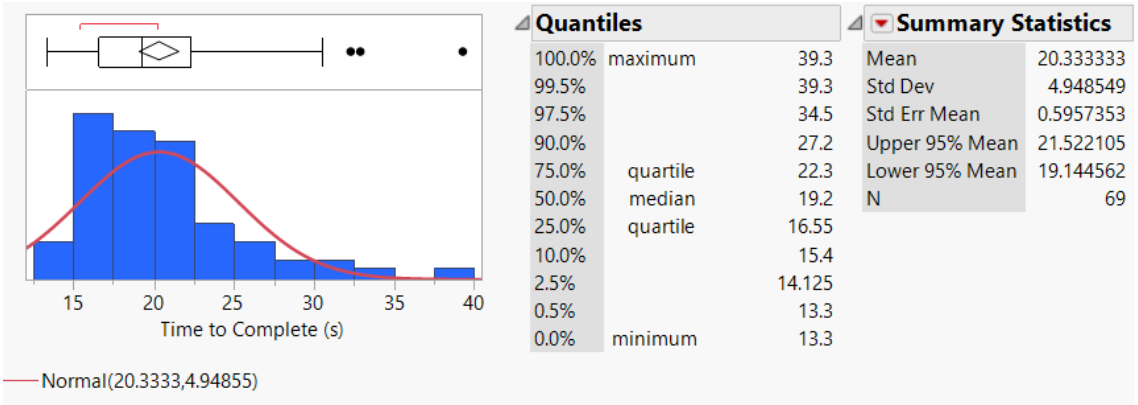
Figure 10.6.1 Histogram of distribution Time to Complete for adult control group who completed the K-D Test (n=26)



Quantiles		
100.0%	maximum	29.4
99.5%		29.4
97.5%		29.4
90.0%		21.35
75.0%	quartile	18.7
50.0%	median	14.6
25.0%	quartile	13.4
10.0%		12.71
2.5%		11.9
0.5%		11.9
0.0%	minimum	11.9

Summary Statistics	
Mean	16.261538
Std Dev	4.1123304
Std Err Mean	0.8064943
Upper 95% Mean	17.922545
Lower 95% Mean	14.600532
N	26

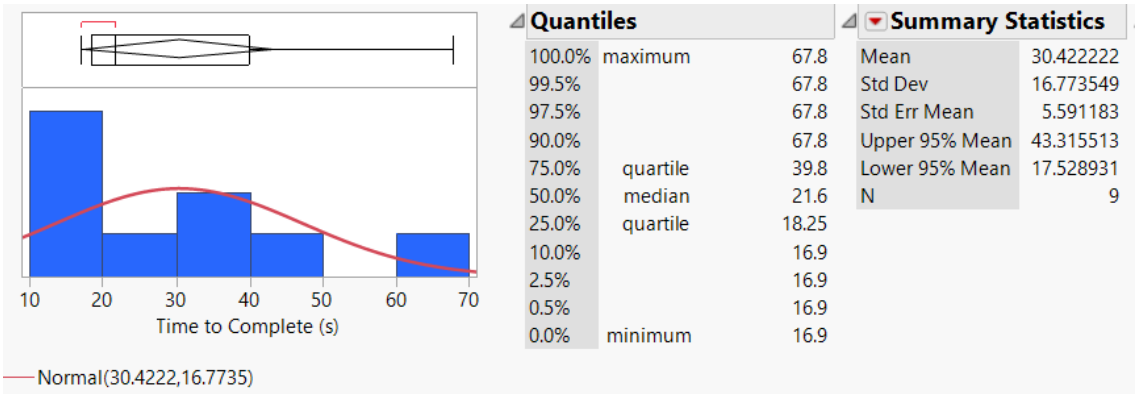
Figure 10.6.2 Histogram of distribution Time to Complete for paediatric control group who completed the K-D Test (n=69)



Quantiles		
100.0%	maximum	39.3
99.5%		39.3
97.5%		34.5
90.0%		27.2
75.0%	quartile	22.3
50.0%	median	19.2
25.0%	quartile	16.55
10.0%		15.4
2.5%		14.125
0.5%		13.3
0.0%	minimum	13.3

Summary Statistics	
Mean	20.333333
Std Dev	4.948549
Std Err Mean	0.5957353
Upper 95% Mean	21.522105
Lower 95% Mean	19.144562
N	69

Figure 10.6.3 Histogram of distribution Time to Complete for Focal Epilepsy Group who completed the K-D Test (n=9)

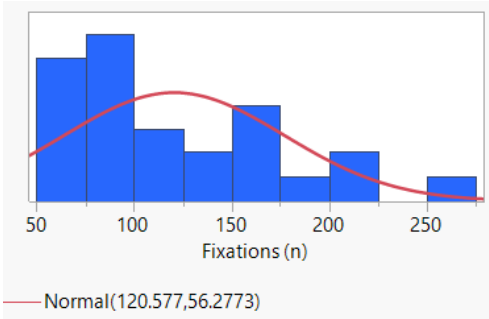


Quantiles		
100.0%	maximum	67.8
99.5%		67.8
97.5%		67.8
90.0%		67.8
75.0%	quartile	39.8
50.0%	median	21.6
25.0%	quartile	18.25
10.0%		16.9
2.5%		16.9
0.5%		16.9
0.0%	minimum	16.9

Summary Statistics	
Mean	30.422222
Std Dev	16.773549
Std Err Mean	5.591183
Upper 95% Mean	43.315513
Lower 95% Mean	17.528931
N	9

10.7 Histograms for Number of Fixations during K-D Test

Figure 10.7.1 Histogram for distribution of Number of Fixations for adult control group (n=26)



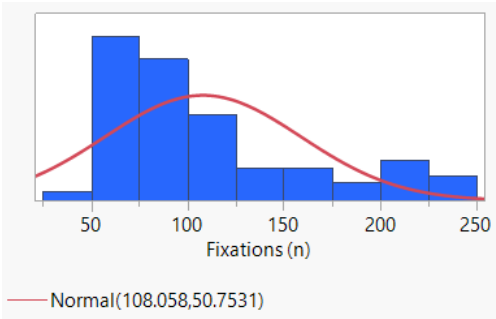
Quantiles

100.0%	maximum	270
99.5%		270
97.5%		270
90.0%		209.2
75.0%	quartile	163.25
50.0%	median	101.5
25.0%	quartile	72.25
10.0%		60
2.5%		59
0.5%		59
0.0%	minimum	59

Summary Statistics

Mean	120.57692
Std Dev	56.277294
Std Err Mean	11.036885
Upper 95% Mean	143.30781
Lower 95% Mean	97.846032
N	26

Figure 10.7.2 Histogram for distribution of Number of Fixations for paediatric control group (n=69)



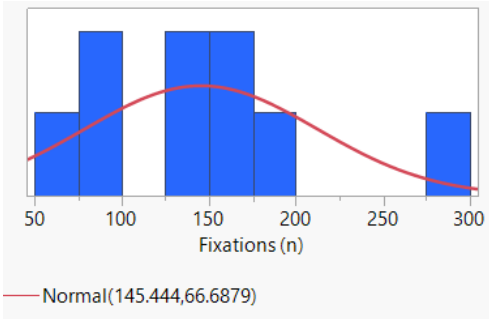
Quantiles

100.0%	maximum	236
99.5%		236
97.5%		232.25
90.0%		208
75.0%	quartile	129.5
50.0%	median	88
25.0%	quartile	69.5
10.0%		59
2.5%		54.25
0.5%		49
0.0%	minimum	49

Summary Statistics

Mean	108.05797
Std Dev	50.753118
Std Err Mean	6.1099574
Upper 95% Mean	120.2502
Lower 95% Mean	95.865741
N	69

Figure 10.7.3 Histogram for distribution of Number of Fixations for focal epilepsy group (n=9)



Quantiles

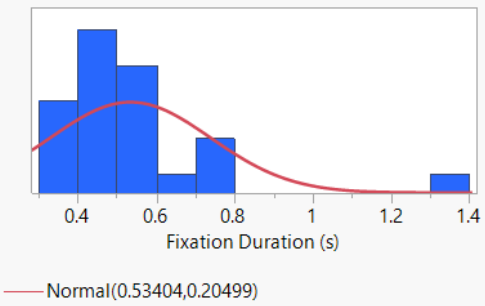
100.0%	maximum	288
99.5%		288
97.5%		288
90.0%		288
75.0%	quartile	178.5
50.0%	median	139
25.0%	quartile	86.5
10.0%		73
2.5%		73
0.5%		73
0.0%	minimum	73

Summary Statistics

Mean	145.44444
Std Dev	66.687913
Std Err Mean	22.229304
Upper 95% Mean	196.70531
Lower 95% Mean	94.183577
N	9

10.8 Histograms for Maximum Fixation Duration for K-D Test

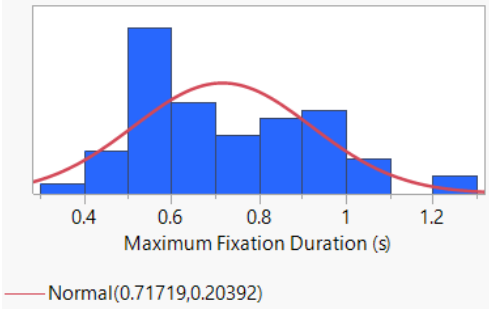
Figure 10.8.1 Histogram of distribution for Maximum Fixation Duration for the adult control group (n=26)



Quantiles		
100.0%	maximum	1.35
99.5%		1.35
97.5%		1.35
90.0%		0.7206
75.0%	quartile	0.586
50.0%	median	0.487
25.0%	quartile	0.425
10.0%		0.3226
2.5%		0.308
0.5%		0.308
0.0%	minimum	0.308

Summary Statistics	
Mean	0.5340385
Std Dev	0.2049873
Std Err Mean	0.0402013
Upper 95% Mean	0.6168346
Lower 95% Mean	0.4512423
N	26

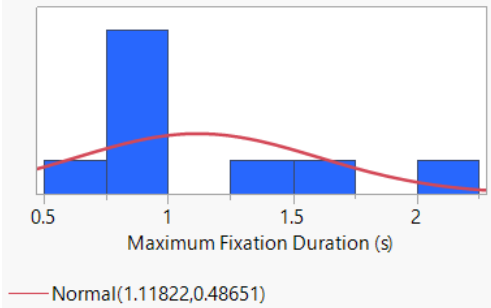
Figure 10.8.2 Histogram of distribution for Maximum Fixation Duration for the paediatric control group (n=69)



Quantiles		
100.0%	maximum	1.25
99.5%		1.25
97.5%		1.24325
90.0%		0.991
75.0%	quartile	0.883
50.0%	median	0.667
25.0%	quartile	0.5625
10.0%		0.5
2.5%		0.3955
0.5%		0.358
0.0%	minimum	0.358

Summary Statistics	
Mean	0.7171884
Std Dev	0.2039232
Std Err Mean	0.0245495
Upper 95% Mean	0.7661761
Lower 95% Mean	0.6682007
N	69

Figure 10.8.3 Histogram of distribution for Maximum Fixation Duration for the focal epilepsy group (n=9)

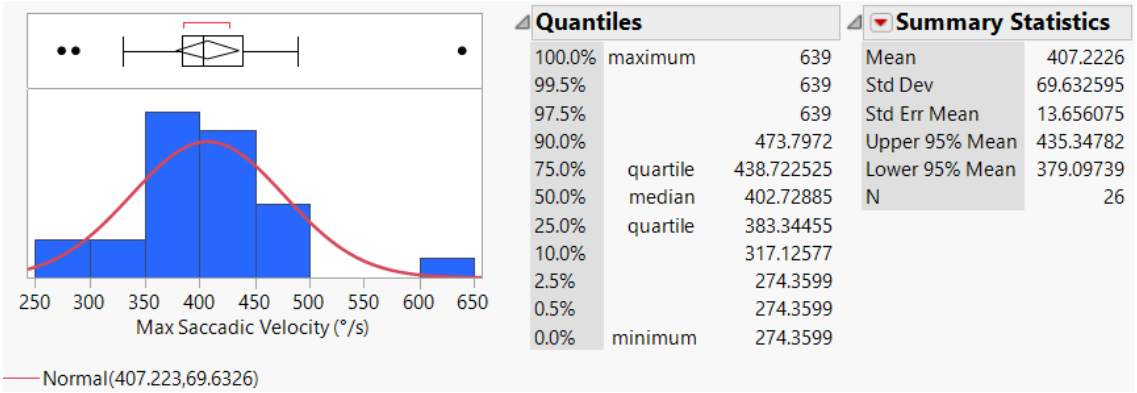


Quantiles		
100.0%	maximum	2.066
99.5%		2.066
97.5%		2.066
90.0%		2.066
75.0%	quartile	1.558
50.0%	median	0.866
25.0%	quartile	0.7915
10.0%		0.7
2.5%		0.7
0.5%		0.7
0.0%	minimum	0.7

Summary Statistics	
Mean	1.1182222
Std Dev	0.4865107
Std Err Mean	0.1621702
Upper 95% Mean	1.4921875
Lower 95% Mean	0.744257
N	9

10.9 Histograms of Maximum Saccadic Velocity for K-D Test

Figure 10.9.1 Histogram of distribution for Maximum Saccadic Velocity for the adult control group (n=26)



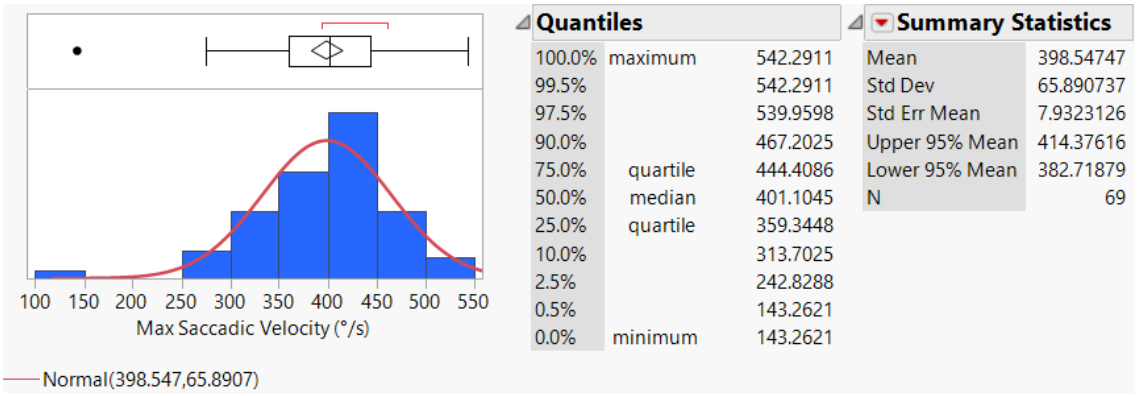
Quantiles

100.0%	maximum	639
99.5%		639
97.5%		639
90.0%		473.7972
75.0%	quartile	438.722525
50.0%	median	402.72885
25.0%	quartile	383.34455
10.0%		317.12577
2.5%		274.3599
0.5%		274.3599
0.0%	minimum	274.3599

Summary Statistics

Mean	407.2226
Std Dev	69.632595
Std Err Mean	13.656075
Upper 95% Mean	435.34782
Lower 95% Mean	379.09739
N	26

Figure 10.9.2 Histogram of distribution for Maximum Saccadic Velocity for the paediatric control group (n=69)



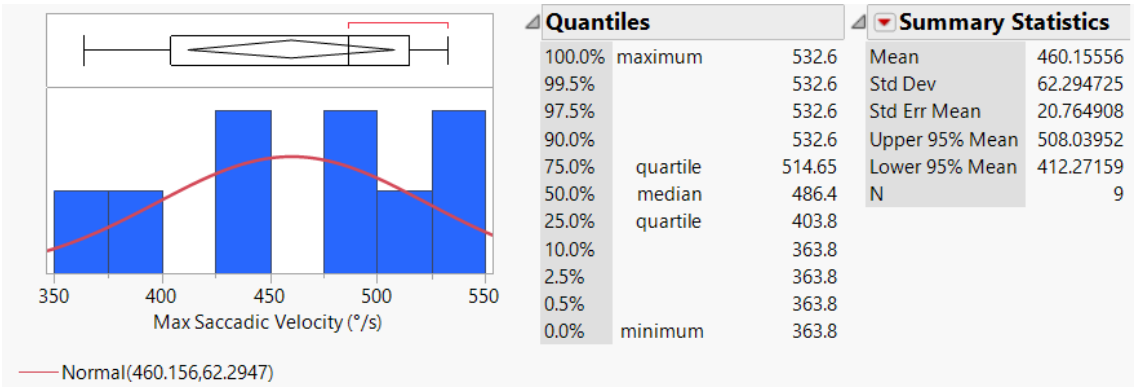
Quantiles

100.0%	maximum	542.2911
99.5%		542.2911
97.5%		539.9598
90.0%		467.2025
75.0%	quartile	444.4086
50.0%	median	401.1045
25.0%	quartile	359.3448
10.0%		313.7025
2.5%		242.8288
0.5%		143.2621
0.0%	minimum	143.2621

Summary Statistics

Mean	398.54747
Std Dev	65.890737
Std Err Mean	7.9323126
Upper 95% Mean	414.37616
Lower 95% Mean	382.71879
N	69

Figure 10.9.3 Histogram of distribution for Maximum Saccadic Velocity for the focal epilepsy group (n=9)



Quantiles

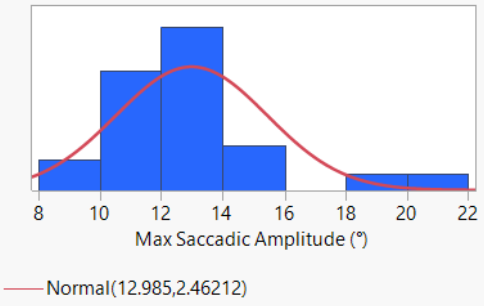
100.0%	maximum	532.6
99.5%		532.6
97.5%		532.6
90.0%		532.6
75.0%	quartile	514.65
50.0%	median	486.4
25.0%	quartile	403.8
10.0%		363.8
2.5%		363.8
0.5%		363.8
0.0%	minimum	363.8

Summary Statistics

Mean	460.15556
Std Dev	62.294725
Std Err Mean	20.764908
Upper 95% Mean	508.03952
Lower 95% Mean	412.27159
N	9

10.10 Histograms of Maximum Saccadic Amplitude for K-D Test

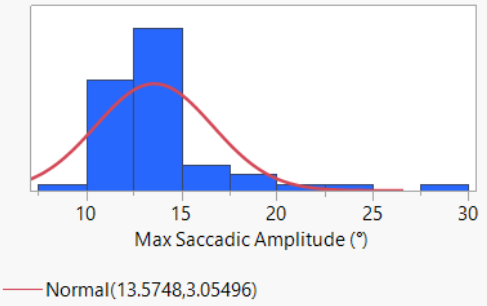
Figure 10.10.1 Histogram of distribution for Maximum Saccadic Amplitude for the adult control group (n=26)



Quantiles		
100.0%	maximum	20.43
99.5%		20.43
97.5%		20.43
90.0%		16.507
75.0%	quartile	13.445
50.0%	median	12.51
25.0%	quartile	11.565
10.0%		10.267
2.5%		9.61
0.5%		9.61
0.0%	minimum	9.61

Summary Statistics	
Mean	12.985
Std Dev	2.4621231
Std Err Mean	0.4828621
Upper 95% Mean	13.979473
Lower 95% Mean	11.990527
N	26

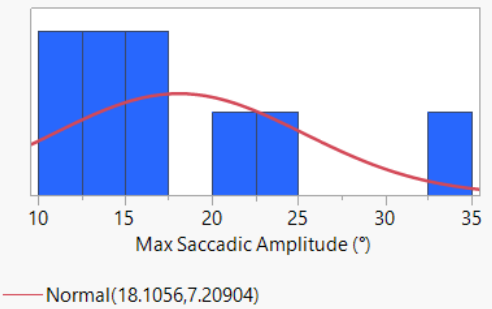
Figure 10.10.2 Histogram of distribution for Maximum Saccadic Amplitude for the paediatric control group (n=69)



Quantiles		
100.0%	maximum	28.74
99.5%		28.74
97.5%		24.255
90.0%		16.85
75.0%	quartile	14.19
50.0%	median	12.96
25.0%	quartile	11.96
10.0%		11.16
2.5%		9.7125
0.5%		8.22
0.0%	minimum	8.22

Summary Statistics	
Mean	13.574783
Std Dev	3.0549635
Std Err Mean	0.3677744
Upper 95% Mean	14.308665
Lower 95% Mean	12.8409
N	69

Figure 10.10.2 Histogram of distribution for Maximum Saccadic Amplitude for the focal epilepsy group (n=9)

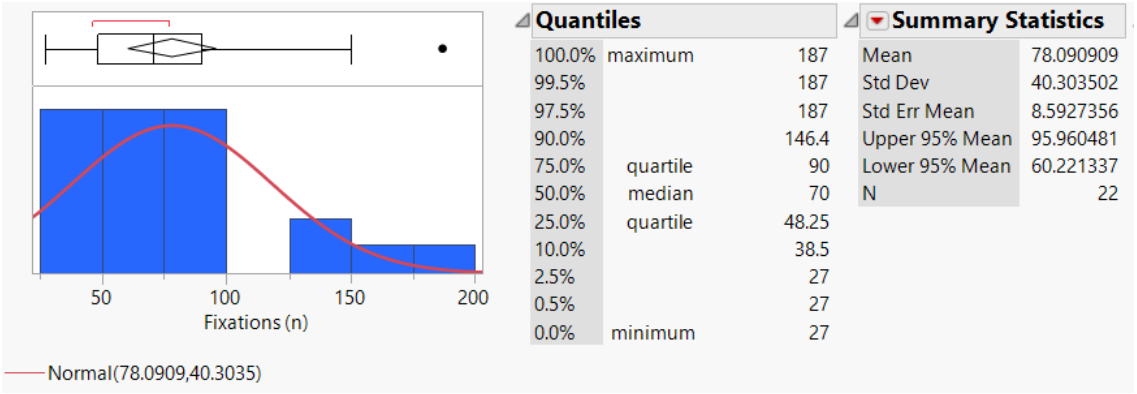


Quantiles		
100.0%	maximum	34.27
99.5%		34.27
97.5%		34.27
90.0%		34.27
75.0%	quartile	22.305
50.0%	median	16.33
25.0%	quartile	12.51
10.0%		12.3
2.5%		12.3
0.5%		12.3
0.0%	minimum	12.3

Summary Statistics	
Mean	18.105556
Std Dev	7.2090431
Std Err Mean	2.4030144
Upper 95% Mean	23.646917
Lower 95% Mean	12.564194
N	9

10.11 Histograms for Number of Fixations during NNVT

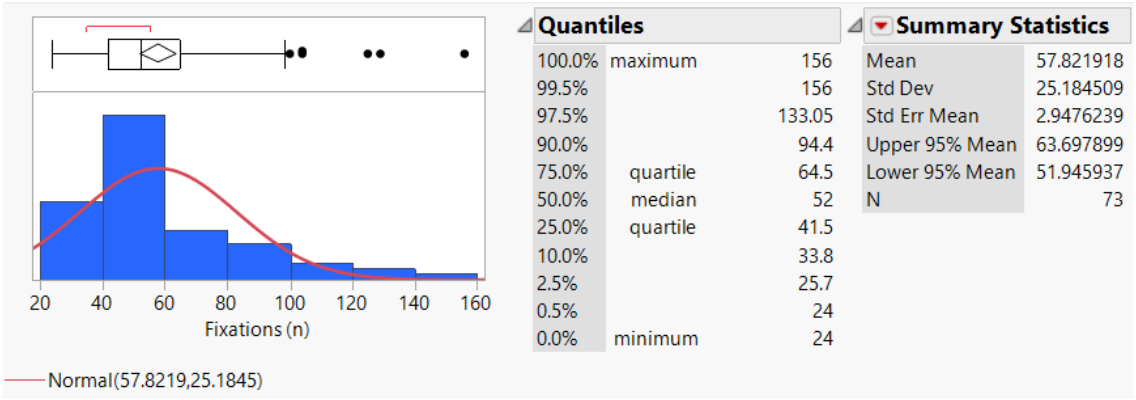
Figure 10.11.1 Histogram of distribution for number of fixations for the adult control group (n=22)



Quantiles		
100.0%	maximum	187
99.5%		187
97.5%		187
90.0%		146.4
75.0%	quartile	90
50.0%	median	70
25.0%	quartile	48.25
10.0%		38.5
2.5%		27
0.5%		27
0.0%	minimum	27

Summary Statistics	
Mean	78.090909
Std Dev	40.303502
Std Err Mean	8.5927356
Upper 95% Mean	95.960481
Lower 95% Mean	60.221337
N	22

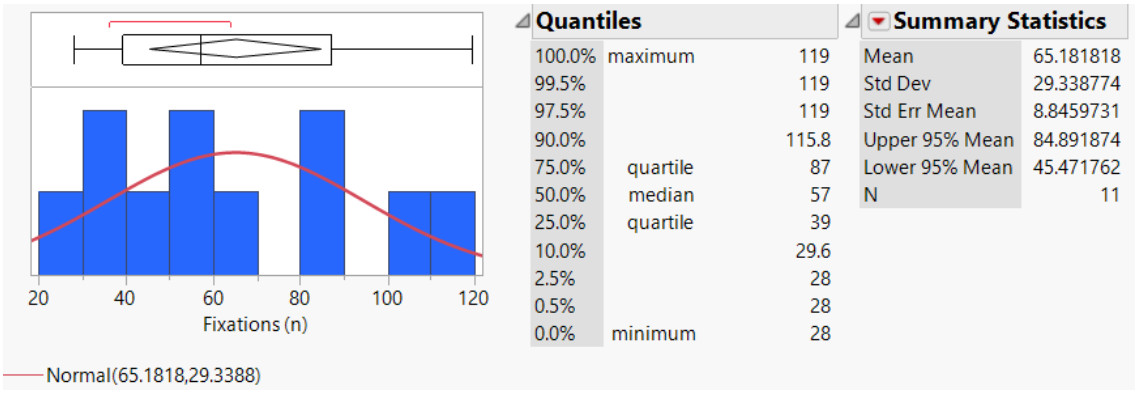
Figure 10.11.2 Histogram of distribution for number of fixations for the paediatric control group (n=73)



Quantiles		
100.0%	maximum	156
99.5%		156
97.5%		133.05
90.0%		94.4
75.0%	quartile	64.5
50.0%	median	52
25.0%	quartile	41.5
10.0%		33.8
2.5%		25.7
0.5%		24
0.0%	minimum	24

Summary Statistics	
Mean	57.821918
Std Dev	25.184509
Std Err Mean	2.9476239
Upper 95% Mean	63.697899
Lower 95% Mean	51.945937
N	73

Figure 10.11.3 Histogram of distribution for number of fixations for the focal epilepsy group (n=11)

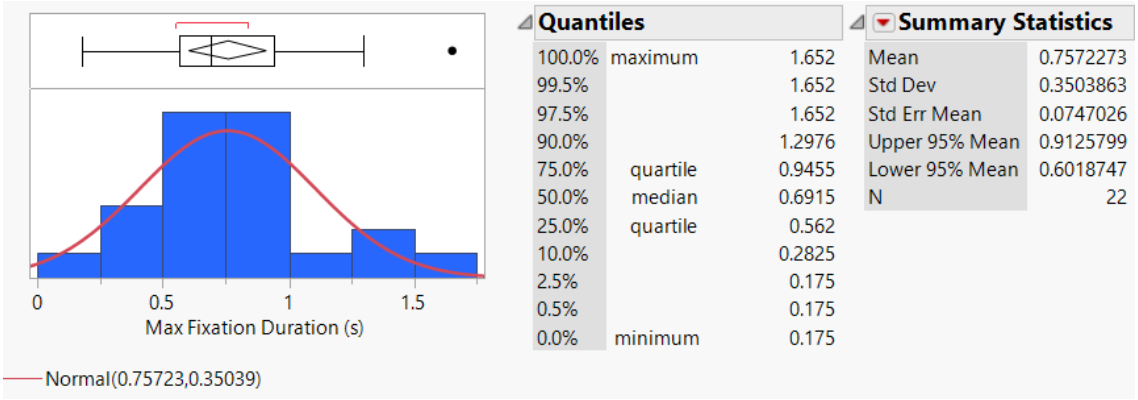


Quantiles		
100.0%	maximum	119
99.5%		119
97.5%		119
90.0%		115.8
75.0%	quartile	87
50.0%	median	57
25.0%	quartile	39
10.0%		29.6
2.5%		28
0.5%		28
0.0%	minimum	28

Summary Statistics	
Mean	65.181818
Std Dev	29.338774
Std Err Mean	8.8459731
Upper 95% Mean	84.891874
Lower 95% Mean	45.471762
N	11

10.12 Histograms for Maximum Fixation Duration for NNVT

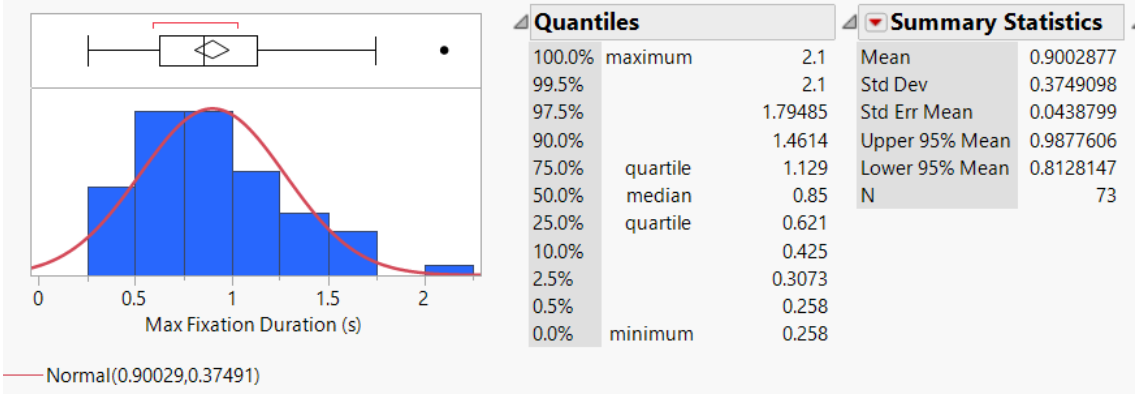
Figure 10.12.1 Histogram of distribution for maximum fixation duration for the adult control group (n=22)



Quantiles		
100.0%	maximum	1.652
99.5%		1.652
97.5%		1.652
90.0%		1.2976
75.0%	quartile	0.9455
50.0%	median	0.6915
25.0%	quartile	0.562
10.0%		0.2825
2.5%		0.175
0.5%		0.175
0.0%	minimum	0.175

Summary Statistics	
Mean	0.7572273
Std Dev	0.3503863
Std Err Mean	0.0747026
Upper 95% Mean	0.9125799
Lower 95% Mean	0.6018747
N	22

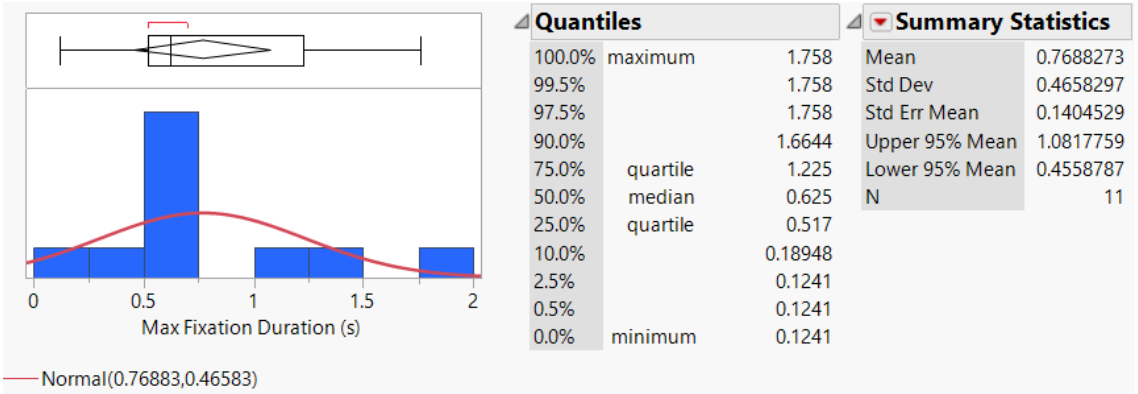
Figure 10.12.2 Histogram of distribution for maximum fixation duration for the paediatric control group (n=73)



Quantiles		
100.0%	maximum	2.1
99.5%		2.1
97.5%		1.79485
90.0%		1.4614
75.0%	quartile	1.129
50.0%	median	0.85
25.0%	quartile	0.621
10.0%		0.425
2.5%		0.3073
0.5%		0.258
0.0%	minimum	0.258

Summary Statistics	
Mean	0.9002877
Std Dev	0.3749098
Std Err Mean	0.0438799
Upper 95% Mean	0.9877606
Lower 95% Mean	0.8128147
N	73

Figure 10.12.3 Histogram of distribution for maximum fixation duration for the focal epilepsy group (n=11)

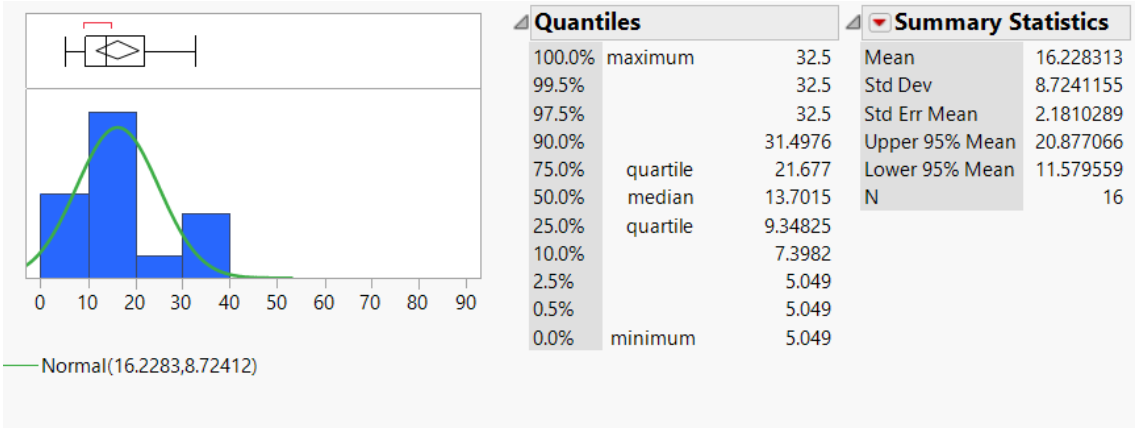


Quantiles		
100.0%	maximum	1.758
99.5%		1.758
97.5%		1.758
90.0%		1.6644
75.0%	quartile	1.225
50.0%	median	0.625
25.0%	quartile	0.517
10.0%		0.18948
2.5%		0.1241
0.5%		0.1241
0.0%	minimum	0.1241

Summary Statistics	
Mean	0.7688273
Std Dev	0.4658297
Std Err Mean	0.1404529
Upper 95% Mean	1.0817759
Lower 95% Mean	0.4558787
N	11

10.13 Histograms of Time to Complete Spot the Difference Task (SDT)

Figure 10.13.1 Histogram for distribution of Time to Complete SDT for Adult Control Group (n=16)



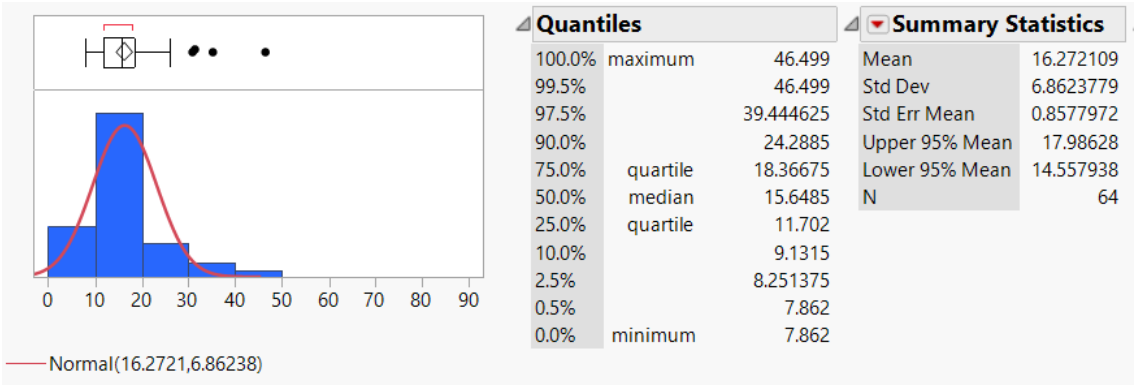
Quantiles

100.0%	maximum	32.5
99.5%		32.5
97.5%		32.5
90.0%		31.4976
75.0%	quartile	21.677
50.0%	median	13.7015
25.0%	quartile	9.34825
10.0%		7.3982
2.5%		5.049
0.5%		5.049
0.0%	minimum	5.049

Summary Statistics

Mean	16.228313
Std Dev	8.7241155
Std Err Mean	2.1810289
Upper 95% Mean	20.877066
Lower 95% Mean	11.579559
N	16

Figure 10.13.2 Histogram for distribution of Time to Complete SDT for Paediatric Control Group (n=64)



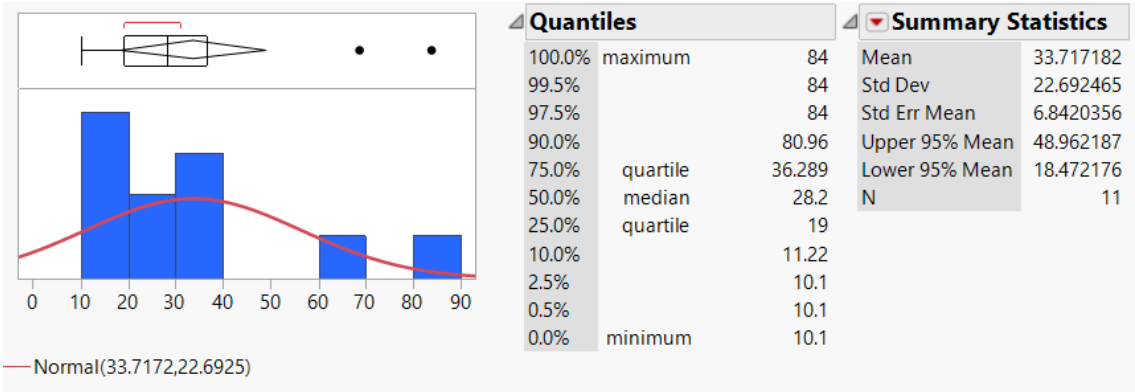
Quantiles

100.0%	maximum	46.499
99.5%		46.499
97.5%		39.444625
90.0%		24.2885
75.0%	quartile	18.36675
50.0%	median	15.6485
25.0%	quartile	11.702
10.0%		9.1315
2.5%		8.251375
0.5%		7.862
0.0%	minimum	7.862

Summary Statistics

Mean	16.272109
Std Dev	6.8623779
Std Err Mean	0.8577972
Upper 95% Mean	17.98628
Lower 95% Mean	14.557938
N	64

Figure 10.13.3 Histogram for distribution of Time to Complete SDT for Focal Epilepsy Group (n=11)



Quantiles

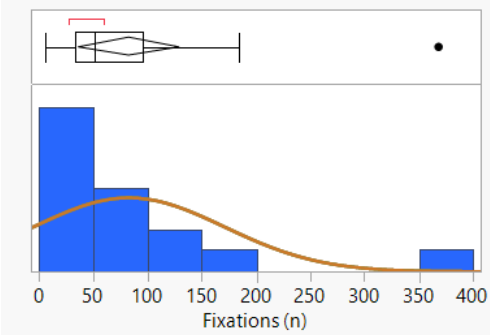
100.0%	maximum	84
99.5%		84
97.5%		84
90.0%		80.96
75.0%	quartile	36.289
50.0%	median	28.2
25.0%	quartile	19
10.0%		11.22
2.5%		10.1
0.5%		10.1
0.0%	minimum	10.1

Summary Statistics

Mean	33.717182
Std Dev	22.692465
Std Err Mean	6.8420356
Upper 95% Mean	48.962187
Lower 95% Mean	18.472176
N	11

10.14 Histograms for number of fixations for SDT

Figure 10.14.1 Histogram of distribution for number of fixations for the adult control group (n=16)



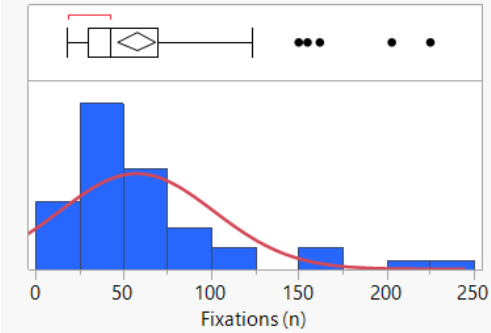
Quantiles

100.0%	maximum	368
99.5%		368
97.5%		368
90.0%		239.9
75.0%	quartile	96.75
50.0%	median	51.5
25.0%	quartile	32.75
10.0%		20.7
2.5%		6
0.5%		6
0.0%	minimum	6

Summary Statistics

Mean	82.8125
Std Dev	87.942571
Std Err Mean	21.985643
Upper 95% Mean	129.67379
Lower 95% Mean	35.951212
N	16

Figure 10.14.2 Histogram of distribution for number of fixations for the paediatric control group (n=64)



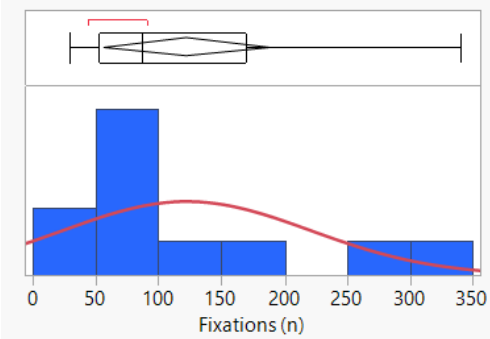
Quantiles

100.0%	maximum	225
99.5%		225
97.5%		211.25
90.0%		123
75.0%	quartile	69.75
50.0%	median	42
25.0%	quartile	30
10.0%		23
2.5%		18.625
0.5%		18
0.0%	minimum	18

Summary Statistics

Mean	57.6875
Std Dev	43.913651
Std Err Mean	5.4892064
Upper 95% Mean	68.656804
Lower 95% Mean	46.718196
N	64

Figure 10.14.3 Histogram of distribution for number of fixations for the focal epilepsy group (n=11)



Quantiles

100.0%	maximum	340
99.5%		340
97.5%		340
90.0%		325.2
75.0%	quartile	169
50.0%	median	87
25.0%	quartile	52
10.0%		31.8
2.5%		29
0.5%		29
0.0%	minimum	29

Summary Statistics

Mean	122.36364
Std Dev	98.450264
Std Err Mean	29.683872
Upper 95% Mean	188.50342
Lower 95% Mean	56.223849
N	11