The effect of visual training on visual function in adults with self – reported reading difficulties

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Abstract

Reading difficulties (RD) affect more than 6.3 million people in the United Kingdom. Previous research suggests that adults with RD may have reduced visual attention, which contributes to the inability to read. Studies on dyslexic children reported that 20 hours of visual training by video gaming improved visual function more so than a year of reading therapy. Yet, it is unknown whether adults display the same improvements.

In this study, initially adults without RD with a previous video gaming experience were assessed. Visual function was measured using psychophysical tests. The results confirmed that gamers had generally higher contrast sensitivity (CS) compared to non-gamers, specifically at temporal CS 20 Hz (p = 0.006). Secondly, participants took part in a 120-hour video-game-based training period, using either an action or casual game, to establish whether training improves CS. The results indicated that it is possible to train the human visual system and enhance CS especially action game training at peripheral temporal CS 24 Hz (p = <0.05). Next, a shorter training period of 40 hours was assessed, which was more effective than 120 hours, resulting in peripheral temporal CS 24 Hz improvements after casual gaming (p = 0.047). The improvement in CS after visual training remained stable for at least 4 weeks. Next, adults with RD were trained with 40 hours of training and showed an improvement in central temporal CS 20 Hz (p = 0.049) but less than in subjects without RD. Finally, a shorter training period of 2 weeks in adults with RD proved to be less effective in improving CS.

In result, visual training using video gaming improved visual function in RD, which may be due to improved visual attention. Video game play may serve as an accessible and inexpensive therapeutic tool in alleviating self – reported RD in adults.

Chapter 1 Introduction

Video games were played by 49% of the population of the United States in 2015 (Statista, 2018) and there are 1.8 billion video gamers in the world (ESA, 2018) which accounts for approximately 25% of the world's population. Due to the large number of video gamers, there has been an interest in conducting scientific research which examines the effect of video game play on visual function as gaming is prevalent in society. On the other hand, it is also of interest to establish whether video gaming may result in potential consequences of the visual system.

The first major study examining the effect of commercial video games on vision (Green & Bavelier, 2003) stated that playing video games improves the gamers ability to focus on the main task whilst ignoring distractors on screen. Additionally, due to video gaming, this has led to using a peripheral visual field which is wider than normal. Due to this study, further research was conducted on gamers which furthermore suggested that playing video games improves the spatial resolution of visual processing in adults with normal visual function (Green & Bavelier, 2007) and that there is an improvement of motor skills, perceptual, and cognitive load after video gaming (Green *et al*., 2012).

As video gaming was reported to have beneficial effects on vision, the concept of visual training was introduced to improve visual function in adults with visual impairments, such as amblyopia. Visual training (also known as visual therapy) is a customized program of visual activities produced by the investigator which aims to improve visual skills. Subjects undergoing video game based visual training play a certain video game over a set amount of time, which allows the examiner to test the visual function before and on completion of the training. Jeon *et al*. (2012) reported

that 40 hours of visual training led to an improvement of visual acuity, motion perception, and spatial contrast sensitivity in amblyopes. Therefore, the improvement of visual function after video gaming is prevalent in those with abnormal vision as well as healthy vison.

As the prior research has been conducted on healthy and amblyopic adults, recent research investigated whether visual training may improve visual function in children. Children with dyslexia were used as dyslexia has been related to defects in the visual system. Therefore, as video game play is prevalent among society, if video gaming may improve visual function and reading ability in children then it can be used as a form of accessible treatment worldwide. Franceschini *et al*. (2013) reported that only 12 hours of visual training improved visual function in dyslexic children, as well as reading ability. This is an important finding as it suggests that video game play may serve as a form of treatment that can be applied to various conditions of the visual system.

Due to the previous research on video game play and vision, both on healthy adults, and adults and children with visual impairments, it is of interest to examine whether visual training improves visual skills in adults with reading difficulties. The aim of this thesis is to progress the field of visual training by examining whether video games improve visual function in adults with self – reported reading difficulties. A reading difficulty is a specific learning difficulty as the way in which information is processed and learned is affected. Dyslexia is the most common cause of reading difficulties among the general population, affecting 6.3 million people in the United Kingdom (Dyslexia Action UK, 2017) which is approximately 10%. Adults with self – reported reading difficulties were examined in this thesis as not all persons with dyslexia have had a clinical diagnosis due to socio-economical background or lack of

funding. An improvement of visual function would be highly beneficial, as video gaming is an accessible and affordable form of treatment, that does not require specialist intervention compared to the traditional reading therapy.

1.1 The Human Visual System

The human visual system is composed in such a way that allows light, which is received by the eyes, to be processed and interpreted in the brain as visual information and objects. This is only a brief overview of how the human visual system processes light into images as the process involves many steps working continuously. I will examine these steps further in detail in the sections that follow.

1.1.1 Basic Eye Anatomy

Although the human eye is small, it is extremely complex and has many parts simultaneously working together to form an image (Figure 1.1). Before investigating the steps, which take place for that image to form, the basic structure of the eye must be introduced, to understand where the processes take place. These structural parts include:

1. The cornea: The cornea covers the iris and the pupil and allows light to enter the eye. It is also responsible for most of the refractive power of the eye.

2. Anterior chamber: The anterior chamber is a space containing clear fluid which is present in the front of the eye and located between the cornea and iris. It contains nutrients which are provided for the cornea and lens. It is the ciliary body which produces the clear fluid.

3. Iris: The iris surrounds the pupil and it is known as the coloured section of the eye, located between the cornea and the lens. The iris acts like a diaphragm as it narrows or widens which in turn controls the amount of light which enters the eye.

4. The pupil: the pupil closes and opens to regulate the amount of light which enters into the retina.

5. Ciliary body (muscle): Located between the iris and the choroid, the ciliary body's main functions are to control accommodation, control the production of the aqueous humour, and to maintain the lens in the correct position.

6. Posterior chamber: The posterior chamber's location is behind the iris.

7. Zonular fibres: The zonular fibres are a ring of fibrous strands that form the zonule. This connects the ciliary body with the crystalline lens present in the eye.

8. Suspensory ligaments: The suspensory ligaments hold the eye lens in position.

9. Lens: The lens is located behind the cornea and allows light to focus correctly on to the retina and to provide accommodation.

10. Retina: The retina is a sensory membrane which receives images from the lens and converts those images into signals which travel through the optic nerve and into the brain.

11. Choroid: The choroid consists of layers of blood vessels which are located between the retina and the sclera. It provides the back of the eye with oxygenated blood and nutrients.

12. Sclera: The sclera coats the outside of the eyeball and is known as the white of the eye. Additionally, it surrounds the optic nerve which is present at the back of the eyeball.

13. Vitreous body: The vitreous humour is located between the retina and the lens. It contains a clear jelly which is known as the vitreous humour.

14. Hyaloid canal: The hyaloid canal acts as a transport canal as it runs through the vitreous body of the eyeball, from the optic nerve disk to the lens.

15. Optic disk: The optic disk is the location where the optic nerve enters the retina, forming the blind spot of the eye.

16. Optic nerve: The optic nerve allows electrical impulses to be carried from photoreceptor cells present in the retina to the visual cortex which is in the brain.

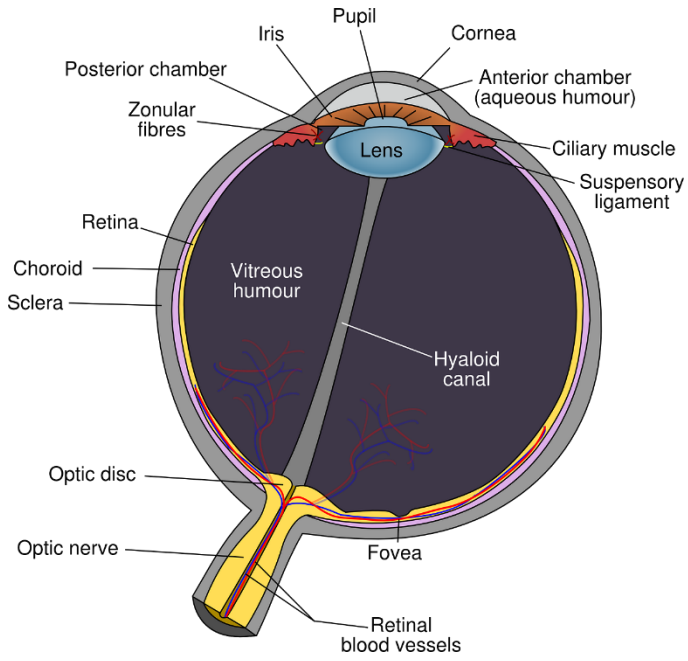

Figure 1.1 Basic Eye Structure

Image obtained from commons.wikimedia.org. There are various structures in the eye which work together simultaneously to form an image. For a human to see an object clearly, light must be focused on to the retina, which lines the back of the eye. This results in the neurons present in the retina to become activated and electrical impulses are then sent via the optic nerve into the brain. Signals are sent into the lateral geniculate nucleus (LGN) which is part of the thalamus. The LGN then separates this retinal information into parallel signals, one containing information on motion and contrast (the magnocellular layers) whilst the other contains information on fine structure and colour (the parvocellular layers). The cells of the two layers then extend to the back of the brain into the primary visual cortex (V1). V1 allows object edge detection and thus visual recognition.

1.1.2 Basic Retina Anatomy

The retina is a remarkable structure as it allows us to convert light into nerve signals, distinguishes between various wavelengths allowing us to see colour, and allows us to see under light and dark conditions. The retina is comprised of two layers – the outer pigmented and the inner neural layer (Figure 1.2). The pigmented layer absorbs light and prevents it from being scattered within the eye. The neural layer is comprised of three main types of cell, as it is responsible for transducing light energy and processing light stimuli. These cells are the bipolar cells, photoreceptors, and the ganglion cells. Once light enters the eye, local currents will be produced and spread from the photoreceptors to the bipolar cells, and then to the ganglion cells. It is in the ganglion cells where action potentials will be generated. The ganglion cell axons are present at the innermost face of the retina and leave as the optic nerve.

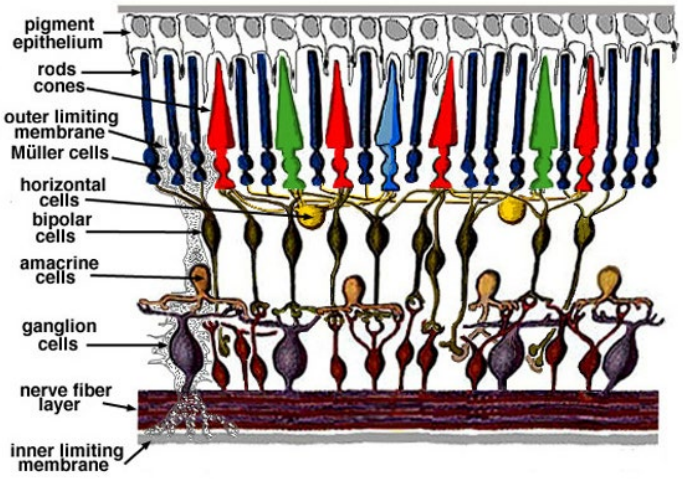

Figure 1.2 Retinal Structure

Image obtained from Cessac & Palacios (2012). Diagram showing the structural layers of the retina in which there are two main layers (outer pigmented layer and inner neural layer). This allows the absorption and processing of light received from the eye. The outer pigmented area contains rods and cones which absorb the light and prevent the light from being scattered within the eye. The inner neural layer is composed of bipolar cells, ganglion cells, and photoreceptors. These pre-processes the light received before it is sent to the optic nerve for further processing.

1.2 Retinal Function

For a clear image to be produced, three processes take place which include the refraction of the light rays, the pupil size changing, and the accommodation of the eyes. Although these three processes are separated procedures, they must all take place for a clear image to be produced and effective vision to take place. Light rays enter through the cornea and are refracted initially, as they pass from one type of density to another. There are six regions that light rays must pass through before reaching the retina, and these includes the conjunctive, the cornea, the aqueous fluid, the lens, and the vitreous body. When abnormal refraction occurs within the eye, then this requires correction using biconcave or biconvex lenses. Generally, the least refraction is needed from distant objects whilst closer objects require more refractive power. For that refractive power to be increased, the ciliary muscle contracts which in turn causing the anterior surface of the lens to bulge forward resulting in an increased convexity. For distant objects, the ciliary muscle relaxes slipping backwards which makes the lens thinner. The light rays enter the pupil. It is the iris which controls the size of the pupil as the iris contains two layers of muscle – one of radiating muscle and one of circular smooth muscle. Once the circular fibres contract, this leads to the constriction of the pupil. Whereas if the radiating fibres contract, this leads to the dilation of the pupil.

The autonomic nervous system controls the size of the pupil (sympathetic and parasympathetic stimulation). The eyes are rotated by the extraocular muscles so that the eyes converge on the object that is being viewed. Autonomic control governs the coordinated muscle activity. When an object is near to the eyes, the larger the eye rotation required to enable convergence. After passing the iris, the light rays then pass through the lens of the eye. The lens allows the light rays to be adjusted for the signal

to be focused properly. The light rays will pass through the vitreous which is a dense substance filling the eyeball and allowing the eye to hold its shape. Lastly, it is the photoreceptors that will receive and process the light signal which will then produce an image, as the retina is photosensitive (light sensitive).

There are two types of photoreceptor cells in the retina which are rods and cones. Rods are more numerous in number and allow us to see in dim light and use our peripheral vision. Rods do not provide colour vision and sharp images. On the other hand, cones work in bright light and allow us to see in high acuity colour vision. The rods and cones respond to light by the method of phototransduction. Phototransduction is a process in which light is converted into electrical signals, and those electrical signals are then processed by the nervous system. Initially, a photon is absorbed resulting in the rhodopsin receptor protein which becomes activated. The activated rhodopsin then stimulates a G-protein, transducin, which converts guanosine triphosphate (GTP) into guanosine diphosphate (GDP) in the process. When the transducin G-protein is active, it then in turn activates nucleotide cyclic guanosine 3'-5' monophosphate (cGMP) phosphodiesterase (PDE) which is an effector protein. This in turn allows PDE to convert cGMP into GMP. PDR will then hydrolyse the cGMP causing it to fall in concentration. This then leads to the retinal ganglion cells undergoing an action potential into the brain. Generally, retinal ganglion cells, when resting, have a negative potential of around -70mV. This causes a tension between both charge carriers and the concentrations of potassium and sodium channels which are present outside and inside the neuron. In other words, potassium ions will decrease in amount in the neuron, whilst sodium ions will increase in the neuron. Once the ganglion cells receive a sufficient level of voltage from bipolar cells, this results in sodium channels to open and sodium ions to rush in. The sodium channels open as

they are voltage gated and this results in the charge being reversed from negative to positive. The voltage then spreads down the main body of the neuron (the axon). This results in the sodium channels to then close and potassium channels to open which results in the cell becoming negative again.

Photosensitive pigments are present in discs (in rods) and sacs (in cones), which are both densely packed in the retina. Pigments include iodopsin which is present in cones whilst rhodopsin is present in rods. It is these photosensitive pigments which absorb the photons which enter the eye. Additionally, the structure of the retina varies from the fovea to the periphery (Figure 1.3). The fovea location is in the middle of the retina and contains a dense array of receptors. The fovea holds the highest density of cone photoreceptors and this can reach up to 200,000 cones/m2 (Curcio *et al.,* 1990) whereas rod density increases with retinal eccentricity until the density peaks at 20° (Curcio *et al.,* 1990). Due to this variation of rod and cone density, this may account for the functional variation in the retina (Figure 1.4). Functional variation occurs as rods and cones have separate structures and therefore varying responses.

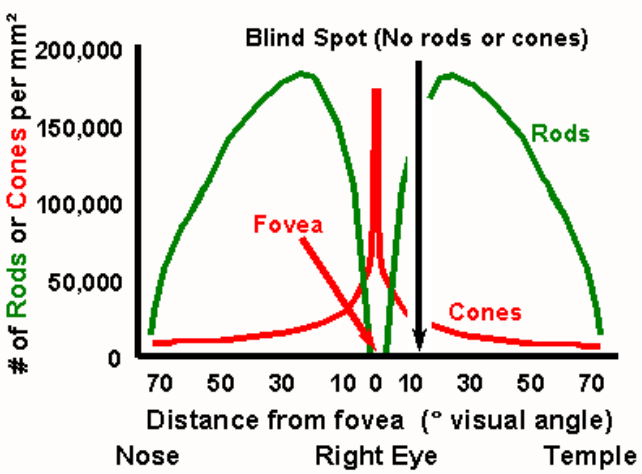

Figure 1.3 The Peripheral Retina

Image from Indiana University Bloomington (2017). Image displays the peripheral retina in a human eye. As the distance increases from the fovea, the density of cones decreases whilst the density of rods increases. It is the central fovea which contains the highest number of cones; thus, this allows us to see in high acuity colour vision which is our visual axis. As the visual field increases, the images become less clear which is correlated with the increase of rods.

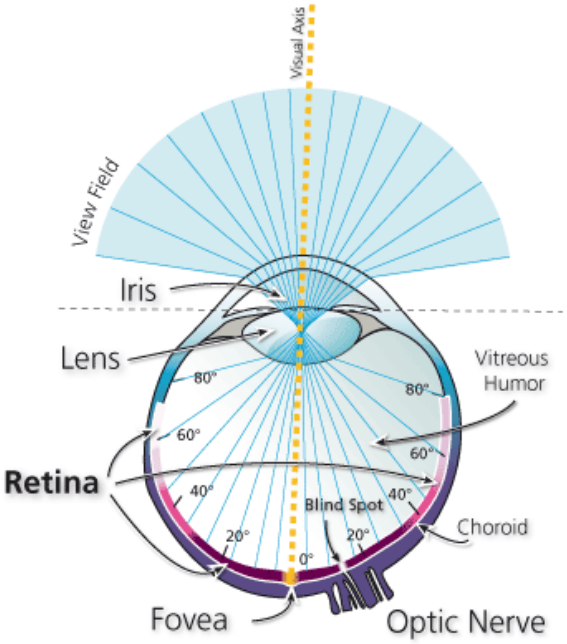

Figure 1.4 Functional Variation of the Retina

Image from sharp-sighted.org (2017). Image displaying the density changes of the rods and cones across the fovea. The central fovea has the highest number of cones, whilst the peripheral fovea has the highest density of rods.

1.3 Primary Visual Cortex

Ganglion cell axons pass via the optic nerve and then the optic tract which leads to the destination which is the lateral geniculate body (LGN). The LGN is present in the thalamus of the brain (Figure 1.5). Most the output of the LGN is then directly relayed into the primary visual cortex (V1). The thalamus is in the middle of the brain and thus acts as the primary information processor in the central nervous system of visual information. As well as receiving signals from the retina and then distributing that information into the V1, it also receives feedback from the V1 region.

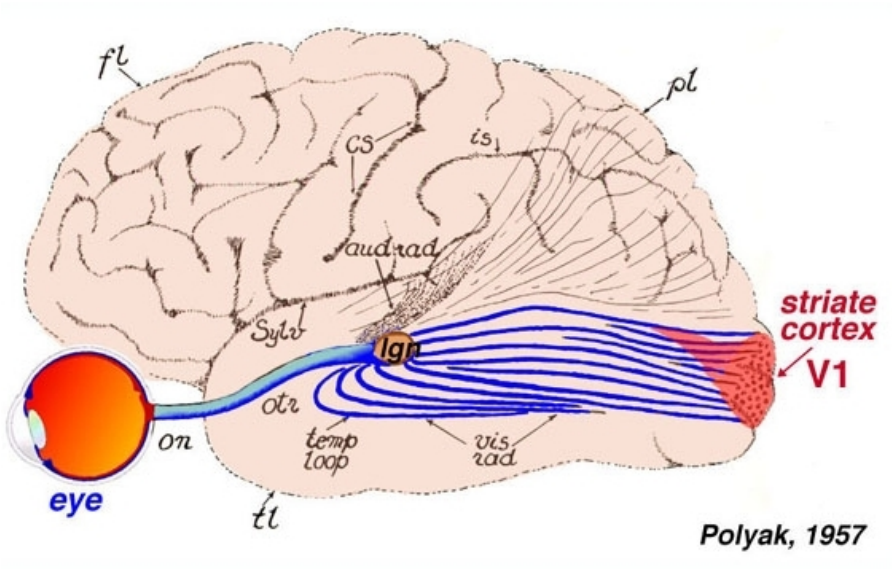

Figure 1.5 The Primary Visual Cortex

Image adapted from Polyak (1957). Image displays the area of the primary visual cortex (V1) which is in the brain. The input from the eyes enter the brain to the LGN and then to the area V1. V1 is in the posterior of the occipital lobe, whilst the LGN is in the centre of the brain.

Additionally, the LGN projects using a method called optic radiation. Optic radiation, also known as the geniculostriate fibers, are axons from the neurons that exit from the LGN into the primary visual cortex. The axons terminate in a retinotopic fashion, meaning that the axons will carry a specific part of information from the visual

field and then terminate in the location of V1 which corresponds to that location of the visual field.

A couple of psychophysical studies investigated the contrast sensitivity of two macaque monkeys once the LGN layer was permanently interrupted and thus destroyed (Merigan *et al.,* 1991a, b). Ibotenic acid was injected into the LGN layer and then psychophysical tests were conducted investigating motion perception, detection, speed difference thresholds, as well as general contrast sensitivity function. The results showed that detection contrast sensitivity had been significantly reduced affecting high temporal frequencies and low spatial frequencies due to magnocellular lesions. Yet, the contrast sensitivity of low spatial temporal frequency or high spatial frequency was not affected. Parvocellular lesions led to a 3 – 4-fold reduced visual acuity as well as chromatic and luminance contrast sensitivity at gratings of two cycles per degree, which refers to the amount of detail existing in the presented stimulus per degree of the visual angle.

1.3.1 Visual Pathways

There are three distinct pathways which are used to transfer information from the LGN in the thalamus to the primary visual cortex. One pathway is the magnocellular (M cell) pathway due to the large neurons in the retina. Another pathway is the parvocellular (P cell) pathway, due to small neurons. Lastly, the koniocellular (K cell) pathway is used when information is transferred from P cell pathway to the V1. Each of the pathways have a speciality which allow them to function correctly. For instance, M cells can accurately detect movement properties such as speed, location, and direction of a moving object. P cells are specialised in spatial recognition, such as identifying the shape, or size of an object as well as colour vision. Lastly, K cells are thought to be involved in the processing of colour vision. Additional differences include

the P cell function being dependent on the wavelength of light which will be present in the receptive field, whilst M cells are not. As well, M cells can induce an action potential once the stimulus is presented and then fade if the stimulus doesn't change, whilst P cells exhibit a sustained response to the stimulus. There is a total of six layers in the lateral geniculate body. The upper four layers are P cells whilst the bottom two layers are M cells. Thus, there is an anatomical difference between the P and M pathways in terms of position.

1.3.2 The Visual Cortex (V1)

The brain has two hemispheres – the left and the right. They are connected by the corpus callosum, which is a tract of fibres. Each of the two hemispheres has four lobes which are the frontal, temporal, parietal, and occipital. It is worth noting that the images seen by the eye on one side are processed by the opposite hemisphere of the brain. This is due to ganglion cells present on each side of the eye crossing at the optic chiasm. Before the visual information reaches the primary visual cortex, the information from each eye does not mix. As mentioned, the primary visual cortex (V1) is in the occipital lobe posterior position covering both cerebral hemispheres particularly lying in the fold of the calcarine sulcus (Figure 1.6). Each part of the calcarine sulcus represents a certain area of the eye. For instance, the fovea is signified at the back of the calcarine sulcus. The remaining peripheral retina is represented at the front. The lower half of the calcarine sulcus represents objects seen above the line of sight, whereas the lower visual field is signified on the top half of the calcarine.

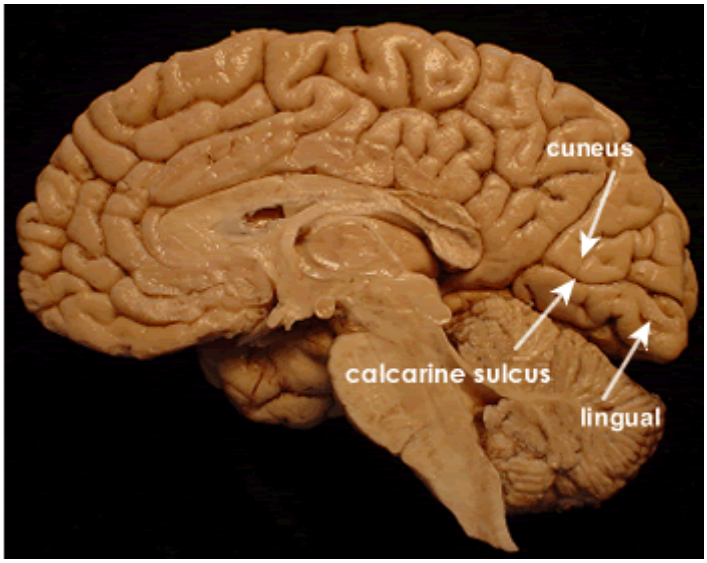

Figure 1.6 The Calcarine Sulcus

Image obtained from www.organanatomy.org (2018). Image shows the area of the brain in which the calcarine sulcus is present at. The cuneus is a smaller lobe and is bound inferiorly by the calcarine sulcus. The cuneus received visual information and functions in basic visual processing. The lingual has a function in processing letters and encoding.

The occipital lobes primarily process visual information. The V1 area has a large presence of myelinated axons, thus it is also referred to as the striate cortex. Due to the presence of the myelinated axons, this causes the appearance of the V1 to appear striped. Additionally, the neurons are arranged into columns and each of the columns have similar functional properties. The area located around the V1 is also associated with the processing of vision. There are three types of cells present in the V1 region of the brain, which include simple and complex cells, as well as double opponent cells (layer 4) (Lennie *et al.,* 1990) which vary structurally. Simple cells have elongated receptive fields and are in a line of specific orientation whereas complex cells are in a line over a larger area of the retina. Layer 4 cells have round receptive fields, like those of ganglion cells.

1.3.3 Further Visual Processing

After visual information is processed in the V1 region of the brain, it is then transferred into V2 and then V3. The information diverges into more locations into the brain, specifically to over three dozen high order visual analysis regions. Each region would process a specific piece of the visual information. The information would flow along to main streams in the brain, which include the ventral and the dorsal stream. The ventral stream is in the inferior part of the temporal lobe of the brain. It processes the recognition of objects as well as perception. The dorsal stream is in the parietal lobe. It processes spatial visual locations.

1.4 Visual Function

The visual function of an individual can be described through examination of visual acuity and contrast sensitivity function. Visual acuity is an important measurement of visual function as it allows spatial resolution to be determined. Visual acuity is especially important for drivers and for those who suffer from conditions such as diabetes, as a loss in visual acuity may indicate a significant change in health (Pandit, 1994). Generally, visual acuity is defined as the ability of the individual to identify the smallest gratings, which consist of the finest lines and letters (Leguire *et al*., 2011). The measurement of visual acuity may be done in various ways which include using the Freiburg Visual Acuity and Contrast Test (FrACT) (Bach, 1996) (Figure 1.7) or the Snellen chart (Snellen, 1862) (Figure 1.8). The current standard of visual acuity testing are Bailey – Lovie logMAR charts (Bailey and Lovie *et al*., 1976).

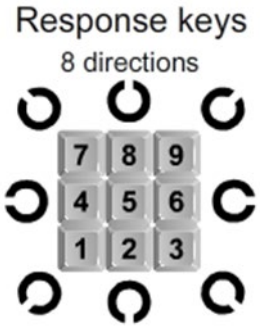

Figure 1.7 Freiburg Visual Acuity and Contrast Test

Adapted from Bach (1996). When the Landolt – C is presented on the screen, the participant will select any of the 8 buttons that represent the position of the gap in the Landolt – C. This establishes the visual acuity of the person. The Landlot – C will change throughout the test; therefore it never stays in the same position.

Figure 1.8 The Snellen Chart

Adapted from Snellen (1862). The subject should be able to discriminate between the smallest letter in the chart which establishes their visual acuity. During the test, the experimenter asks the participant to start reading from the top, to the bottom, stopping at the line in which the participant is no longer able to distinguish the letters.

The FrACT is computer based and to measure the visual acuity threshold, the test uses Landolt C optotypes (Bondarko & Danilova, 1997). The results from the test can either be presented on screen as Snellen fraction, decimal acuity, or the minimum angle of resolution which is in the form of log10 (logMAR). A Snellen fraction is an illustration of visual acuity as a fraction (e.g. 6/6), in which the numerator is testing distance in feet and the denominator is the exact distance in which the smallest letter is distinguished by the eye. The result can also be presented as a decimal acuity, for instance a Snellen fraction of 6/6 is converted into a decimal acuity of 1.0. Furthermore, the number can be converted and presented as logMAR. Therefore, the results can be presented in various ways which have the same meaning.

The FrACT is used for testing acuity by experts within the field of vision as it is officially recognized by the European system for testing acuity (EN ISO 8596) (Bach, 1996). The Snellen chart was invented by Doctor Hermann Snellen in 1862, a Dutch ophthalmologist. It is the most common form of acuity measurement as it is easy to perform and readily available (Kaiser, 2009). Yet, there are some disadvantages of Snellen charts. The distance between rows and letters is not standardised, thus when letters are placed too closely there is a crowding effect affecting acuity. Additionally, there is minimal crowding on the poor vision lines, whilst the good acuity lines have greater crowding (Kaiser, 2009).

1.4.1 Spatial Contrast Sensitivity

Contrast sensitivity allows the individual to distinguish between what is visible and what is invisible. Contrast is defined as the difference in luminance of the visual target and the background, when the visual target is presented on a background that is uniform (Figure 1.9). The contrast can either be presented as RMS contrast LO'/ Lμ (for natural stimuli), Weber contrast Lmax – Lmin / Lbackground (for letter stimuli), or Michelson contrast Lmax – Lmin/ Lmax + Lmin (for gratings) where LO', Lμ, Lmax, Lmin, and Lbackground are respectively standard deviation (SD), mean, luminance maximum, luminance minimum, and background (Pelli & Bex, 2013).

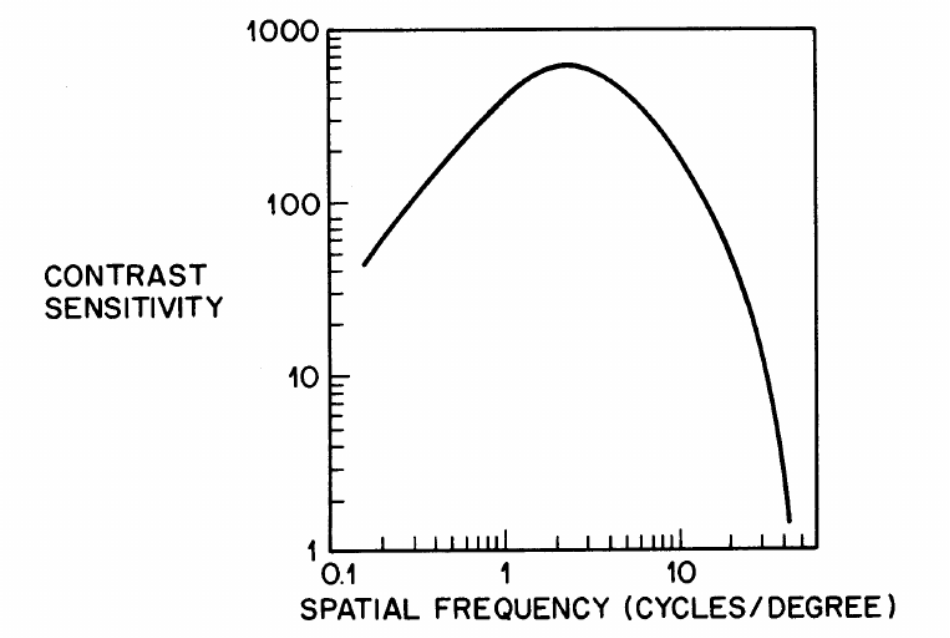

Figure 1.9 Spatial Frequency and Contrast Sensitivity

Seshadrinathan et al. (2009) Spatial contrast sensitivity function. Figure shows the relationship between spatial frequency and contrast sensitivity; As spatial frequency increases, as does contrast sensitivity, with peak sensitivity is reached at approximately 3 cycles per degree (cpd). Following 3cpd there is a sharp decline in contrast sensitivity as the spatial frequency increases. Thus, this produced an inverted 'U' shape.

Contrast sensitivity is the reciprocal of the contrast threshold. An individual's ability to detect pattern stimuli which is of a low contrast is a measurement of contrast sensitivity function (CSF), with the first reported measurement in 1956 by Schade (Pelli & Bex, 2013). CSF is measured by using several spatial frequencies presented as sinusoidal gratings over a log scale against the threshold at which contrast is detected. It is possible to define CSF by using this method (Leguire *et al.,* 2011). The peak sensitivity usually occurs at low spatial frequencies, yet there are conditions and diseases which prevent the individual from reaching a normal sensitivity at a specific spatial frequency such as in amblyopia (Freedman & Thibos, 1975), and age related macular degeneration (Mei & Leat, 2007). Amblyopia is an impairment of the eye's visual acuity due to a developmental disorder whereas age related macular

degeneration is the deterioration of the macular (the central portion of the retina). The visual acuity is determined by the visual systems identification of the smallest gratings which are present. The sensitivity naturally decreases as an individual becomes older, especially at spatial frequencies that are higher (Owsley *et al.,* 1983). At the spatial frequencies of four to six cycles per degree, the human eye is most sensitive. As the spatial frequencies becomes higher than six cycles per degree and lower than four cycles per degree, then the sensitivity starts to drop. The spatial acuity can be determined by the highest spatial frequency and this becomes worse with progressing age of the person or a disease of the visual system.

1.4.2 Temporal Contrast Sensitivity

Temporal contrast sensitivity is a measure of the light difference which is required by an observer to distinguish a light source as steady versus unsteady. There are general characteristics which apply to the temporal contrast sensitivity function. Peak sensitivity is reached in the mid – temporal frequencies whilst the lowest sensitivity is present at high temporal frequencies. When there is loss of sensitivity then the individual is unable to detect the flicker rate (Rasengane *et al.,* 1996) (Figure 1.10). As the eccentricity increases, temporal contrast sensitivity decreases (Virsu *et al.*, 1982). The visual eccentricity is the angular distance from the centre of the visual field. Temporal contrast sensitivity is closely related to motion perception, however there is a clear distinction between spatial and temporal contrast sensitivity. Spatial frequency is measured by the number of complete periods that a signal goes through a unit of distance, which in this case is cycles per degree. On the other hand, Temporal frequency is measured by the number of complete periods that a signal goes through a unit of time, which in this case is hertz (Hz). Therefore, the main difference is the unit of measurement.

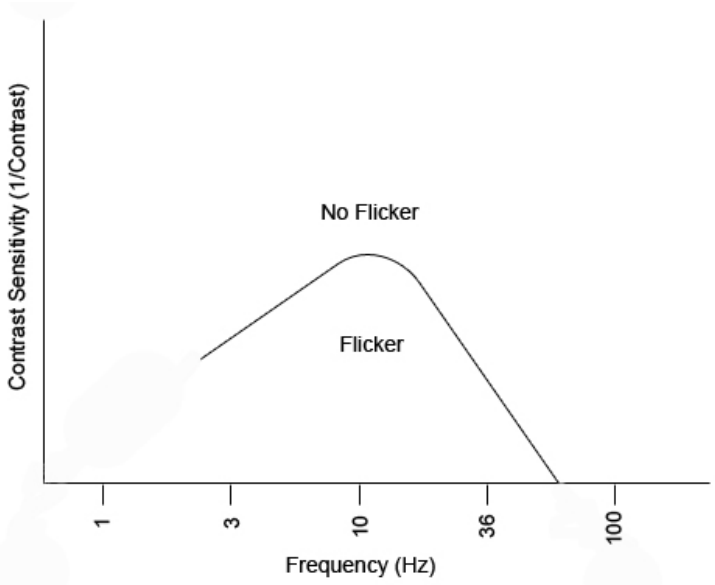

Figure 1.10 Temporal Contrast Sensitivity

University of Calgary (2019) Figure demonstrates the relationship between contrast sensitivity and temporal frequency. As frequency in hertz increases, so does contrast sensitivity. Sensitivity is at peak levels in the middle region of the temporal frequencies. However, at approximately 10 Hz, contrast sensitivity begins to decline sharply. At approximately 80 Hz, contrast sensitivity is no longer visible. In terms of flicker, flicker is visible in the mid regions of contrast sensitivity. The higher the contrast sensitivity, the less flicker visible.

1.4.3 Peripheral Contrast Sensitivity

The peripheral retina, which is responsible for peripheral vision, varies greatly from the central retina. The central retina is thicker due to the increased density of photoreceptors present, and cones. As the retinal eccentricity increases, the quality of colour perception will on the other hand decrease as the cone density decreases. Rod density is much greater in the peripheral retina compared to the central retina, with a peak being reached at about 20° (Panorgias *et al.,* 2009). Due to the variations in cone and rod density within the retina, this may account for the functional variation.

Sensitivity decreases as the presented stimulus is further away from the centre and into the periphery, with the highest contrast sensitivity being in the central area which corresponds to the fovea (Whiteside, 1976). Human vision extends to

eccentricities of more than 100 degrees, yet the only stimuli visible at high eccentricities will be bright because the pupil area which is effective will have decreased dramatically.

1.4.4 Motion Perception

Motion is analysed in the cerebral cortex of the brain, specifically the middle temporal motion area. If the middle temporal motion area is incorrectly functioning, this results in the perception of motion becoming lost. Stimulus velocity and spatial frequency content affect motion perception. Yet, the limit of motion perception is established by the temporal resolution of the human's visual system (Burr & Ross, 1982).

1.4.5 Colour Vision

Colour vision is dependent on the cones of the retina, specifically three types of cone which differ in the photopigment that they contain. Each of the three photopigments has a varying sensitivity to light of different wavelengths which includes blue, green, and red colour and known as short, medium, and long wavelength cones. The wavelength type describes their sensitivity to the spectrum.

To evaluate colour vision using psychophysics, the zone model is used which is supported by previous studies of neurobiological visual processing (Hurvich & Jameson, 1960) (Figure 1.11). The model states that light is absorbed by the three types of photoreceptor types which have varying spectral sensitivities. The photoreceptors are alpha (short wavelength sensitive), gamma (long wavelength sensitive), and beta cones (medium wavelength sensitive). The input processed by the alpha (α) cones travels in opposition to the input processed by the gamma (γ) cones as well as beta (β) cones. This then forms a blue-yellow channel. Input from γ cones is then processed in opposition to β cones forming a red-green channel. Once

the input is combined from all three types of cones, this then produces a luminance channel.

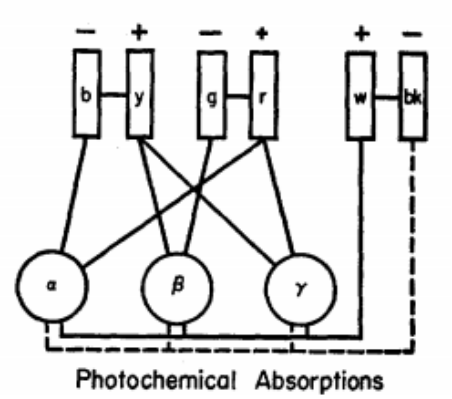

Figure 1.11 Zone Model (Hurvich & Jameson, 1960)

Light is absorbed by the three types of photoreceptor types each varying in spectral sensitivities. Input processed by the alpha (α) cones travel in opposition to the input processed by the gamma (γ) cones as well as beta (β) cones. This forms a blue-yellow channel (B-Y). Input from γ cones is processed in opposition to β cones forming a red-green channel (R-G). Once the input is combined from all three types of cones, this then produces a luminance channel.

1.5 Visual Training

As discussed, there are various visual parameters which contribute to the correct visual function in humans (central, temporal, and peripheral contrast sensitivity). A deficit in any visual parameter may leads to incorrect visual processing and function. For instance, amblyopic subjects have a significantly lower contrast sensitivity compared to normal subjects (Chatzistefanou *et al.,* 2005). Yet, visual training on amblyopes using video games has proven to increase contrast sensitivity across all spatial frequencies (Li *et al.,* 2015).

However, visual training can also be applied to subjects with normal contrast sensitivity values. Green & Bavelier (2007) found that playing video games led to better visual acuity, enhanced peripheral vision, and enhanced contrast sensitivity.

These improvements can also be applied to general life skills and learning. Playing an action video game for only 5 or 10 hours leads to an improvement in visuomotor control, and thus the ability to drive better (Li Li, 2016).

Aside from the improvement of visual function, visual training can also result in an improvement of reading ability. Visual training using video games has led to an improvement in visual function and reading ability in Italian and English-speaking dyslexic children, more so than one year of reading therapy (Franceshini *et al.,* 2013, 2017). Therefore, action game play is a type of visual training method that can significantly enhance visual skills in healthy and affected subjects. So, it is of interest to examine whether visual training can be applied to adults with reading difficulties, as an inexpensive and easily accessible tool available at home.

1.6 Aims and objectives

As visual training has been shown to improve certain features of visual function in healthy subjects, it is important to determine whether active computer use, such as video gaming, can also enhance visual skills of those with adult reading difficulties. Thus, psychophysical tests will be carried out to assess sensitivity to flicker, and contrast in central and peripheral vision in individuals with reading difficulties before and after video game training. The training results will be compared to the improvements seen in amblyopic subjects from previous literature, which already suggest that visual training improves visual function of those with amblyopia.

As a result, video gaming may serve as a therapeutic intervention, allowing the individual to enhance their visual abilities. Computer gaming could potentially serve as a low cost and enjoyable treatment for adults with reading difficulties, to improve visual

function and possibly reading skills. Computer gaming can be relatively inexpensive and completed from the comfort of their home.

The aims of this PhD were therefore to explore the following two questions:

1. Do the improvements seen in the visual function of action video game players also appear in users of other types of computer games?
2. Do computer games provide a suitable visual training task for adults with reading difficulties?

The hypothesis in this thesis is that action video game play will act as a suitable visual training task for adults with reading difficulties, as they will produce a visual improvement after action video game training. It is hypothesised that action gaming may produce a larger improvement compared to that in casual gaming. Additionally, the null hypothesis states that video game play will produce no change in visual function after visual training.

Chapter 2 Background

2.1 Reading Difficulties

A reading difficulty is referred to as a specific learning difficulty, of which there are several (Table 2.1). A specific learning difficulty affects the way in which information is processed and learned, as the individual has a deficit in neurological processing rather than a psychological one (British Dyslexia Association UK, 2017). The most common causes of reading difficulties include developmental dyslexia, auditory processing disorder, dyscalculia, and dysgraphia. All the specific learning disabilities are recognised under the Equality Act in the United Kingdom. Developmental dyslexia's the most common type of reading difficulty in the general population (Quercia *et al.,* 2013) compared to the other specific learning disabilities. It is estimated that 1 in 10 people in the UK suffer from dyslexia, which is approximately more than 6.3 million people (Dyslexia Action UK, 2017). Of those, an estimated 1 in 6 adults have the reading skills of an 11-year-old due to dyslexia (National Literacy Trust UK Impact Report 2013 – 2014).

Thus, participants having the signs and symptoms of developmental dyslexia were used in this study, compared to the other specific learning disabilities. This is easy to set apart as dyscalculia specifically affects mathematics, dysgraphia is the inability to write coherently, whilst an auditory processing disorder affects the auditory system causing a hearing problem. The table below describes the most common types of specific learning disabilities. As developmental dyslexia is the most common type of reading difficulty, it will be discussed in further detail in the next sections of the thesis.

Types of Specific Learning Difficulties	
Main Causes of Reading Difficulties	
Type	**Signs**
Dyslexia	Mixing up letters Difficulty spelling and reading
Dyspraxia	Affected motor coordination
Dyscalculia	Difficulty understanding maths Difficulty in basic numeracy

Table 2.1 Specific Reading Difficulties

Adapted from British Dyslexia Association UK (2017). The table describes several of the most common specific learning disabilities, which are dyslexia, dyspraxia, and dyscalculia. Each specific learning difficulty has unique signs which help the to be distinguished from one another.

2.1.1 Effects and Diagnosis

Generally, dyslexia and reading difficulties present themselves as the inability to accurately read and spell words. A 9 – year old boy, Alexander, was asked by The Dyslexia Institute to describe his struggle to read: "*I have blond her, Blue eys and an infeckshos smill. Pealpie tell mum haw gorgus I am and is ent she looky to have me. But under the surface I live in a tumoyl. Words look like swigles and riting storys is a disaster area because of spellings. There were no ply times at my old school untill work was fineshed wich ment no plytims at all. Thechers sead I was clevor but just didn't try. Shouting was the only way the techors comuniccatid with me. Uther boys made fun of me and so I beckame lonly and mishroboll*" (The Dyslexia Institute '*As I See It'* Walker Books, 1990). Although Alexanders description of dyslexia dates from 1990, the difficulty presents itself in the same way at present in 2018. According to a 2009 report from Sir Jim Rose, the President of the Education Development Trust, he stated that ''Dyslexia is a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling…''. From what Alexander has written

in 1990, it is evident that he clearly struggles with spelling and reading words to a standard of a regular nine-year-old.

As well as problems with reading and writing, a child who has reading difficulties has abnormalities of visual function, compared to children who are not poor readers. For instance, a child with reading difficulties has both a binocular accommodative facility as well as a monocular accommodative aptitude which is significantly reduced (Palomo-Álvarez & Puell, 2008). Accommodative function impairment indicates that the child will have difficulty in school as they will be unable to focus clearly on close objects, in turn prevent them from reading (Sterner *et al.,* 2006). Further deficiencies include an increase of visual crowding, which refers to the inability to recognize objects when they are surrounded by clutter, thus limiting objects recognition. (Spinelli *et al.,* 2002; Moores *et al.,* 2011).

To establish whether an individual has developmental dyslexia (DD), a clinical diagnosis is required. Quercia *et al.* (2013) stated that there are several ways in which to diagnose DD successfully particularly focusing on the child's language. Initially, a Wechsler Intelligence Scale for Children is used which allows the medical practitioner to identify the overall intelligence of the child to exclude any other conditions. The Wechsler Intelligence Scale of Children is the most widely used intellectual ability assessment for children between the ages of 6 and 16 (Pearson Clinical, 2018). The test measures verbal, visual, working memory, reasoning, and processing speed which then produces a full-scale IQ score. The test can identify specific learning disabilities, such as dyslexia. This is followed by a timed assessment in which the task of the child is to read a text that has no precise meaning which includes a variety of words that are not used frequently as well as with variable difficulty. Conducting a timed reading assessment will allow the practitioner to define whether the child's

reading age is that of a ‘normal’ reading age, as a child with DD will display a minimum delay similar to that of someone who is 18 – 24 months younger). If the child does indeed display a difficulty in reading, a selection of three tests will be conducted to identify which reading component causes the difficulty. The first test specifies whether the child has a weakness in decoding text, by reading a specific word list containing pseudo words, regular, and irregular words. The second test identifies whether the child has phonological awareness, and this is done by manipulating and representing various sounds. Lastly, the third test assesses the child’s visual function abilities.

Yet the diagnosis of dyslexia varies from country to country. For instance, a study conducted by McBride-Chang *et al.* (2011) suggested that Chinese poor readers have poorer morphological awareness compared to English poor readers. Whilst Paulesu *et al.* (2001) reported that Italian dyslexics performed better in certain reading tasks compared to French and English dyslexics. Thus, there are cultural variations in the diagnosis of dyslexia. Additionally, requesting a dyslexia assessment is time consuming and the outcome may not always result in an assessment. Initially, a child will receive additional support in the classroom (such as applying different teaching methods) and an assessment is only suggested after initial interventions have failed (Dyslexia Diagnosis, NHS Choices 2017). As a result, officially undiagnosed children who display signs of dyslexia into and throughout adulthood may present themselves as having reading difficulties rather than dyslexia due to the lack of diagnosis. However, it is important to distinguish dyslexia from other problems. This is important as some health problems may be the reason for the inability to write or see correctly, such as hearing problems (glue ear), vision problems (short – sightedness) or other conditions (attention deficit hyperactivity disorder) (Dyslexia Diagnosis, NHS Choices 2017).

2.1.2 Types and Causes

Developmental dyslexia (DD) was first mentioned and described in a scientific article in 1896 (Pringle – Morgan, 1896). DD is a type of reading difficulty which is the most common as it accounts for 10% of children (Quercia *et al.,* 2013) predominantly boys (Stein, 2001). DD is diagnosed more often in boys than in girls because boys have a higher rate of comorbid disorders such as attention-deficit hyperactivity disorder (ADHD) (Willcutt & Pennington, 2000). A very significant risk factor for DD is family history as 23 – 65% of children who reported having DD also have a family member who has DD (Scarborough, 1990). Even though the main cause of DD is undecided, there are several proposed theories (Quercia *et al.,* 2013; Ramus, 2003; Ramus *et al.,* 2003).

2.1.2.1 The Magnocellular Deficit Theory

The magnocellular and parvocellular neurons are required for responding to the various frequencies of spatial and temporal vision (Derrington *et al.,* 1984). The magnocellular deficit theory suggests that dyslexia is due to a reduction in sensitivity of the magnocellular neurons, which then leads to a deficit in that specific pathway of the visual system (Stein & Talcott, 1999). In contrast, the other main pathway contributing to correct visual function, the parvocellular pathway, is normal with those who have DD (Stein & Talcott, 1999). When an individual is reading, magnocellular neurons normally serve to detect visual motion by providing the timing for the visual events which will occur during the task of reading (Stein, 2001). The reason for the deficit in the magnocellular pathway is due to the abnormal development of the magnocellular system in dyslexics, leading to an abnormal magnocellular layer in the lateral geniculate nucleus. The magnocellular layer is impaired by autoantibodies which will then affect the developing brain. This was analysed by investigating major

histocompatibility complex (MHC) Class 1 short arm of chromosome 6 which is responsible for controlling the production of antibodies. (Stein, 2001). This leads to the dyslexics' motion sensitivity being considerably decreased. Impairment in the magnocellular system also results in higher contrast sensitivity at high spatial frequencies compared to those without DD (Mason *et al.,* 1993). Another consequence of the impaired system results in the flicker sensitivity of the individual with DD being considerably lower than the controls' sensitivity (Martin & Lovegrove, 1987; Talcott *et al.,* 1998).

Yet, the magnocellular theory is commonly disputed as being an incorrect explanation of DD, thus it is a rather controversial theory (Skottun, 2000). Many studies have indicated no evidence of magnocellular deficits in dyslexia (Gross – Glenn *et al.,* 1995). Generally, a study which supports the magnocellular deficit would indicate a reduced contrast sensitivity of the dyslexic individual to spatial frequencies which are below 1.5 cycles per degree (Skottun, 2000), yet no study does indeed meet these criteria. The reason why a reduced contrast sensitivity would be noticed below 1.5 cycles per degree, is because the magnocellular deficit will influence low spatial frequencies. Monkeys had lesions applied to various layers of their LGN, and any reductions in contrast sensitivity observed were due to lesions specifically in the magnocellular layers (Merigan *et al.,* 1991). Out of the 13 studies which claim evidence for the magnocellular theory (Lovegrove *et al.,* 1980; Hill & Lovegrove, 1987, 1993; Martin & Lovegrove 1984, 1988; Cornelissen 1993; Evans *et al.,* 1993, 1994; Mason *et al.,* 1993; Walther – Muller, 1995; Cornelissen *et al.,* 1995; Borsting *et al*., 1996; Demb *et al.,* 1998), only four spatial contrast sensitivity studies (Lovegrove *et al.,* 1982; Martin & Lovegrove, 1984; Martin & Lovegrove 1988; Borting *et al.,* 1996) showed a reduced contrast sensitivity at low and medium frequencies (<8 cycles per degree).

2.1.2.2 The Phonological Theory

Another theory of dyslexia is the phonological theory which states that the individual has a deficit in correctly processing and representing speech sounds (Ramus, 2003). Phonological awareness is important as it allows the individual to understand that speech is comprised of various phonemes and syllables which thus allow the child to learn and read correctly. Normal phonological awareness will be developed at the age children are taught how to read, which is approximately at the age of 6 (Temple *et al.,* 2001). A study conducted by Bradley & Bryant (1983) suggested that phonological awareness at an early age can predict the individual's ability to read, regardless of their IQ score. The phonological theory suggests that it is the lack of phonological awareness which causes the dyslexia (Kovelman *et al.,* 2012). The neurological reason behind this deficit is suggested to be due to a dysfunction which is primarily congenital in nature and affecting cortical areas in the brain which are involved in reading and phonological awareness (Temple *et al*., 2001). Studies using functional neuroimaging have demonstrated that dyslexic adults have absent to hyponormal activity in the language areas of the brain, particularly the left tempo-parietal cortex zone (Brunswick *et al.,* 1999; Shaywitz *et al.,* 1998; Rumsey *et al.,* 1997). The left hemisphere also allows the correct connection between orthographic representations and phonology (Ramus *et al.,* 2003). Individuals who have suffered trauma to the left hemisphere of the brain have resulted in language disorders which have led to acquired dyslexia (Eden *et al.,* 1996) thus the left hemisphere is associated with language processing. As the previously noted studies used adults (Brunswick *et al.,* 1999; Shaywitz *et al.,* 1998; Rumsey *et al,.*1997), a study conducted by Temple *et al.* (2001) confirmed that children also lack left tempo-parietal cortex activity during letter rhyming activities, which is a phonological task. Further support for the phonological

deficit theory comes from dyslexic individuals' reduced performance on tasks which involve the use of phonological awareness (Bradley & Bryant, 1978). Dyslexics have also been shown to have an inadequate short-term verbal memory as well as a much slower naming, which indicates that perhaps there is a deficit in the access and retrieval or indeed the quality of representations which are phonological in nature (Snowling, 2000).

2.1.2.3 The Visual Deficit Theory

The visual deficit theory states that there are certain visual impairments which prevent correct processing of words on a page. This in turn, leads to an incorrect ability to read (Stein & Walsh, 1997; Lovegrove *et al.,* 1980). These visual impairments include oculomotor abnormalities which result in abnormal reaction times of eye movements involving the formation of saccades, which are rapid movements of the eye between certain fixation points (Fischer & Weber, 1990). It has been found that dyslexic individuals do have eye movement abnormalities which result in fixations of a greater length as well as saccade amplitudes which are much shorter. This was suggested in a study conducted by Pavlidis (1981) in which dyslexic children presented with erratic eye movements when following a dot moving across the screen. Thus, abnormal eye movements are present even when the dyslexic individual is not reading text. A suggested cause of the visual dysfunction is that the magnocellular pathway of the visual system is disrupted. Disrupted eye movements include abnormalities with the oculomotor system (Fischer & Weber, 1990; Martos & Vila, 1990). As a result, this causes abnormal control of binocular vision, insufficiencies in visual processing, as well as irregular visual and spatial attention (Lovegrove *et al.,* 1980; Stein & Walsh, 1997; Hari *et al.,* 2001). Unfortunately, many studies have failed to replicate Pavlidis (1981) findings, as well as failing to find a difference between dyslexic and normal

individuals' eye movements principally at tasks which do not involve reading (Rayner, 1998; Olson *et al.,* 1983).

2.1.2.4 The Cerebellar Dysfunction Theory

The cerebellar theory of dyslexia claims that dyslexic individuals have a cerebellar abnormality causing a cerebellar dysfunction (Nicolson *et al.,* 1999; Nicolson *et al.*, 2001). For an individual to be articulate in their speech, the cerebellum is required for the motor control during speech articulation. Thus, phonological processing would be impaired as there is a lack of correct articulation of speech (Ramus *et al.,* 2003). A study conducted by Fawcett & Nicolson (2010) identified that a high proportion of dyslexic children showed impairments in the cerebellar tests conducted as well as over 95% of the children showing a deficit in muscle stability or tone as well as deficits on postural stability.

Research suggests that dyslexic individuals have a dysfunction in their vestibulo – ocular reflex (VOR) which is mediated in the cerebellum (Levinson, 1990). The VOR is a reflex in which the vestibular system is activated, and this results in eye movement. The main role of the VOR is to stabilize visual images and maintain eye fixation during head movements (Cassidy *et al.,* 2000). Thus, an unstable VOR prevents the dyslexic individual from maintaining visual fixation on the words, leading to the inability to read correctly.

The effects of crowding have a significant impact on reading rate, as it is the main limiting factor. Crowding is the inability to recognise letters or objects in a cluttered environment, such as reading a book which has paragraphs on the page. Several studies have suggested that abnormalities in crowding lead to the effects of reading difficulties present in dyslexics (Martinelli *et al.,* 2009). Normally, a healthy

reader will adapt the distance navigated by their saccadic eye movements during the process of reading. As a result, the numbers of fixations will not vary substantially between words that have different lengths. On the other hand, poor readers will increase their number of fixations and those fixations will be dependent upon the length of the word (Martinelli *et al.,* 2009).

2.1.3 Treatment

Currently, the treatment for dyslexia involves the individual achieving phonological awareness, such as training on phonics, the alphabet, enhancing reading ability and fluency, as well as word analysis (Snow *et al.,* 1998). Generally, it is advised that intervention takes place before the child is officially diagnosed with dyslexia (Vaughn *et al.,* 2010) as problems in fluency can be prevented in the short term when the child received intervention from the age of 5 to 7 (Torgesen, 2005). There is still quite a deal of remediation required for dyslexia (Gabrieli, 2009). Additionally, simple treatments can be provided such as blue or yellow filters which help improve reading.

There is no ‘cure’ for dyslexia, as dyslexia is not a disease, as well as no medications. Unfortunately, there are many companies claiming to ‘cure’ dyslexia, yet they ask for a large fee and do not promise to help (Dyslexia Research Trust UK). This is due to there being little scientific research on their methods of ‘curing’, such as the use of holistic treatments to treat dyslexia (fish oil supplements). The treatment therapy for reading difficulties is like that of dyslexia, yet there is no single ‘gold standard’ treatment, as in dyslexia.

2.2 Amblyopia

As in dyslexia, amblyopia is a condition which can affect the visual system of the individual. Amblyopia is a developmental disorder which decreases the visual acuity

of the individual. There are different types of amblyopia which result in differing levels of visual impairment. Additionally, dyslexia and amblyopia can present themselves at the same time, a condition called 'amblyopic dyslexia' (Barban *et al.,* 2010). Thus, it is important to understand the amblyopic condition, and its relationship with dyslexia, before evaluating whether visual training can be applied and successfully used.

2.2.1 Causes

As the main and primary cause of amblyopia has not been conclusively established, there are various explanations of the condition. Largely, most amblyopia is associated with either strabismus (squint) or anisometropia (both eyes having an unequal refractive error), although there may be a combination of both. This leads to a restriction in the development of the individuals' visual system (Moseley *et al.,* 2002).

2.2.2 Effects and Diagnosis

Amblyopia occurs in early childhood, particularly during the stage of neural plasticity around the age of four (Ciuffreda *et al.,* 1991). Thus, this is classified as a developmental disorder. Amblyopia presents with a decrease in visual acuity specifically affecting either or both unilateral and bilateral vision (Vincent *et al.,* 2012).

Generally, the reduced visual acuity is predominantly due to two factors: increased susceptibility to visual crowding, and impaired spatial resolution (acuity) (Levi & Klein, 1985; Sireteanu *et al.,* 1993; Hariharan *et al.,* 2005; Levi *et al.,* 2007). Visual crowding is generally defined as an individuals' inability to recognize objects when they are in a cluttered surrounding. Crowding occurs when the surrounding stimuli have disruptive effects and thus isolated items cannot be recognized and identified due to the resolution limits (Hussain *et al*., 2012). In other words, amblyopic individuals have improved visual acuity when letters are presented in isolation instead

of presented in a chart or line. As well as the reduction in acuity, amblyopia results in reduced contrast sensitivity, decreased contour integration, and spatial distortion (Simmers et al., 1999; Levi & Saarinen, 2004; Bonneh *et al.,* 2004; Simmers *et al.,* 2005; Moseley *et al.,* 2006). In addition, amblyopic individuals have impaired contour detection (Hess *et al.,* 1997; Kovács *et al.,* 2000) as well as irregular binocular summation and decreased stereoacuity (Polat *et al.,* 2004).

Studies have demonstrated that amblyopia may result in a dysfunctional area of the brain, due to a binocular mismatch in the retinal image. The primary visual cortex, specifically area V1 (Figure 2.1), has recurrently been shown to be dysfunctional using amblyopic primate animal models (Kiorpes & McKee, 1999). The animals were made amblyopic by suturing the eyelids of primarily young animals which resulted in amblyopia. This has been confirmed by functional imaging studies, in amblyopic humans, which displayed abnormalities of processing in V1, as well as suggesting that higher cortical areas may also have further deficits (Anderson & Swettenham, 2006). Two studies (Mendola *et al*., 2005 and Xiao *et al*., 2007) using voxel – based morphometry indicated that the amblyopic child has a visual cortex with morphological changes, specifically with a reduction of grey matter volume in the regions of the visual cortex. This suggests that there may be abnormalities in the development of the visual cortex during the child's period of critical growth (Xiao *et al.,* 2007).

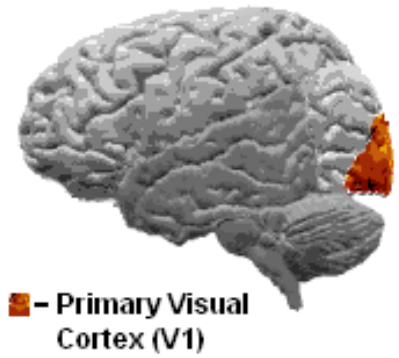

Figure 2.1 V1 Region of the Brain

Image created by Travis Taylor (2006). Side profile of brain, focusing on the location of the Primary Visual Cortex (V1). The V1 region has been shown to be dysfunctional in those who have amblyopia.

The signs of amblyopia are used as markers to diagnose the condition in younger children. The correct and early diagnosis of amblyopia is very important, as deprivation amblyopia may cause blindness (Sjöstrand, 2008). To diagnose amblyopia in adults, the individual should present with a reduced Snellen visual acuity that cannot be improved by wearing corrective spectacles (and thus refractive correction) (McKee *et al.,* 2003). Additionally, the adult should lack an organic cause. Unfortunately, conventional treatment is not given to the amblyopic adult (Levi & Li, 2009) thus they must live their daily life with the negative visual effects of amblyopia.

2.2.3 Amblyopic Dyslexia

In rare cases, a patient may present themselves as having both amblyopia and dyslexia. Barban *et al.* (2010) investigated a patient who had both conditions due to a white matter and left extra-striate lesion which resulted in a deficit in the right visual field. This resulted in a visual deficit which would be naturally caused by amblyopia, which gave rise to reduced colour, form, and light sensitivity. Additionally, the patient was unable to correctly name letters and read due to the dyslexia.

2.2.4 Epidemiology

Amblyopia is the leading cause of loss of monocular vision in children (Birch, 2013). Dependent on the study location and population size, the occurrence of amblyopia can

vary from 1% to 5% (Williamson *et al.,* 1995; Simons 1996; Eibischitz-Tsimhoni *et al*., 2000; Kvarnström *et al.,* 2001 and von Noorden & Campos 2002).

Families who have low incomes and are therefore unable to seek and pay for ophthalmological help, have higher prevalence rates of amblyopia (Williamson *et al.,* 1995; Dunbar et al., 2002). As there are cases of amblyopia in which the child has failed to receive adequate screening and treatment (Williamson *et al.,* 1995), the estimated incidence of this condition in adults is 2.9% (Attebo *et al.,* 1998). However, this may be a much higher rate, as age related visual impairments may hide the signs of amblyopia in the older adult (Vinding *et al.,* 1991).

2.2.5 Treatment Methods

There are three treatment methods which includes patching, penalization, and perceptual learning. Patching involves patching of the non-amblyopic eye as well as the individual wearing corrective spectacles. Penalization is a treatment in which atropine is given to the patient once a day to prevent accommodation from occurring in the non-amblyopic eye. This results in a blurry image in the good eye which forces the amblyopic eye to be used instead for visual experience. Perceptual learning is an alternative method of treatment as it may be used instead. Perceptual learning is a form of active treatment, unlike patching, as the patient must actively participate in the treatment tasks. An example of perceptual learning is video game play. This results in the subject moving their eyes during the video gaming and actively participating in the content of the perceptual learning game. When practice is undertaken, perceptual learning improves the performance of a variety of tasks which use the visual system in those who have normal visual function as well as in amblyopes. This includes

improvement in contrast sensitivity function (Snowden et al., 2002) and vernier acuity (Levi & Polat, 1996; Levi et al., 1997). A study conducted by Polat et al. (2004) using perceptual learning in amblyopic patients between the ages of 9 and 55 (after the sensitive period) suggested that there were improvements in the patients' contrast sensitivity function and visual acuity.

Studies on anisometropic adults, conducted by Huang *et al.* (2008) and Zhou *et al.* (2006), involved the use of contrast detection tasks which showed significant improvement in visual function. Again, the improvement was seen in contrast sensitivity function and visual acuity. Previously, it has been thought that deficiencies in the visual system are irreversible after the individuals' critical/sensitive period (Greenwald & Parks, 1999). This new research into amblyopia suggests the opposite – that the adults' visual system may still show plasticity with perceptual learning treatment (Zhou *et al.,* 2006). A study conducted by Li *et al.,* (2008) indicated that severe amblyopia in adults requires more than 50 hours of perceptual learning to show a 5-fold improvement of visual function. This improvement leads to a substantial amount of neural plasticity which is long lasting.

In result, there is a vast amount of research investigating the effects of video game play as a form of treatment for adult amblyopia. However, there is insufficient research on whether the same visual treatment can be applied to adults with reading difficulties.

2.3 Video Gaming as a form of Visual Training

As discussed in previous sections, video game play is extremely effective for those who suffer from child dyslexia and adult amblyopia. Video game play is a form of perceptual learning and visual training, as it leads to changes and improvements in

visual function. Aside from video game play improving visual function in adults with visual conditions, game play can also result in improvements in healthy adults. Yet, it is important to initially understand what a video game is and the type of game available.

2.3.1 Action Video Game Play

Video gaming is extremely popular today, with over 1.8 billion video game players worldwide (Entertainment Software Association ESA, 2015). Additionally, the ESA measured the video game play activity of over 4,000 American households, being the most in-depth video gaming survey study of its kind. The results indicated that action games had a popularity of 30% whilst non-action games had a popularity of 61%. Examples of non-action (casual) games include the ‘Civilization’ series, ‘The Sims’ series, and ‘Candy Crush’. Action games include the ‘Call of Duty’ series, the ‘Doom’ series, and ‘Diablo’.

A large quantity of literature suggests that action video game play has a significant effect on the visual function of individuals. Action video games differ from other genres, such as casual video games, in a variety of different dimensions. The properties of this genre result in a change of visual function in individuals. Action games contain random object appearance during gaming and high velocity character movement which results in a wide range of possibilities affecting the motor, perceptual as well as cognitive load (Green *et al.,* 2012). As many of the objects during gaming appear at the screen edges, the gamer must constantly predict where the object will appear on the screen (Figure 2.2). This specific property results in the individual using their peripheral processing. As a result, the action video game player (AVGP) has an enhanced contrast sensitivity, increased peripheral and central acuity, a larger useful

field of view, and is able at focus their attention on the main task whilst ignoring distractors in the periphery (Maurer & Hensch, 2012).

Figure 2.2 Action Game Screenshot

Call of Duty Black Ops 3 game play. It is an action game, as it features war – like scenarios. This result in fast game play both in the central and peripheral regions of the visual field.

The normal playing region of non-action (casual) games is 0 – 5^{o} from fixation yet AVGPs show an enhanced distribution of visual attention over 5^{o} from fixation. This was established through AVGPs significantly performing better than non-video game players (NVGPs) using the Useful Field of View task at eccentricities of 10^{o}, 20^{o}, and 30^{o}. This showed that AVPGs can allocate their spatial attention even at untrained regions of the visual field, with their normal average playing range being 18^{o} from fixation (Green & Bavelier, 2003). Thus, the AVGPs spatial distribution of visual attention has a wide range.

2.3.2 Casual Video Game Play

Casual video games contain simple game play which generally lasts for a short amount of time (Baniqued *et al.,* 2013). They are generally easy to learn, and although they do last a short amount of time, they have challenging objectives and in-game rules (Figure 2.3). The player has a wide variety of choices as to which console to play the casual games on, as they are available on mobile phones, computers, the Internet,

as well as tablets. Thus, casual games are easily accessible and are usually are free of charge (e.g. Farmville on Facebook). Additionally, casual games can be applied in education, as a tool for learning outside of the classroom (Price *et al.,* 2015). Yet, there has been a lack of research investigating the role of casual games in education and learning (Litchfield *et al.,* 2007). Yet there is supporting evidence which reports that casual game play does indeed improve attentional capacity (Baniqued *et al.,* 2013), and working memory (Oei & Patterson, 2013),

Figure 2.3 Casual Game Screenshot

A screenshot of Sims 3 game play. The Sims series are casual video games as they contain short game play and longer decision-making times. The aim of the game is to simulate a person's day – to day life, such as work, family, and interior design.

Baniqued *et al*. (2013) investigated the role of casual games as a form of brain training. The goal was to identify whether casual games improved working memory, reasoning and perceptual speed (word recall, letter comparison, logical memory, etc.) and attentional control after 10 sessions of training (approximately 13 hours). The results reported that there was a significant group effect for attention ($p = 0.001$). Additionally, compared to the control group, the training participants reported that the study positively changed the way the participants performed their daily activities ($p = 0.018$).

Oei & Patterson (2013) conducted a study investigating the effects of different types of games, both action and casual. After 20 weeks of visual training, the improvement in The Sims (Casual) group was significant before the Bonferroni adjustments for complex verbal span performance (p = 0.025) (Figure 2.4) (A Bonferroni correction protects from Type 1 error, which are false positives). This may have been due to the game parameters, as the game includes the use of planning and strategy.

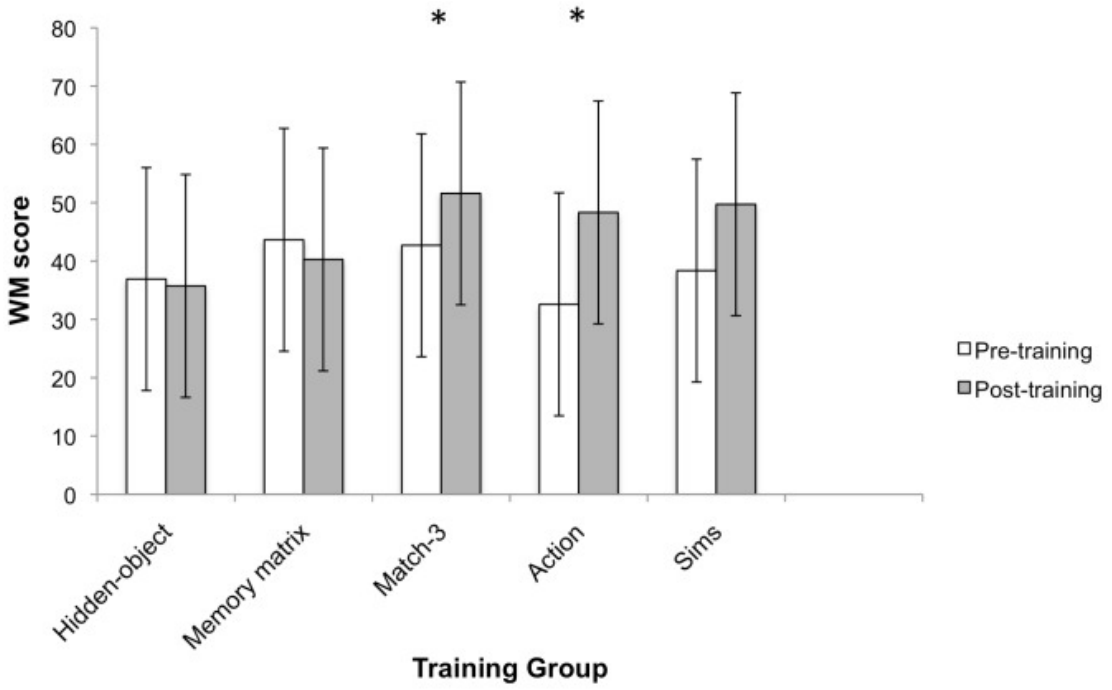

Figure 2.4 Training Results of Various Games

Bar chart adapted from Oei & Patterson (2013) Bar chart shows the results pre-and post-visual training investigating complex verbal span performance. Various game genres are used which includes both action and casual types. The Sims group (a casual game) was significant before Bonferroni correction of alpha – level. (* represents statistical significance post training. Error bats denote 95% confidence intervals).

Green *et al*. (2012) investigated the difference between action and non – action (casual) visual training over 50 hours. The casual game use was The Sims 2 and The Sims 2: Open for Business. The results indicated that the casual game group enhanced their task – switching abilities. Yet, numerous studies reported that casual

games do not provide a significant improvement in visual function and instead action games do (Green & Bavelier, 2013, 2017; Green, Pouget, & Bavelier, 2010; Spence *et al*., 2009). Thus, the improvement is not significant across studies and this may be due to differing experimental methods, training durations, or game types.

2.3.3 Visual Attention in Video Game Play

Visual attention is also known as attentional capacity, which is the individual's ability to allocate their visual processing resources, to a certain extent. Normally as the game is progressing, it consequently becomes more difficult. Attention allows the individual to prevent their visual resources, which contribute to visual attention, to exhaust less rapidly as the game becomes progresses. This is particularly true in AVGPs, as confirmed by Green & Bavelier (2003). They used a model called the flanker compatibility effect, which is used routinely in attentional studies, to confirm that AVGPs do have a greater attentional capacity compared to NVGPs. The flanker compatibility effect measured the consequence of the distractor on the individual when the focus is on the target task. The results had shown that the AVGP could select relevant visual information whilst at the same time supressing the information which was not deemed as relevant. As a result, as the game progresses and thus increases in difficulty, the AVGP will still possess enough resources to ignore the distractors and focus on the target task, whilst in the NVGP those resources will have been depleted (Huber – Wallander *et al.,* 2011). The AVGP will also be able to precisely apprehend more than one visual target during the game play compared to the NVGP (Green & Bavelier, 2003).

2.3.4 Visual Attention and Reading Difficulties

Those with reading difficulties are demonstrated to have abnormalities in visual attention in several studies. A study by Facoetti *et al*. (2000) established that individuals with reading difficulties had slower reaction times in detection tasks when presented with peripheral distractors. The aim of the peripheral distractors was to induce an exogenous attention orienting mechanism. Additionally, subjects with reading difficulties are shown to have difficulty identifying peripheral cues. Roach & Hogben (2008) found that several participants were not able to reach 80% accuracy with a maximum peripheral dot cue contrast. Furthermore, participants who had reading difficulties were less accurate than controls (74% vs. 90%) in spatial frequency peripheral cue localisation tasks. This suggests that improving visual attention may improve visual function and reading abilities in those with reading difficulties.

2.3.5 Video Gaming and Reading Difficulties

An excellent way to improve visual function and reading ability is by applying visual training as the treatment method. This is important as dyslexia and reading difficulties are common among the population, and recent research indicates that video games improve visual function in dyslexic children. A study conducted by Franceschini *et al.* (2013) demonstrated that playing action video games does indeed improve reading ability of those who have dyslexia. As little as 12 hours of action game play (80 minutes per day) improved the children's reading speed, visual function, and attentional skills, without the inclusion of phonological training. In contrast, casual game play did not improve reading speed. The results indicate that only action video game play improved the dyslexic child's ability to read with adequate speed. Yet, the study had a small sample size as it only contained 20 participants, all of whom were children. Thus, it is

not possible to draw a reliable conclusion and to apply the conclusions to a wider age range. Another disadvantage of the study is that only 12 hours of game play were assessed; longer game play may result in more enhanced visual improvements. Thus, further studies are required to investigate the role of action gaming in reading acquisition (Franceschini *et al.,* 2013). The mechanism underlying this training effect during video game play in the dyslexic individual could be the magnocellular dorsal (M – D) pathway, which is responsible for visual attention (Gori & Facoetti, 2014). This was proposed because AVGPs show a large peripheral distribution of visual attention and a high motor load, all of which is largely processed by the M – D pathway (Franceschini *et al.,* 2013).

2.3.6 Video Gaming and Amblyopia

Similarly, several studies have been carried out investigating whether perceptual learning improves visual tasks of those with amblyopia. Chen *et al.* (2008) conducted a contrast detection task for amblyopes, which served as a perceptual learning tool. The study comprised of individuals beyond the critical period (4 years of age to adults over 18) and the results suggested that there was an improvement in contrast sensitivity as well as visual acuity following perceptual learning. Unfortunately, the study was small, and a larger study is required to produce more statistically significant results. As well, a future follow-up study is required to determine the effectiveness of perceptual learning on the visual system.

Specifically, action video game training has also been shown to improve the visual acuity, sensitivity to motion, and spatial contrast sensitivity in those who have bilateral deprivation amblyopia (Jeon *et al*., 2012). Yet, only 40 hours of game play was assessed over one month and only action games were used. Thus, more hours are required over a longer training time to show whether there is a larger visual

improvement as well as the use of a casual video game for comparison in training results.

Additionally, Li *et al.* (2011) investigated whether playing video games with adults who have amblyopic eyes can result in brain plasticity in the visual system. This was measured by calculating acuity and spatial attention. The pilot study suggested that video game training does indeed cause visual plasticity in adults who have amblyopia, improving both high level and low-level visual processing. The study had a wide age range (15 – 61 years) yet the sample size was small (20 adults) and there were differences in numbers between the intervention groups, thus it was treated as a pilot study.

2.4 Conclusion

As discussed, video game play has a variety of benefits on visual function and reading ability on both dyslexic children and healthy and amblyopic adults. Yet, there is no research which supports whether video game play can improve visual function in adults who have reading difficulties. Thus, the intention of the study is to investigate whether there is an improvement after casual and action game training and whether that is comparable to visual training for dyslexic children and amblyopic adults.

Chapter 3 Methodology

The following research methodology is for a small-scale study on the effect of video gaming on visual function in adults, which includes adults without any visual abnormalities as well as those with, particularly for those who have reading difficulties Initially, subjects who have prior experience in video game play will be recruited to establish whether they present with a higher contrast sensitivity, compared to controls. The subjects' vision will be tested only once, as there is no visual training involved.

Following that, subjects with healthy vision will undergo a visual training period to determine whether video game play improves visual function in an experimental study. The subjects will have their visual function tested before and after visual training. Additionally, there will be two testing periods of over 120 hours and over 40 hours. Furthermore, the stability of visual function will be examined one-month post training.

Lastly, subjects with self – reported reading difficulties will undergo a visual training period. Once again, the subjects will have their visual function tested before and after visual training. The results will indicate whether visual training does indeed improve visual function in those with reading difficulties.

3.1 Subject Recruitment

Subjects were recruited using posters advertised around Kingston University and e-mails sent to academic undergraduate course lists (Appendix B). Additionally, adverts were posted onto social media (*Facebook* groups: 'Kingston Buy or Sell', various 'Kingston University' groups) which provided most of the participants (Appendix C). The participants included a mix of Kingston University students as well as members of the public. Participants completed several tests which included:

- A non-reading difficulty questionnaire and assessment
- A reading difficulty questionnaire and assessment
- Screening tests of visual function
- Main psychophysics experiments

Ethical approval for the research was obtained from the Ethics Committee of Kingston University (the Faculty of Science, Engineering, and Computing) (Appendix A). There were 78 subjects recruited for the research. A total of 32 subjects dropped out during the research due to:

- Not completing both psychophysical tests in the laboratory
- Not completing the requisite number of video gaming hours
- Changing their mind after initial psychophysical testing
- Becoming affected by illness (one participant)

A full assessment of a subject took a total of seven hours; thus, a total of 322 hours was spent on the subjects who completed the study and 112 hours on those who dropped out (a total of 434 hours). After completing the screening tests adequately, the subjects were then recruited for a series of 6 experiments. Subjects took part in the same 6 experiments throughout. These included:

1. Effect of contrast sensitivity of Existing and Non-Gamers (Experiment 1)
2. Effect on contrast sensitivity on visual training of healthy subjects over three months (120 hours) (Experiment 2)
3. Effect on contrast sensitivity on visual training of healthy subjects over one month (40 hours) (Experiment 3)

4. Effect on contrast sensitivity on stability of effects of visual training after a one-month period (Experiment 4)
5. Effect on contrast sensitivity on visual training of people with reading difficulties (40 hours) (Experiment 5)
6. Effect on contrast sensitivity on visual Training of people with reading difficulties (20 hours) (Experiment 6)

3.2 Experimental Methods (Experiments 1 – 6)

As the study included a total of six experiments, each of the experiments will be discussed in further detail below. The visual function measures used in the experiments are of spatial contrast sensitivity. The stimuli are spatial Gabor patches, and it is the contrast of the grating at different spatial frequencies that is varied to determine the detection threshold.

3.2.1 Experiment 1: Existing Gamers & Controls

Experiment 1 consisted of previous video gamers action video game players (AVGPs) and casual video game players (CVGPs) as well as non-video game players (NVGPs) which are the controls. A questionnaire allowed the participants to be grouped into three separate classifications according to their answers. Thus, the participant was either classified as an AVGP, CVGP, or NVGP by the selection of games played or the lack of gaming in total. The criteria used to classify an individual as an AVGP or NVGP was proposed by Green *et al.* (2012) and Green & Bavelier (2003). A video game player was classified as playing a minimum of five hours per week for the previous six months prior to testing, whilst an NVGP did not participate in gaming for the last six months prior to experimentation. There was no payment given for participation, thus it was voluntary.

The reason for Experiment 1 is to test the hypothesis on whether video gaming does cause visual changes in healthy subjects. If so, further studies are worth carrying out in those who have visual abnormalities. On the other hand, if the results showed that there is no visual change in either current AVGP or CVGP groups, compared to NVGPs, then future studies would not be worthwhile.

3.2.1.1 Subjects

A total of 26 participants were recruited for the assessment of visual function of prior video game players and non-video game players, which acted as controls. The results of the questionnaire indicated that none of the 26 participants had photosensitive epilepsy, lazy eye, nor reading difficulties. Figure 3.1 displays the difference in time spent on video gaming per session for both gaming groups whilst Figure 3.2 summarises the participants in Experiment 1.

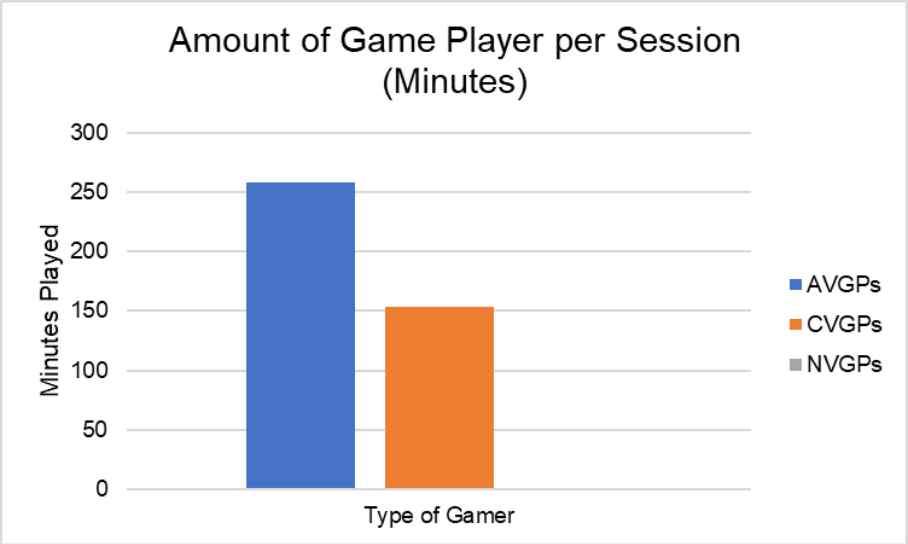

Figure 3.1 Time Spent Gaming

The bar chart displays video game play per session in minutes for the two groups, action video game players (AVGPs) and casual video game players (CVGPs). The bar chart displays that AVGPs play a more compared to CVGPs (105 – minute difference). The non-video game players are not displayed as they acted as controls due to no prior video game play. AVGP n = 11; CVGP n = 6; NVGP n = 9.

Action Video Game Players (AVGPs)	Casual Video Game Players (CVGPs)	Non Video Game Players (NVGPs)
•11 AVGPs •Average age 25 •4 hr 18 min game play per session •10+ hr per week •18+ month game play	•6 CVGPs •Average age 20 •2 hr 33 min game play per session •10+ hr per week •18+ month game play	•9 CVGPs •Average age 24 •No previous game play 6 months

Figure 3.2 Participants for Experiment 1

A summary showing the participants used for Experiment 1. There was a total of nine NVGPs with an average age of 24 (SD 3.37). There was a total of 11 AVGPs with an average age of 25 (SD 2.26). NVGPs specified that they had not played any video games for the previous six months prior to testing. The AVGP participants played an average of 4 hours and 18 minutes per session and 10+ hours per week for an average of 18+ months. There was a total of 6 CVGPs with an average age of 20 (SD 2.04). The CVGP participants played an average of 2 hours and 33 minutes per session and 10+ hours per week. The CVGPs also reported having played games for an average of 18+ months.

3.2.2 Experiment 2: Visual Training of Healthy Subjects (120 hours)

A total of four healthy non-video game players (NVGPs) completed 120 hours of training over a three-month period. The subjects used for both experiments had no prior experience of video gaming for the previous six months, in accordance with the questionnaire. Subjects were given one of two games, either an action game (Doom 3) or a casual game (Civilization 4) at random. Video game play was completed on a personal computer or laptop at the participant's home. Visual function was examined before and after training using psychophysics tests written using MATLAB. After participation, the subject received a £15 Amazon voucher.

3.2.2.1 Subjects

The same questionnaire was used as in the existing subjects' experiment. None of the four participants had any health concerns which would have prevented them from taking part in the visual training. A summary of the participants used is shown in Figure 3.3.

Action Video Game Training (3 month)	Casual Video Game Training (3 month)
•2 participants •No game play 6 months prior training	•2 participants •No game play 6 months prior training

Figure 3.3 Participants for Experiment 2

A summary showing the participants used for Experiment 2. A total of four participants took part in the 3-month training period with the participants having ages of 23 and 27 (action with an SD of 2.80) and 26 and 35 (casual with an SD of 6.40). Two participants played the casual game whilst the other two the action game. All four participants had not played a video game for the previous 6 months prior to participation; thus, they were initially classified as NVGPs according to the criteria proposed by Green *et al.* (2012) and Green & Bavelier (2003).

3.2.3 Experiment 3: Visual Training of Healthy Subjects (40 hours)

Healthy non-video game players completed 40 hours of training over a one-month period. This enabled the investigator to identify whether there is a similar improvement in visual function compared to the 120-hour training period. The subjects used for both experiments had no prior experience of video gaming for the previous six months, in accordance with the questionnaire. Subjects were given one of two games, either an action game (Doom 3) or a casual game (Civilization 4) at random. Video game play was completed on a personal computer or laptop at the participant's home. Visual function was examined before and after training using psychophysics tests written

using MATLAB. Additionally, participants are tested one month after the game play ended in order to identify whether video gaming remains stable one month after finishing the game play. After participation, the subject received a £15 Amazon voucher.

3.2.3.1 Subjects

None of the participants had any health concerns which would have prevented them from taking part in the visual training. A summary of the participants used is shown in Figure 3.4.

Action Video Game Training (40 hours/1 month)	**Casual Video Game Training (40 hours/ 1 month)**	**Controls - No Game Training**
•5 participants •No game play within the last 6 months •Average age 24	•6 participants •No game play within the last 6 months •Average age 22	•5 particpants •No game play within the last 6 months •No game play during the 1 month •Average Age 28

Figure 3.4 Participants for Experiment 3

A summary showing the participants used for Experiment 3. A total of 16 participants took part in the experiment with an average age of 22 (action SD 3.24), 28 (casual SD 4.12), and 26 (controls SD 2.74). Out of these 16 participants, five were assigned to the action game group, six as casual gamers, and there were five controls who did not undergo any training during the period. Out of these, five participants had their visual function measured one month after finishing their visual training.

3.2.4 Experiment 4: Stability of Visual Training

The study was conducted to identify whether visual training remained stable one month after the termination of the visual training. This was to identify whether game training induced a lasting effect in the visual function of the individual. The subjects did not play any games during the one-month period after finishing their visual training.

3.2.4.1 Subjects

The same questionnaire was used as in the existing subjects. None of the participants had any health concerns which would have prevented them from taking part in the visual training. A summary of the participants used is shown in Figure 3.5.

1 Month Post Training (Action Gamers)
•3 participants
•No game play 1 month after training
•Average age 21

1 Month Post Training (Casual Gamers)
•2 participants
•No game play 1 month after training
•Average age 26

Figure 3.5 Participants for Experiment 4

A summary showing the participants used for Experiment 4. Five of the 11 gamers had their visual function measured one month after finishing their training. This included three action gamers (out of the five original) and two casual gamers (out of the six original). The other six participants were unable to attend due to life commitments. The participants had an average age of 24 (SD=3.1).

3.2.5 Experiment 5: Visual training of people with reading difficulties (40 hours)

Experiment 5 investigated the visual improvement of people with reading difficulties after video gaming. Subjects with reading difficulties underwent training of 40 hours over a one-month period. Participants were either given an action (Half Life 2) or casual (Civilization 4) game to play on their home computers. Visual function is examined before and after training using psychophysics tests written using MATLAB.

3.2.5.1 Subjects

A total of four participants took part in experiment 5 (Figure 3.6). None of the four participants had any health concerns which would have prevented them from taking part in the visual training.

Experiment 5 Reading Difficulties
• 4 Participants • Casual Game - 2 Subjects (Average age 25) • Action Game - 2 Subjects (Average Age 24) • No game play within the last 6 months • Average age 24 (SD 4.7)

Figure 3.6 Participants for Experiments 5

A summary showing the participants used for Experiment 5. All participants had not played a video game for the previous 6 months prior to participation; thus, they were initially classified as NVGPs according to the criteria proposed by Green *et al*. (2012) and Green & Bavelier (2003). An even number of participants was selected for both gaming genres in order to improve result reliability and accuracy after statistical analysis. SD for age is 4.7.

3.4.6 Experiment 6: Visual training of people with reading difficulties (20 hours)

Experiment 6 investigated the visual improvement of people with reading difficulties after video gaming, as in Experiment 5. Subjects with reading difficulties underwent 20 hours over a two-week training period. Participants were either given an action (Half Life 2) or casual (Civilization 4) game to play on their home computers. Visual function is examined before and after training using psychophysics tests written using MATLAB

3.2.6.1 Subjects

A total of six participants took part in experiment 6 (Figure 3.7). None of the six participants had any health concerns which would have prevented them from taking part in the visual training.

Experiment 6 **Reading Difficulties**
• 6 Participants • Casual Game - 3 Subjects (Average age 28) • Action Game - 3 Subjects (Average Age 25) • No game play within the last 6 months • Average age 27 (SD 3.12)

Figure 3.7 Participants for Experiments 6

A summary showing the participants used for Experiment 6. All participants had not played a video game for the previous 6 months prior to participation; thus, they were initially classified as NVGPs according to the criteria proposed by Green *et al.* (2012) and Green & Bavelier (2003). An even number of participants was selected for both gaming genres in order to improve result reliability and accuracy after statistical analysis. SD for age is 3.12.

3.3 Visual Psychophysics

Visual psychophysics is measured using the programming software Matrix Laboratory (MATLAB). A specific script is written for each psychophysical test, which is then presented on a computer screen. The subject responds to the test using a mouse which in result produces a contrast sensitivity result.

3.3.1 Monitor and Software

Experimental stimuli were displayed on an ASUS 27-inch LCD monitor. The monitor measured 60 centimetres horizontally and 33 centimetres vertically. The horizontal

resolution was 1920 pixels whilst the vertical resolution was 1080 pixels. The refresh rate of the ASUS monitor was 120 Hz. An Nvidia GeForce GTX 650 graphics card was used, whilst the monitor model was VG278H. The operating system was Windows 7 and was eventually updated to Windows 8 by the University. Psychophysical experiments were written and presented on MATLAB, version 2013 – 2017 using the Psychophysical toolbox extensions (Brainard, 1997). The experiments were written by Dr. Jan S. Lauritzen and Dr. Johann Klein and edited by Agne Mikailionyte.

3.3.2 Experimental Paradigm

A chin rest was used to support the participants head as it was 486 mm from the monitor. The main laboratory ceiling lights were off, and a small lamp was switched on. This was to ensure that the participant did not get tired eyes, as the lab lights were very bright for the small size of the room. Binocular viewing conditions were in place and the participants could have visual correction, if required.

Gabor patches were presented as stimuli on screen. A Gabor patch is presented as sinusoidal gratings on a grey background. The contrast of the Gabor patch was defined by Michelson contrast:

Contrast = (Maximum Luminance – Minimum Luminance) / (Maximum Luminance + Minimum Luminance)

A staircase procedure was used in order to vary the contrast in each trial, which was a 3-down 1-up procedure. A staircase procedure begins with a stimulus of high intensity which is then reduced resulting in the stimulus being harder to detect. Once the participant makes a mistake, then the staircase would reverse resulting in an increase of intensity, and so on. The number of reversals ensured that there was contrast variation in the step size. Threshold and standard deviation was calculated

by using the data gathered from the last three reversals in the test. If the standard deviation was greater than 0.200, then the data was discarded as it would have been inaccurate and unreliable for statistical analysis. A lower standard deviation value indicates that the results were closer to the mean, whereas a high standard deviation means that the data points would be spread out over a wide selection of values making the results less reliable. Participants took a total of 32 runs, which were the six distinct psychophysical experiments.

The psychophysical experiments analysed central static, peripheral static, central flicker (20 and 24 Hz), and peripheral flicker (20 and 24 Hz) contrast sensitivity. The Gabors were of one colour combination which was achromatic (black and grey). There was a total of four different spatial frequencies tested; 0.5, 2, 10, and 20 cycles per degree. The reason as to why two separate temporal frequencies were chosen (20 Hz and 24 Hz) were to assess whether a slight change in frequency would be able to result in a change in the contrast sensitivity of temporal vision. Additionally, both tests were available on the MATLAB software, therefore it was of use to use both measurements due to their availability. It was also interesting to identify whether only a 4 Hz difference would produce different results, or similar.

The visual function measurements used in the training experiments are all spatial contrast sensitivity. The stimuli use throughout are Gabor patches, and it is the grating which varies in contrast due to the differing spatial frequencies. The contrast is varied in order to identify the detection threshold, which produces a result which can be measured statistically. For example, when the Gabor stimulus flicker at 20 Hz, the variable that is measured is spatial contrast sensitivity, rather than temporal contrast sensitivity. The test is used to detect the spatial grating pattern, rather than the flicker.

3.3.3 Producing a Gabor

A Gabor patch is produced by using a sinusoid grating which is enveloped by a Gaussian mask (Figure 3.8). The Gaussian mask enables the edges of the Gabor patch to be lower in contrast compared to the centre of the Gabor. MATLAB is used to create a Gabor patch. There are various steps written in the script which are required to create a basic Gabor patch in MATLAB (Appendix D).

Figure 3.8 Gabor Patch

The Gabor patch is presented on a grey background. The subject responds to the Gabor patch by using a computer mouse. This generates results that are presented as contrast sensitivity results.

3.4 Statistical Methods

Results were analysed using repeated measures ANOVA on SPSS. The role of the ANOVA test is to identify whether there are any significant differences between the means. An advantage of repeated measures ANOVA is that the test controls for factors that may cause variability between the subjects. As a result, repeated measures ANOVA is more accurate and sensitive compared to a basic ANOVA measurement (Dancey, 2011). Additionally, due to the statistical power of repeated measures ANOVA, the design can statistically test fewer subjects which is beneficial for my study. On the other hand, this method of statistical analysis is sensitive to outlier data. Thus, the method calculates the statistical analysis for data which is distant from the main observations and this could result in experimental error. A Cont – Test

compares the results of two groups to determine whether any group differences are significant or can be accounted for by chance.

I will provide a methodological overview of how ANOVA has input into SPSS and analysed. Firstly, a subject label as a nominal value is added which corresponded to the type of group, whether it was action, casual, or control group. Secondly, the contrast sensitivity values are inputted corresponding to the type of subject label. The values are added according to spatial frequency, which is added as cycles per degree on the headings. Data is added to both sides of the subject group, therefore the left side corresponding to values before training, and data to the right side corresponding to the values after training. If no training has been used, then only one set of data is present. This data is then analysed using repeated measures ANOVA Bonferroni correction, as each participant repeats the measures on at least one factor (special frequency). Furthermore, results were tested using either an independent or a paired t – Test. A t – Test is used to identify whether there is a significant difference between the means of two separate groups. An independent t – Test would measure the results for the same variable, however for two separate groups (e.g. comparing action and casual gamers for the same cycle per degree and before and after training). However, a paired t – Test measures the results for two separate variables but for the same group (e.g. comparing action gamers before and after visual training on the same cycle per degree).

3.5 Sample Size

A larger sample size ensures that the results are accurate and there is a lesser chance of an error occurring whilst sampling. As a result, this would ensure that the data would represent the wider general population. A higher number of experimental steps was used in this study which improved the reliability and accuracy of the experimental data,

however, may have perhaps resulted in a smaller quantity of participants. The reason for this is the large number of experimental steps, and thus the long duration of the testing. Thus, less participants would be willing to take part in the research and the drop – out rate would be higher.

3.6 Conclusion

In conclusion, the experimental methods allowed the participants to be recruited, tested, and a result to be produced. This result will then be statistically analysed to test and establish the hypothesis, whether video game training improves visual function in adults with self – reported reading difficulties.

Prior to conducting the experimental investigations, subjects were required to complete an initial recruitment and screening test. This was to ensure that they fit the required criteria, as well to establish the extent of their difficulty or non – difficulty. Out of the 56 subjects in the study, 46 of the subjects were classed as having no reading difficulties whilst 10 were classed as having reading difficulties.

3.7 Vision Questionnaire 1: Non-Reading Difficulty Subjects

A vision questionnaire (Figure 3.9) was used prior to experimentation, for Experiments 1 to 5 (non – reading difficulty participants) to assess individuals' reading experience, gaming history, and any prior or current visual deficit conditions. The information could then be used to exclude any health risks, such as photosensitive epilepsy, and examine potential confounding factors which may include age, gender, and video gaming experience. This is one of the two vision questionnaires which were provided during the entire experimental research. This questionnaire is specifically for those who do not have reading difficulties.

Non- Reading Difficulty Vision Questionnaire 1

1. **What is your gender?** Male Female

2. **What is your age?**

3. **Do you have any health concerns which prevent you from playing video games?**

4. **Do you suffer from photosensitive epilepsy?** Yes/ No

If you answered yes to question 3 or 4, please do not continue with the questionnaire.

5. **Have you been diagnosed with lazy eye?** Yes/ No

6. **Do you consider yourself to have reading difficulties or have you been diagnosed to have reading difficulties?** Yes/ No

7. **Do you play video games?** Yes/ No

If you answered yes to question 7 (but no to questions 5 or 6) please complete the rest of the questionnaire.

8. **How many hours do you play per session?**

9. **How many hours do you play per week on average?**

   1 – 5 6 – 10 10+

10. **How long have you been playing video games for?**

    0 – 2 months 2 – 6 months 6 – 12 months 12 – 18 months 18+ months

11. **Which video games do you play? Please select the genre and write the game name.**

    Casual games (e.g. non-action such as Sims):

    Action games (e.g. Call of Duty):

Figure 3.9 Healthy vision questionnaire.

Vision questionnaire 1 for healthy subjects, displaying the questions asked of the participants. The questionnaire asked basic information such as gender and age, as well as more in depth questioning of video gaming habits.

3.7.1 Results

None of the 46 participants who completed the research suffered from health concerns or photosensitive epilepsy. One participant (participant number 47) informed me that they have a degenerative disorder (Multiple Sclerosis) and as a result they were excluded from the study before full participation. Furthermore, none of the participants had amblyopia or reading difficulties, which would have also excluded them from participation.

3.7.2 Discussion

Although the questionnaire did not ask about an extensive medical history of the subject, it did require enough basic information to analyse the participants' results. It was assumed the participants answered the questions truthfully, as there was no time pressure placed on the answers and they were allowed a private space to answer the questions. Although the best possible conditions and privacy were provided for the participants, it was not guaranteed that these conditions will lead to truthful answers. Additionally, the questionnaire was anonymous as only a signature was required rather than the full name. To correlate individuals with their completed forms, rather than using their name, an ID number was used e.g. Participant number 32.

Participants were given a wide selection of answer options to choose from, which ensured accuracy. For example, when questioned about how many hours the participant played per session, they were given three options. When asked how long they have been playing video games for, they were given five options in total. Although participants may have been gamers for more than 12 months (e.g. 3 years), the criteria for a video game player is 6 months of continuous game play as set by Green & Bavelier (2007). Therefore, this criterion was applied to classify the participants. In

conclusion, the main aim of the questionnaire was to assess whether the subject suffered from ill health and whether they play video games.

3.8 Reading Difficulty Screening

Subjects were selected as having self-reported reading difficulties, either previously diagnosed at school or self-reported to suffer from difficulty reading. As a qualified psychologist was not present during the study, three screening tests were used to confirm that the subject indeed has a reading difficulty. These included a reading difficulty questionnaire, a comparative rate of reading test (CREST) test, and a Wilkins Rate of Reading Test. The three tests were completed by 10 subjects with self-reported reading difficulties, as well as 10 control subjects who do not have any self-reported reading difficulties (recruited from the non – reading difficulty group). The control subjects were chosen at random and 10 were chosen specifically to match the same number of subjects with reading difficulties.

Reading difficulties are characterised by inadequate word processing, specifically affecting the word accuracy and fluency. Research into the processing difficulties which adults with reading difficulties experience is less clear compared to research with children. Therefore, the best assessment and identification practices have not been identified in the adult population, to correctly diagnose an adult with a reading difficulty. Additionally, it is not clear what the exact number of adults that suffer from reading difficulties is, yet it is estimated to approximately affect 3 – 5% of the general population (National Adult Literary Survey, 1992). Epidemiological studies completed on children with reading difficulties suggests that the ability to read is demonstrated along a wide ‘’reading spectrum’’, with proficient reading being at the top end whilst reading difficulties exist at the lower tail of the normal distribution.

Although it is not possible to diagnose an individual as having dyslexia without a qualified psychologist, it is possible to assess the extent of the reading difficulty by using methods that involve decoding, comprehension, and fluency in terms of reading, which are the classical signs of reading difficulties (Taymans *et al*., 2011). A study by Taymans *et al.* (2011) investigated the exact number of research studies examining adults with reading difficulties and without reading difficulties in terms of cognition and performance. A cut off IQ score of 80 was used during the analysis. In the study, adults with RD were selected as having an average intelligence (IQ score of 80) and poor reading skills. The search found a total of 52 studies which use the term 'reading difficulty subject' rather than 'dyslexic subject'. Additionally, the results demonstrated that the adults with reading difficulties had a lower mean standard score for work speed, recognition, as well as phonological processing (below 25%). The studies used various screening tests to establish the nature of the reading difficulty such as reading words (which includes irregular words), reading comprehension, and naming speed. As already mentioned, reading difficulties are demonstrated by reading slowness (Nergard-Nilsse & Hume, 2014) and difficulty with the alphabetic code (Snowling *et al.*, 2007). In order to establish and assess a reading difficulty, a detailed reading ability questionnaire and reading test must be carried out.

3.8.1 Vision Questionnaire 2: Reading Difficulties

Vision questionnaire 2 (Figure 3.10) is adapted from Panchagnula *et al*. (2013), with permission from the author and was used for the screening of those with reading difficulties. The questionnaire gathers information on the participant by asking them questions on the various factors associated with a reading difficulty such as impaired rapid reading, word reversal, blurry text, and so on. Reading experience was analysed using questions about characteristics which are common in dyslexia (the main cause

of reading difficulties), such as difficulty reading rapidly and so on. The participant's answers were used to assess their reading experience and the extent of the reading difficulty in a quantitative manner using a scale from 1 - 4. Additionally, as in the Vision Questionnaire for non-reading difficulty subjects the questionnaire assessed health and safety concerns yet in more detail.

The questions chosen for the Reading Difficulty Questionnaire include those signs which are most common with someone with a reading difficulty or dyslexia, according to the National Health Service UK (NHS) 2017 checklist (https://www.nhs.uk/conditions/dyslexia/symptoms/). These include poor spelling, difficulty writing letters, finding it hard to read aloud, letters appearing blurred, and general poor phonological awareness. As the official checklist is not available for public use, a questionnaire was composed which included the signs of dyslexia from previous research as well as current NHS symptoms. The NHS UK do not provide a free screening test for dyslexia (the most common cause of reading difficulties). The cost of a test is £450 (+VAT) to be diagnosed by a specialist teacher and this rises to £800 (+VAT) to have a diagnosis by an educational psychologist or specialist psychologist (British Dyslexia Association, 2017). These high prices may prevent an individual from being tested for dyslexia, as well as the assessment length being 3 - 6 hours in total. Additionally, dyslexia is not a topic which forms part of the British medical training curriculum and is not considered a medical issue (British Dyslexia Association, 2017). Additionally, there is no single assessment which can screen for dyslexia and that can be used as the main reference guide, as each private company provides their own screening test composed by a qualified psychologist. As well, a specific learning disabilities psychologist is required who is trained in adult dyslexia; a child learning disabilities psychologist is not able to diagnose adult dyslexia. According to NHS

Scotland Psychology Workforce by Professional Group (31 March 2016), learning disabilities psychologists represent only 7% of the total NHS psychology workforce. This highlights the difficulty of obtaining an assessment as the number of learning disabilities psychologists is low. Additionally, only a proportion of these would specialise in adult dyslexia.

Reading Difficulty Questionnaire 2

Reading Difficulty Questionnaire

Background Information

1. Date of Birth (dd/mm/yy)
2. Gender (male/ female)
3. Is English your first language or an additional language?

Health

4. Do you have amblyopia (also known as lazy eye), strabismus, (partial or full) blindness or any other condition affecting your normal vision?
5. Have you ever been diagnosed with photosensitive epilepsy?
6. Do you suffer from migraines?
7. Have you ever been diagnosed with a reading difficulty?
8. If you haven't been diagnosed, do you CONSIDER yourself to have a reading difficulty?
9. Do you use visual correction (glasses, contact lenses)?
10. Have you had ever had eye surgery (e.g. laser eye surgery)?

Reading

Please answer by selecting either:

- Rarely or never
- Sometimes
- Often
- Always

11. Do you have a good reading experience?
12. Do you ever experience headaches, nausea or dizziness when reading?
13. Do words in a sentence appear on top of each other or appear jumbled up?
14. Do words/letters appear to move around when you are reading?
15. Do you have difficulty keeping your place when reading?
16. Do you often need to re-read text you have already gone over?
17. Do you have difficulty reading rapidly?
18. Does closing one eye help you to read better?
19. Does reading with a coloured overlay or through tinted lenses improve your reading?
20. Do you prefer reading coloured text (e.g. blue writing)?
21. When reading do words fade away and then reappear?
22. Do letters/words appear blurred?
23. Do letters/words appear as double images?
24. When reading black text on a white background, does the background ever appear to cover or overlap the text?
25. Do letters/words flicker when reading?
26. Do letters/words appear to move apart when reading?
27. Do you find it hard to recite the alphabet?
28. Do you find it hard to read aloud?
29. Do you find it hard to organise your thoughts on paper when writing?

Figure 3.10 Reading difficulty questionnaire.

Presented is the Vision Questionnaire 2 assessing reading experience. In the questionnaire, the participants answered questions 4 to 10 as either 'Yes' or 'No'. Questions 11 to 29 were answered using a scale of 1 to 4, 1 being 'Rarely or Never', 2 being 'Sometimes', 3 being 'Often', and 4 being 'Always'.

3.8.2 Results

No participants suffered from any health condition nor amblyopia, photosensitive epilepsy, or migraines. Additionally, none of the participants had a degenerative disorder, such as Alzheimer's disease, which may have affected their reading ability. A total of 10 participants took part in the questionnaire. Six participants had been previously diagnosed to have reading difficulties, whilst four participants had daily traits associated with having reading difficulties. None of the participants had undertaken reading therapy before nor during participation in these measurements.

The results were analysed in a quantitative manner and presented in a table (Table 3.1) and the reading scores were further statistically analysed (Table 3.2 and Table 3.3). The overall total reading score for each group (reading – difficulty and non – reading difficulty) is calculated as a total average of the individual scores. The same questionnaire scoring method is used by the NHS Care Quality Commission used to assess patient responses.

Reading Difficulty Questionnaire Results

Question	Rarely or Never (%)		Sometimes (%)		Often (%)		Always (%)	
	RD	Control	RD	Control	RD	Control	RD	Control
Do you have a good reading experience?	0	0	50	0	40	20	10	80
Do you ever experience headaches, nausea or dizziness when reading?	50	100	40	0	10	0	0	0
Do words in a sentence appear on top of each other of appear jumped up?	20	100	40	0	40	0	0	0
Do words/ letters appear to move around when you are reading?	30	90	40	10	30	0	0	0
Do you have difficulty keeping your place when reading?	0	70	0	30	60	0	40	0
Do you often need to re-read text you have already gone over?	0	80	0	20	70	0	30	0
Do you have difficulty reading rapidly?	0	70	40	30	40	0	20	0
Does closing one eye help you to read better?	80	100	20	0	0	0	0	0
Does reading with a coloured overlay or through tinted lenses improve your reading?	30 (50 DK)	40 (DK)	0	0	0	0	20	0
Do you prefer reading coloured text?	20 (20 DK)	80	40	20	0	0	20	0
When reading do words fade away and then reappear?	80	100	0	0	10	0	10	0
Do letters/words appear blurred?	20	100	50	0	30	0	0	0
Do letters/words appear as double images?	30	100	50	0	20	0	0	0
When reading black text on a white background, does the background ever appear to cover or overlap the text?	50	100	30	0	20	0	0	0
Do letters/ words flicker when reading?	30	100	40	0	30	0	0	0
Do letters/ words appear to move apart when reading?	70	90	30	10	0	0	0	0
Do you find it hard to recite the alphabet?	30	100	40	0	30	0	0	0
Do you find it hard to read aloud?	20	90	30	10	20	0	30	0
Do you find it hard to organise your thoughts on paper when writing?	0	70	50	30	0	0	50	0

Table 3.1 Questionnaire results. Presenting the Reading Difficulty questionnaire results assessing the subjects reading ability. Results are shown as a percentage (%) out of the 10 participants. Box shaded in yellow indicates zero (0%). DK = Don't know.

Total Reading Scores Table for Reading Difficulty Subjects

Question	Subject Number (Reading Difficulties) (/76)										Average Score
	1	2	3	4	5	6	7	8	9	10	
1	3	2	2	2	3	2	3	3	1	3	
2	2	1	1	1	2	2	3	1	2	1	
3	3	2	3	1	2	3	3	2	2	1	
4	1	3	3	1	2	2	2	3	2	2	
5	3	3	3	3	2	3	3	3	3	3	
6	4	3	3	3	4	4	4	3	3	3	
7	3	4	3	2	3	2	4	2	2	3	
8	1	2	1	1	1	1	2	1	1	1	
9	4	1	1	1	1	1	4	1	1	1	
10	4	1	1	4	2	2	1	2	2	1	
11	1	1	1	1	3	1	4	1	1	1	
12	3	3	2	1	3	2	2	2	2	1	
13	1	2	2	1	2	2	3	3	2	1	
14	1	3	2	1	2	1	3	1	1	2	
15	2	3	1	3	1	1	3	2	2	2	
16	1	2	2	1	2	1	1	1	1	1	
17	1	3	3	2	1	2	2	3	1	2	
18	1	3	3	4	2	1	4	4	2	2	
19	4	2	2	4	4	4	2	2	4	2	
Total Score	43	44	39	37	42	37	53	40	35	33	40

Table 3.2 Reading scores of reading difficulty subjects. Table presenting the total reading scores for reading difficulty subjects extracted from the reading difficulty questionnaire.

Total Reading Scores Table for Non – Reading Difficulty Subjects

Question	Subject Number (Non-Reading Difficulties) & Score (/76)										Average Score
	1	2	3	4	5	6	7	8	9	10	
1	1	1	1	2	1	1	2	1	1	1	
2	1	1	1	1	1	1	1	1	1	1	
3	1	1	1	1	1	1	1	1	1	1	
4	1	2	1	1	1	1	1	1	1	1	
5	1	2	1	2	1	1	1	1	1	2	
6	1	1	1	1	2	2	1	1	1	1	
7	2	1	1	2	1	1	2	1	1	1	
8	1	1	1	1	1	1	1	1	1	1	
9	1	1	1	1	1	1	1	1	1	1	
10	2	1	1	1	1	1	2	1	1	1	
11	1	1	1	1	1	1	1	1	1	1	
12	1	1	1	1	1	1	1	1	1	1	
13	1	1	1	1	1	1	1	1	1	1	
14	1	1	1	1	1	1	1	1	1	1	
15	1	1	1	1	1	1	1	1	1	1	
16	2	1	1	1	1	1	1	1	1	1	
17	1	1	1	1	1	1	1	1	1	1	
18	1	1	1	1	1	1	1	1	2	2	
19	2	2	1	1	1	1	1	1	2	1	
Total Score	23	22	19	22	20	20	22	19	21	21	21

Table 3.3 Reading scores of healthy subjects. Table presenting the total reading scores for non - reading difficulty subjects extracted from the reading difficulty questionnaire. Many subjects scored 1 which indicates ‘rarely or never’.

The two groups were compared (RD and NRD) in terms of the total score of points on the questionnaire and analysed using an independent samples t - Test. The analysis displays a significant difference between the reading score of the reading difficulty subjects (Mean = 40.30, SD = 5.68) and non – reading difficulty subjects (Mean = 20.90, SD = 1.37); t (18) = 10.50, p = 0.00. Therefore, there is a difference in the reading scores between both subjects.

3.8.3 Discussion

The questionnaire allowed an in depth understanding of the reading experience of participants. Additionally, the questions were not available through visual function assessments nor through reading tests, only through a designed questionnaire.

The participants were given privacy to answer the questions and only their signature was used as proof of completion, rather than full name which would have reduced privacy. Thus, it is assumed that the questions were answered truthfully and without pressure. Yet there may have been difficulty in controlling some of the psychological biases whilst the participant was completing the questionnaire. For instance, the participant may not have understood the question fully or the phrase of the question. For example, the ‘Rarely’ in ‘Rarely or Never’ may have been like ‘Sometimes’ for some participants, as a difference between ‘Rarely’ and ‘Sometimes’ is not stated precisely. There may have been a difference in several hours per day or a week per month in some participants.

For more precise results, clarification of the terms would have to be included to help increase the reliability. Some of the questions used for the questionnaire were extracted from the Conlon visual discomfort survey (Conlon *et al.,* 1999). Also, participants answered on a scale of 1 to 4 which allows a uniform frame to be set and

in result the responses were scaled. This allowed the results to be analysed and evaluated. Participants were also motivated to express their feelings toward the reading difficulty, rather than having a middle ground of 'Not Sure' or 'I don't know'. This increased the sensitivity of the questionnaire as all the participants could choose their preferred answer.

As the participants received a £15 gift voucher for their participation, it was assumed that the participants answered truthfully rather than giving false answers, as they were being 'paid' for volunteering their time. In result. it was assumed that they would answer truthfully as they were receiving a reward in return. Aside from the drawbacks of the questionnaire, the questions enabled a thorough understanding of the reading ability and experience of those who suffer from reading difficulties.

3.9 Reading Tests

A selection of reading tests was used in order to assess the extent of the reading difficulty. This includes the comparative rate of reading speed test (CREST) and the Wilkins rate of reading test.

3.9.1 The Comparative Rate of Reading Speed Test (CREST)

The comparative rate of reading speed test (CREST) was used for the experiment investigating the subjects who have reading difficulties. The test is used to assess the reading difficulty. CREST consists of two passages which contain nonsensical words, which are composed of letters which were in random groupings (a-z). Participants were asked to read the fifth lines of each passage aloud. The letters of each of the two CREST tests differed in colour and contrast: the first passages were composed of a high contrast font of serif design (Figure 3.11), whilst the second passages were teal in colour and non-serif font (Figure 3.12). The reading rates as well as behavioural

traits of the participants were recorded during the visual test. The reading speed is measured by the amount of time in seconds it takes for the participant to read the fifth passage from start to finish, by simply reading each letter individually.

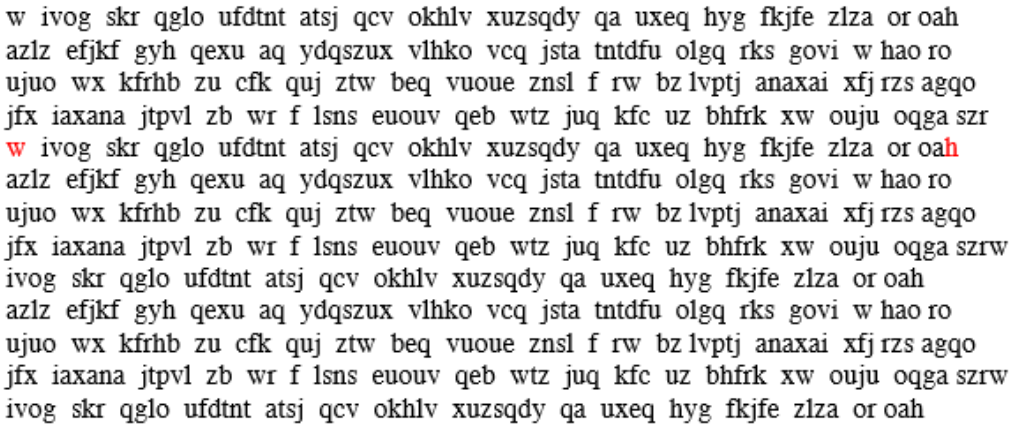

Figure 3.11 Comparative rate of reading speed test (CREST) Passage 1.

The passage is comprised of 13 lines with each line consisting of 60 letters. Participants were asked to read the 5th line from start to finish, indicated by a red character.

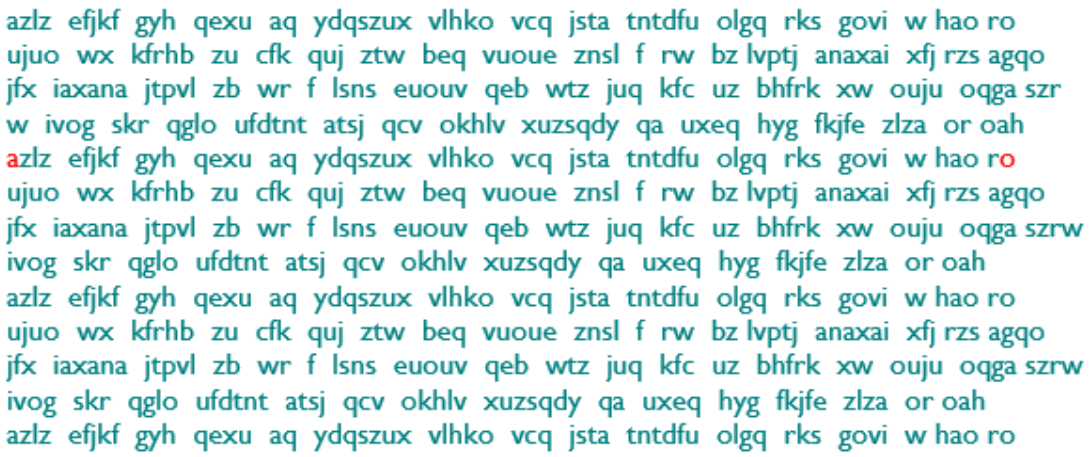

Figure 3.12 Comparative rate of reading speed test (CREST) Passage 2.

As passage 1, passage 2 contained 13 lines with each line containing 60 letters. Participants were asked to read the 5th line from start to finish, indicated by a red character.

The behavioural traits displayed by the participants when reading the passages were recorded. These traits are indications of a reading difficulty. (Panchagnula *et al.*, 2013).

The traits included were:

- Body or voice tremor
- Missing out letter characters
- Rapid fatiguing
- Losing the place or re-reading
- Reading characters inaccurately
- Inability to read more than a few characters if any
- Change of head posture
- Following the test with the finger or thumb
- Sighing when finishing the test
- Gripping the test card
- Facial contortions
- Marking the beginning of the line with the thumb
- Saying the characters phonetically
- The card starts to flop
- Test card held too far away (greater than 30 cm)
- Test card held too close (closer than 30 cm)
- Body becomes tense or tense breathing
- Heightened anxiety and excessive body movement

3.9.2 Results

CREST Passage 1 and 2 Reading Rate in seconds													
Passage	**Subject**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**SD**	**Average(s)**
Passage 1 (s)	**RD**	36	53	47	40	35	27	45	40	26	42	8.46	39.1
	NRD	27	24	32	29	24	33	35	29	30	25	3.82	28.8
Passage 2 (s)	**RD**	41	41	35	39	35	22	45	39	30	35	6.52	36.2
	NRD	27	23	27	28	20	30	25	31	26	21	3.61	25.8

Table 3.4. Comparative rate of reading speed test (CREST) results. Results presented for both passage 1 and passage 2 for both subject groups (reading difficulty and non – reading difficulty). The results are presented in average seconds. RD = Reading Difficulty, NRD = Non – Reading Difficulty.

Statistical analysis was carried out using an independent samples t-Test comparing the two different groups of subjects with reading difficulties (RD) and no reading difficulties (NRD) (Table 3.4). For passage 1, there was a significant difference in the reading scores for the RD subjects (mean = 39.1, SD = 8.46) and the NRD subjects (mean = 28.8, SD = 3.82); t (18) = 3.51, p = 0.003. For passage 2, there was also a significant difference in the reading scores for the RD subjects (mean = 36.2, SD = 6.53) and the NRD subjects (mean = 25.8, SD = 3.61); t (18) = 4.41, p = 0.00. The results show that there is a difference between reading date for those who have self-reported reading difficulties and those who do not. Additionally, both groups reported that the teal coloured text was easier to read compared to the black coloured text.

3.9.3 Discussion

The CREST test allowed a quantification of the reading ability of the subjects. Detecting traits which may be indicators of a reading difficulty are important whilst completing the CREST as this would further support the suspicion of a reading

difficulty. Yet, there may have been some experimental error as some traits displayed by the subject may have just been normal actions, rather than characteristics of a reading difficulty. Or the experimenter may have missed a genuine trait due to falsely detecting a trait when none or due to being occupied with measuring the reading rate of the subject. However, as the experimenter was indeed focused on the subject there was little chance that the traits have been missed or falsely accused. Most the participants did display traits correlated with having a reading difficulty throughout the test, which indicates that they were having difficulty throughout the passages.

To improve the reliability of the CREST examination, a video camera may be used to record the participant reading. This would enable to examiner to look back at the recording and to carefully analyse the traits displayed, as well as the reading rate.

Aside from the drawbacks, CREST is an excellent tool which enables the examiner to quantitively and qualitatively analyse the extent of the reading difficulty in the subject. Discomfort of the subject could be assessed as well as the speed of the reading, setting apart the subjects from those who do not have reading difficulties.

3.9.4 Wilkins Rate of Reading Test

The Wilkins Rate of Reading Test is used to measure the reading ability of the individual (Wilkins et all, 1996). The subjects are told to read the passage aloud as rapidly as possible, which contains randomly ordered 15 words. The letters were read over. The results were measured in rate per second (Table 3.5), therefore the number of words read per minute.

3.9.5 Results

Wilkins Rate of Reading Test in those with RD												
Subject	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**SD**	**Average**
Rate(s)	129	188	127	120	120	174	118	135	172	144	25.88	**142.7**
Errors	10	14	4	12	11	13	8	12	13	10	2.95	**10.7**
Wilkins Rate of Reading Test in those with NRD												
Subject	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**SD**	**Average**
Rate(s)	111	120	118	136	124	120	108	146	125	116	11.35	**122.4**
Errors	5	4	4	5	0	2	0	7	5	4	2.27	**3.6**

Table 3.5 Results of the Wilkins Rate of Reading Test. Statistical analysis using the independent t -Test stated that there is a significant difference in the reading score between the subjects with reading difficulties (Mean=142.70, SD=25.88) and subjects without reading difficulties (Mean=122.40, SD=11.35); t(18)=2.27, *p*=0.036.

3.9.6 Discussion

Wilkins *et al.* 1996 stated that fast readers can read up to four times quicker compared to slow readers when completing the Wilkins Rate of Reading test. My results indicate that fast readers can read twice quicker compared to slow readers. Generally, the errors which were noted during reading assessment were word

repetitions, omissions, replacement, reversal, incorrect words, long pauses, and mixing up the order of the words.

Although the Wilkins Rate of Reading test was originally used to assess the reading rate of children whilst using a colored overlay over the test, it is a sufficient test to screen for reading difficulties. This is because the reading test measures the quality of the reading and that is assessed by the number of errors during the reading. Those errors are all qualities of someone who does have a reading difficulty. Yet, the reading test may not be comparable to real life reading. The individual is asked to read as quickly and loudly as possible, something which is not asked for when reading in everyday life.

3.10 Reading Difficulty Screening Overall Discussion

Although several of the participants have had a previous diagnosis of dyslexia, all the subjects were treated as one group with self – reported reading difficulties to prevent differences within the group. This allows all the subjects to undertake the same screening tests which would allow the investigator to assess whether the group does indeed have reading difficulties, rather than having separate tests for those with a previous diagnosis. The screening tests confirmed that there are significant differences between the two groups of subjects with and without reading difficulties. The significant differences are present in the reading questionnaire as well as both reading assessment tests. In conclusion, the individuals with self-reported reading difficulties do indeed have reading difficulties, according to my screening tests.

3.11 Exclusion Criteria

The exclusion criteria used prior to psychophysical examination included visual

acuity, colour vision, visual field testing, and the assessment of binocular vision. The exclusion tests were applied to all 56 participants in the study.

3.11.1 Visual Acuity

To assess the visual acuity of the participant, the Freiburg visual acuity and contrast test (FrACT) was used (Bach, 1996; 2007). The FrACT uses the Landolt C optotype which after testing produces the resolution visual acuity (VA). 46 participants selected the orientation of the Ladolt C optotype by using a keyboard using their binocular vision. The stimuli were presented one at a time on the screen with eight possible orientations. Participants with a VA lower than 1 were excluded from the study. The maximum VA is 2, whereas a VA lower than 1 indicates poor VA. None of the 46 participants were excluded from the study as all the participants had a VA greater than 1. The average acuity score from the 56 participants was 1.6 out of 2 with an SD of 0.21.

3.11.2 Colour Vision

The Ishihara test for colour blindness was used to identify whether any of the participants had colour blindness. Participants were given 15 plates and each plate contained a varying degree of luminance and spatial noise (Figure 3.13). The participants task was to identify the numbers on each of the plates. A failure to identify more than four plates suggests a colour vision impairment. None of the 46 participants in the study incorrectly identified more than four plates, thus none of the subjects had colour vision defects. The average number of correct plates recognised by the 56 participants was 13 out of 15, with an SD of 1.57.

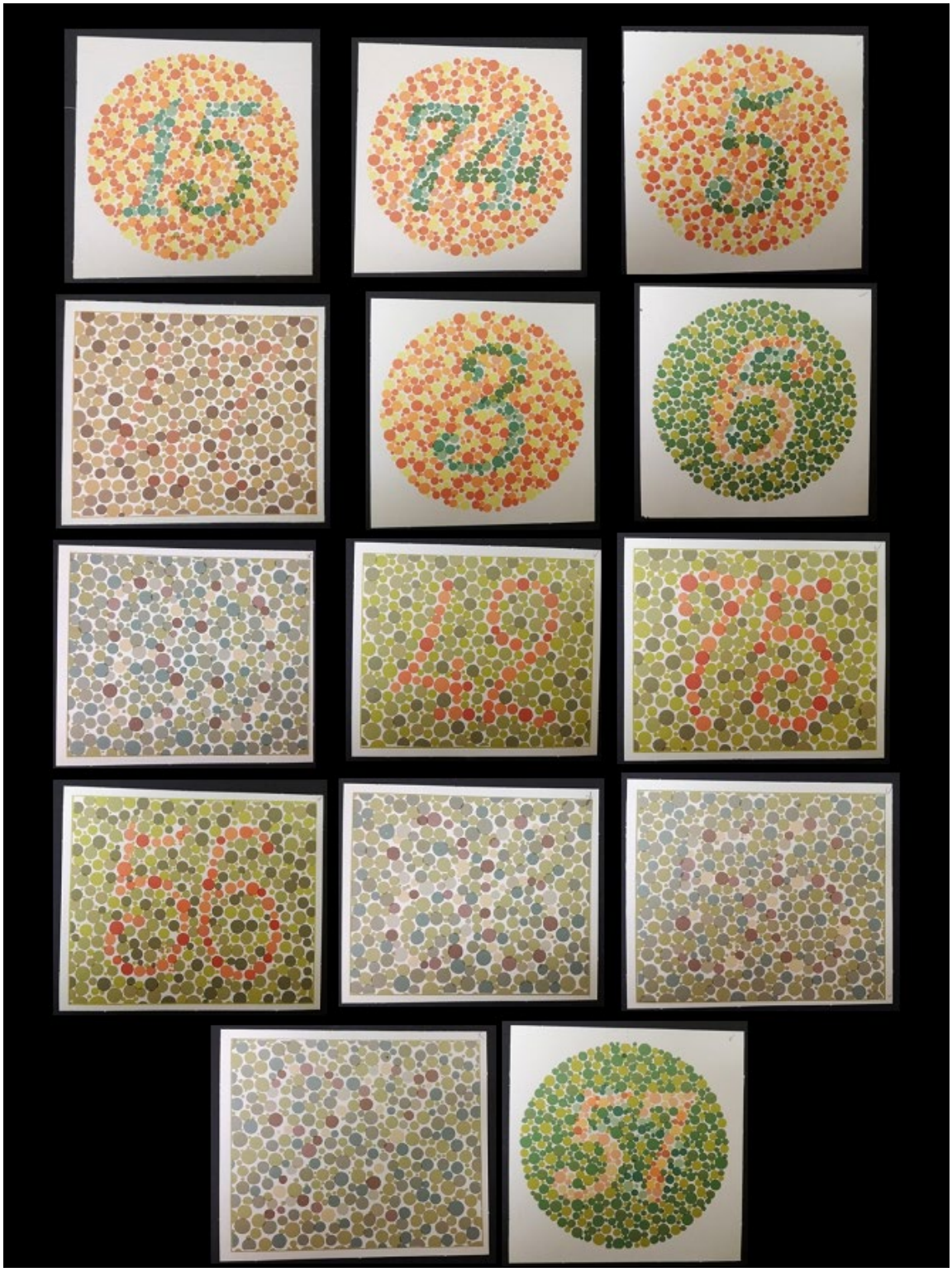

Figure 3.13 Ishihara Colour Plates.

A total of 15 different colour plates were used to assess whether the subject had colour vision defects. If more than 4 plates were incorrectly identified, then this is a suggestion of a colour vision impairment.

3.11.3 Visual Field

A manual perimeter was used to measure the participants visual field in brief. The perimeter ranged from 0 to 90 degrees which was positioned from the centre to the edge of the apparatus (Figure 3.14). Detection thresholds were measured to obtain the degree eccentricity. In total, there were 8 meridians on the horizontal plane (0° and 180°), vertical plane (90° and 270°), diagonal plane (45° and 225°) and lastly another diagonal plane (135° and 315°). During the examination, participants were asked to focus on a small mirror which was positioned in front of the at the centre of the manual perimeter. The non-experimental eye was closed to reduce error and a cheek rest was provided to minimise head movement. A long stick with a circle at the end of it was inserted at the end of the perimeter and moved downwards towards the centre. The participant indicated once their experimental eye saw the circle as then it is assumed that the stimulus has moved within their visual field.

None of the 56 participants had abnormalities in their visual field nor any unexpected blind spots. If they were to have abnormalities, this would Impair their binocular vision when completing the psychophysical experiments in the study.

Figure 3.14 Manual Perimeter.

A photograph of the perimeter which was used in the study. The perimeter was fixed onto a table and there is a cheek rest present to minimize head movement.

3.11.4 Binocular vision

Binocular vision was assessed using a series of tests for accommodation, oculomotility, and convergence. This ensured that the participants did not have impaired binocular vision and were fit to take part in the psychophysical tests.

3.11.4.1 Accommodation and Convergence

A budgie stick (Figure 3.15) was used to assess the accommodation and convergence of the participant's eyes. To test accommodation, participants were told to focus on the third line on the budge stick (T, H, C) and maintain fixation as the stick was moved by the examiner gradually towards their eyes. Once the image became blurry the participant indicated that point and then the distance was recorded. This is referred to as the near point of accommodation. None of the 56 participants tested had an abnormal near point of accommodation as they were all under the age of 50 and had the correct visual correction, if needed. For the near point of convergence to be measured, this was also completed using a budgie stick. As the budge stick came nearer to them, they had to maintain fixation on a certain detail such as the Police Officer. Once the image became double (diplopia), then they indicated, and this distance was the near point of convergence. None of the 56 participants had an abnormal near point of convergence.

Figure 3.15 Budgie Stick.

Image obtained from Louise Stone Optical (2017). A budgie stick is used in order to assess the participants near points of accommodation and convergence.

3.11.4.2 Oculomotility

Participants eye movements were tested by the examiner as they followed a specific target which was moving along 8 different radial angles. To ensure accuracy, the position of the head remained stationary. Throughout testing, none of the 56 participants presented with abnormal oculomotility.

3.11.4.3 Cover Test

The presence of heterophorias and/ or heterotropias was assessed by using the cover and alternating cover tests. Initially, the eyes were examined when uncovered to check for the correct alignment. Participants were told to maintain focus on a near point of fixation on the wall. Afterwards, one eye at a time was covered with a piece of paper which in result interrupted binocular vision. The alignment of the eye, which was uncovered, was then observed. Afterwards, the occlude was rapidly moved to cover the other eye, which was previously uncovered. The alignment of the eye which was just uncovered was then observed and recorded. The cover and alternating cover tests did not suggest any abnormal deviations of the eye, particularly the alignment in the 56 subjects.

3.11.5 Exclusion Criteria Discussion

The exclusion criteria enabled the investigator to identify any possible abnormalities of the visual function in the participants. If there were to be an abnormality, then that may have affected the performance as well as the reliability and accuracy of the experimental results. For instance, an oculomotility abnormality may have resulted in the participant's inability to maintain stable fixation on the central target which would, in result, reduce the reliability of the results drastically. Additionally, setting a cut off threshold for visual acuity results ensured that the participant could resolve the details

of the psychophysics Gabor's presented on screen. The visual field test was incredibly important as deficits in the visual fields would have resulted in the participant not being able to see the peripheral contrast sensitivity experiments presented on screen (10°) or central vision. This would have impaired their contrast sensitivity results for central and peripheral vision. If the participants were to have had irregularities in their convergence and accommodation, hen this may have influenced the ability of the participant to accurately and reliably accommodate and converge their vision onto the main fixation point.

Errors could have occurred during the exclusion criteria assessments, for instance boredom of the participants. The screening tests took a long time to complete, especially as they were repeated to ensure accuracy. Yet, the participants were given breaks in between the screening tests and the tests were engaging and generally brief. It is unlikely that the participant may have suffered from wandering attention throughout the test, as the participant was actively involved in participation rather than being passively involved, such as watching a long video.

Chapter 4 Results

4.1 Visual Function of Existing Gamers

The visual function of 17 existing gamers was examined using the MATLAB Psychophysics Toolbox to establish whether there is a change of contrast sensitivity in existing video game players, which is also referred to as visual training. Both action (n = 11) and casual (n = 6) video game players were examined to determine the difference in visual improvement, if any. This was compared to 9 controls (non-video game players). This experiment establishes whether video gaming does indeed result in a change of contrast sensitivity and whether there is a difference between gamers and non – gamers, as well as comparing two different game genres. The visual function parameters assessed were for:

- Central static contrast sensitivity
- Central temporal contrast sensitivity (20 Hz and 24 Hz)
- Peripheral static contrast sensitivity (5° eccentricity)
- Peripheral temporal contrast sensitivity (20 Hz and 24 Hz)

The results were presented as contrast sensitivity (log) across four spatial frequencies (0.5, 2, 10, and 20 cycles per degree in log form). Statistical analysis was carried out using repeated measures ANOVA and independent samples t-test with a 95% confidence interval. Statistical significance is identified as being $p < 0.05$.

The repeated measures ANOVA compared the results of all three groups in each visual function parameter (control, casual, and action gamers). For each parameter that showed a significant difference, t -Test was used to compare the means of three groups (control vs casual, control vs action, casual vs control) to

establish which groups were statistically different from each other and at which spatial frequency this difference occurred. An independent t – Test has been used if comparing two separate groups, whereas a paired t – Test has been used whilst comparing the same group.

4.1.1 Existing Gamers and Controls: Central Static Contrast Sensitivity

A graph (Figure 4.1) displays the contrast sensitivity results from the three groups as well as a table of central static contrast sensitivity values (Table 4.1).

4.1.1.1 Graph

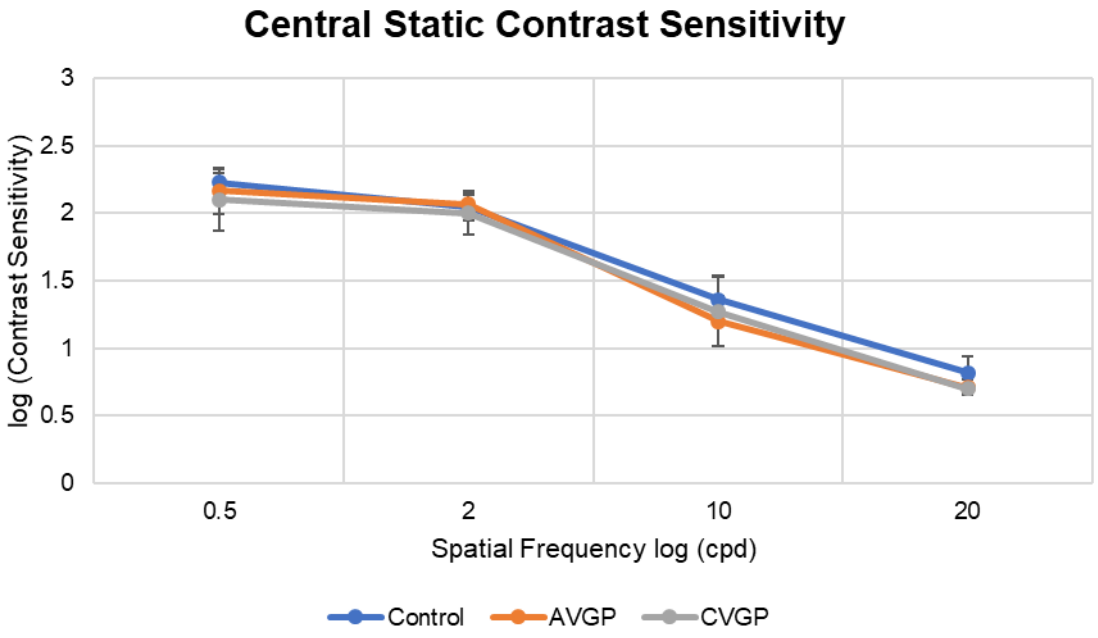

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Figure 4.1 Central Static Contrast Sensitivity Experiment 1

Central Static Contrast Sensitivity Graph in Existing Gamers. Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. AVGP = action video game player. CVGP= casual video game player. AVGP n = 11; CVGP n = 6; NVGP n = 9.

Central Static Contrast Sensitivity (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Control	**Mean CS**	2.23	2.05	1.34	0.82
	SD	0.11	0.15	0.27	0.19
AVGPs	**Mean CS**	2.17	2.07	1.20	0.71
	SD	0.29	0.11	0.31	0.10
CVGPs	**Mean CS**	2.10	2	1.27	0.70
	SD	0.28	0.20	0.32	0.04

Table 4.1 Central Static Contrast Sensitivity Experiment 1

Table showing the static contrast sensitivity results of existing video game players (action and casual) as well as controls. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. AVGP n = 11; CVGP n = 6; NVGP n = 9.

4.1.1.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 69) = 245.948, p = 0.00. Therefore, contrast sensitivity values change on changing spatial frequency. However, there is no significant effect of either of the three subject groups on contrast sensitivity values: F (6) = 0.716, p = 0.607. This suggests that none of the three groups differ from one another across all four spatial frequencies.

4.1.2 Existing Gamers and Controls: Central Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.2) displays the contrast sensitivity results from the three groups as well as a table of contrast sensitivity values (Table 4.2).

4.1.2.1 Graph

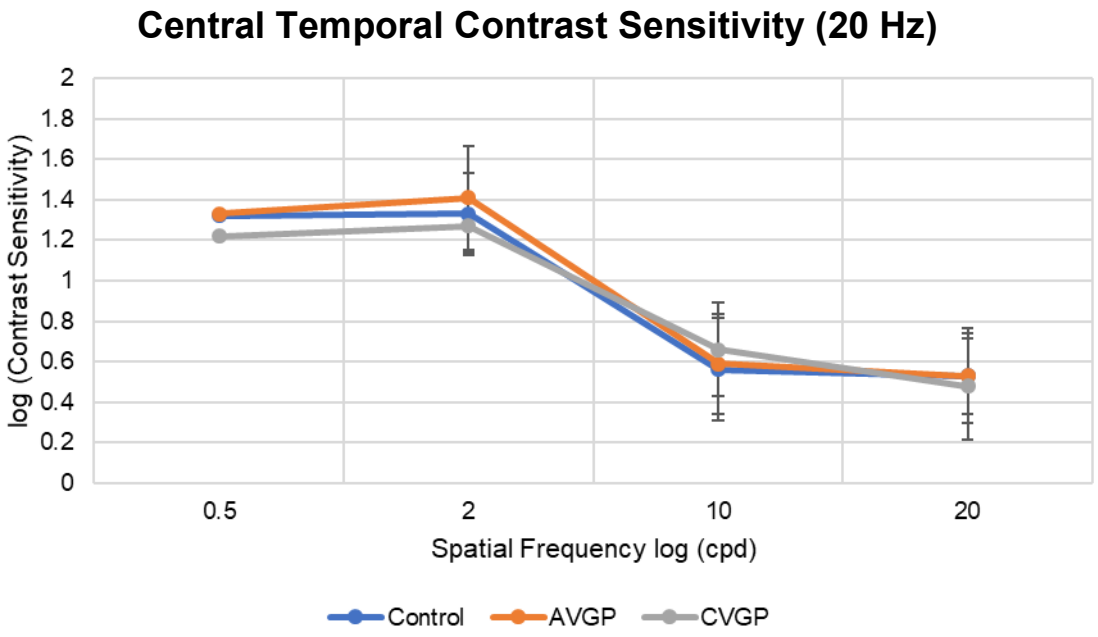

Figure 4.7 Central Temporal Contrast Sensitivity 20 Hz Experiment 1

Central Temporal contrast sensitivity (20 Hz) Graph in Existing gamers. Error bars show 95% confidence intervals. The graph shows an overlap of confidence intervals at all four spatial frequencies of all three groups. cpd = cycles per degree. AVGP = action video game player. CVGP = casual video game player. AVGP n = 11; CVGP n = 6; NVGP n = 9.

Central Temporal Contrast Sensitivity 20 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
AVGPs	**Mean CS**	1.46	1.57	0.63	0.57
	SD	0.34	0.10	0.18	0.19
CVGPs	**Mean CS**	1.30	1.42	0.67	0.60
	SD	0.37	0.27	0.15	0.19
Control	**Mean CS**	1.28	1.42	0.63	0.49
	SD	0.39	0.21	0.31	0.16

Table 4.4 Central Temporal Contrast Sensitivity 20 Hz Experiment 1

Table showing the temporal contrast sensitivity 20 Hz results of existing video game players (action and casual) as well as controls. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. AVGP n = 11; CVGP n = 6; NVGP n = 9.

4.1.2.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 69) = 110.352, p = 0.00. Therefore, contrast sensitivity values change on changing spatial frequency. However, there is no significant effect of either of the three subject groups on contrast sensitivity values: F (6) = 0.584, p = 0.698. This suggests that none of the three groups differed statistically significantly from one another across all four spatial frequencies.

4.1.3 Existing Gamers and Controls: Central Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.3) displays the contrast sensitivity results from the three groups as well as a table of contrast sensitivity values (Table 4.3)

4.1.3.1 Graph

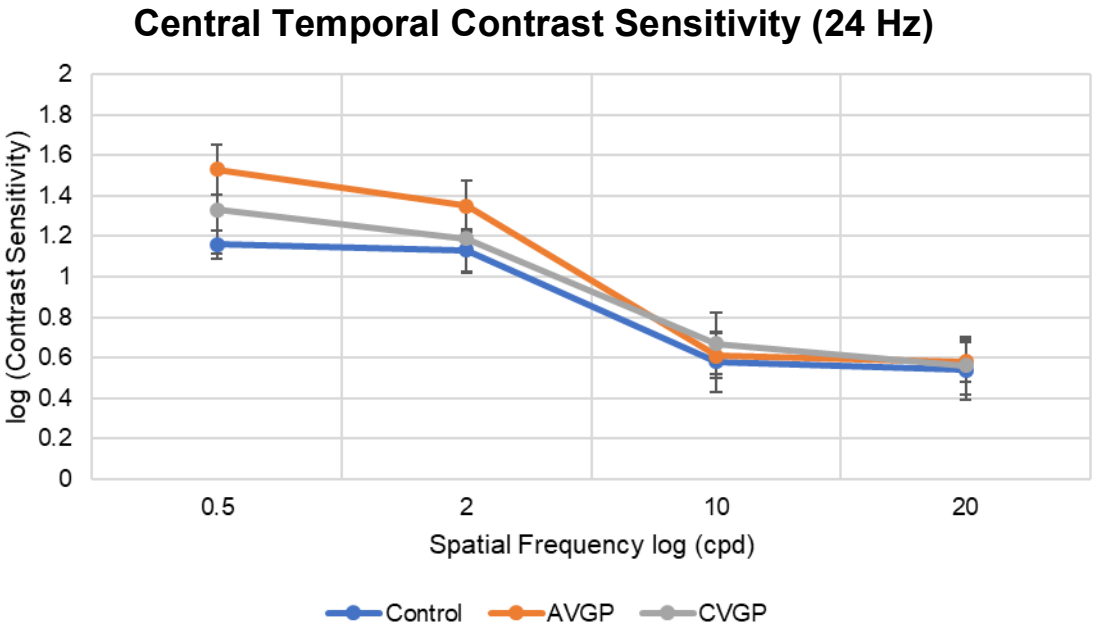

Figure 4.8 Central Temporal Contrast Sensitivity 24 Hz Experiment 1

Error bars show 95% confidence intervals. The graph shows an overlap of confidence intervals at all four spatial frequencies of all three groups. cpd = cycles per degree. AVGP = action video game player. CVGP = casual video game player. AVGP n = 11; CVGP n = 6; NVGP n = 9.

Central Temporal Contrast Sensitivity 24 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
AVGPs	**Mean CS**	1.53	1.35	0.61	0.58
	SD	0.21	0.21	0.19	0.17
CVGPs	**Mean CS**	1.33	1.19	0.667	0.56
	SD	0.27	0.21	0.19	0.18
Control	**Mean CS**	1.15	1.13	0.58	0.54
	SD	0.11	0.16	0.23	0.23

Table 4.6 Central Temporal Contrast Sensitivity 24 Hz Experiment 1

Table showing the temporal contrast sensitivity 24 Hz results of existing video game players (action and casual) as well as controls. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. AVGP n = 11; CVGP n = 6; NVGP n = 9.

4.1.3.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant change of contrast sensitivity values across the four varying spatial frequencies: F (3,63) = 214.313, p = 0.00. Therefore, contrast sensitivity values differ on changing spatial frequency. Additionally, there is a significant effect of subject group on contrast sensitivity values: F (6) = 3.826, p = 0.006. This suggests that there was a statistically significant difference between the three groups in terms of their contrast sensitivity values. To distinguish which of the groups were statistically significant from one another, a t – Test was conducted.

4.1.3.3 t – Test

Statistical analysis using an independent t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values across all four spatial frequencies between:

- Controls (mean = 1.17, SD = 0.11) and action (mean = 1.50, SD = 0.19) gamers at 0.5 cycles per degree (cpd): t (16) = 4.353, *p* = 0.000493.
- Controls (mean = 1.13, SD = 0.17) and action (mean = 1.33, SD = 0.22) gamers at 2 cpd: t (16) = 2.136, *p* = 0.048.

4.1.3.4 Comparing 20 Hz vs 24 Hz

A separate ANOVA was carried out to compare the results at temporal contrast sensitivities of 20 Hz and 24 Hz. The ANOVA reported that there is a significant effect of spatial frequency: F (2.213, 50.909) = 243.488, *p* = 0.000. This indicates that the contrast sensitivity values differ on changing spatial frequency. Additionally, there is a significant difference of contrast sensitivity values between the two varying spatial frequencies (20 Hz and 24 Hz) across the spatial frequencies: F (3, 69) = 6.492, *p* = 0.001. Therefore, the two different temporal frequencies will result in different contrast sensitivity values from each other as they each measure different flicker rates. Furthermore, there is significant difference between subject contrast sensitivity results in both temporal frequencies (20 Hz and 24 Hz) across spatial frequency F (6) = 2.311, *p* = 0.043. This specifies that there was a statistically significant difference in the results produced by 20 Hz and 24 Hz. In summary the analysis suggest that CS differs on each spatial frequency, 20 Hz and 24 Hz are two separate flicker rates, and that the tests produce different contrast sensitivity results, respectively.

4.1.4 Existing Gamers and Controls: Static Peripheral Contrast Sensitivity

A graph (Figure 4.4) displays the contrast sensitivity results from the three groups as well as a table of contrast sensitivity values (Table 4.4).

4.1.4.1 Graph

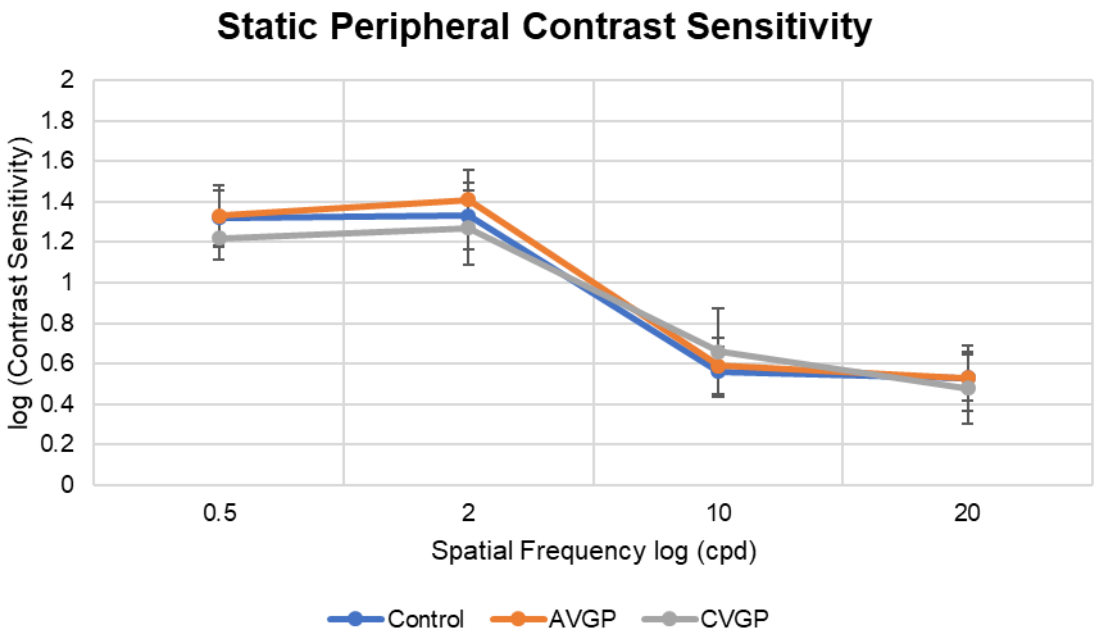

Figure 4.11 Static Peripheral Contrast Sensitivity Experiment 1

Error bars show 95% confidence intervals. The graph shows an overlap of confidence intervals at all four spatial frequencies of all three groups. cpd = cycles per degree. AVGP = action video game player. CVGP = casual video game player. AVGP n = 11; CVGP n = 6; NVGP n = 9.

Static Peripheral Contrast Sensitivity (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
AVGPs	**Mean CS**	1.33	1.41	0.59	0.53
	SD	0.26	0.25	0.24	0.19
CVGPs	**Mean CS**	1.22	1.27	0.66	0.48
	SD	0.13	0.23	0.26	0.22
Control	**Mean CS**	1.32	1.33	0.56	0.53
	SD	0.20	0.25	0.19	0.25

Table 4.7 Static Peripheral Contrast Sensitivity Experiment 1

Table showing the static peripheral contrast sensitivity results of existing video game players (action and casual) as well as controls. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players.

4.1.4.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (2.299, 52.866) = 109.568, p = 0.00. Therefore, contrast sensitivity values change on changing spatial frequency. However, there is no significant effect of either of the three subject groups on contrast sensitivity values: F (4.597) = 0.517, p = 0.748. This suggests that none of the three groups differed statistically significantly from one another across all four spatial frequencies.

4.1.5 Existing Gamers and Controls: Peripheral Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.5) displays the contrast sensitivity results from the three groups as well as a table of contrast sensitivity values (Table 4.5).

4.1.5.1 Graph

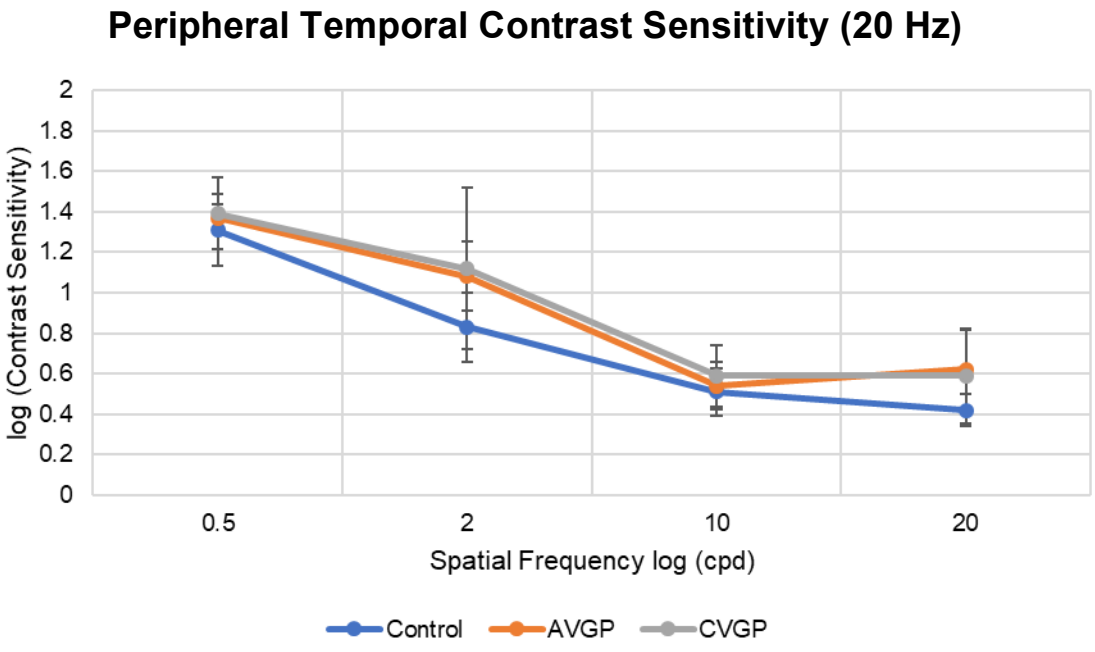

Figure 4.13 Peripheral Contrast Sensitivity 20 Hz Experiment 1

Error bars show 95% confidence intervals. The graph shows an overlap of confidence intervals at all four spatial frequencies of all three groups. cpd = cycles per degree. AVGP = action video game player. CVGP = casual video game player. AVGP n = 11; CVGP n = 6; NVGP n = 9.

Peripheral Temporal Contrast Sensitivity 20 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
AVGPs	**Mean CS**	1.37	1.08	0.54	0.62
	SD	0.11	0.29	0.20	0.12
CVGPs	**Mean CS**	1.39	1.12	0.59	0.59
	SD	0.22	0.50	0.19	0.29
Control	**Mean CS**	1.31	0.83	0.51	0.42
	SD	0.27	0.27	0.18	0.12

Table 4.8 Peripheral Temporal Contrast Sensitivity 20 Hz Experiment 1

Table showing the static peripheral contrast sensitivity results of existing video game players (action and casual) as well as controls. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. AVGP n = 11; CVGP n = 6; NVGP n = 9.

4.1.5.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: $F(3, 69) = 76.216$, $p = 0.00$. Therefore, contrast sensitivity values change on changing spatial frequency. However, there is no significant effect of either of the three subject groups on contrast sensitivity values: $F(6) = 0.654$, $p = 0.687$. This suggests that none of the three groups differed statistically significantly from one another across all four spatial frequencies.

4.1.6 Existing Gamers and Controls: Peripheral Temporal Contrast Sensitivity 24 Hz

Graph (Figure 4.6) displays the contrast sensitivity results from the three groups as well as a table of contrast sensitivity values (Table 4.6).

4.1.6.1 Graph

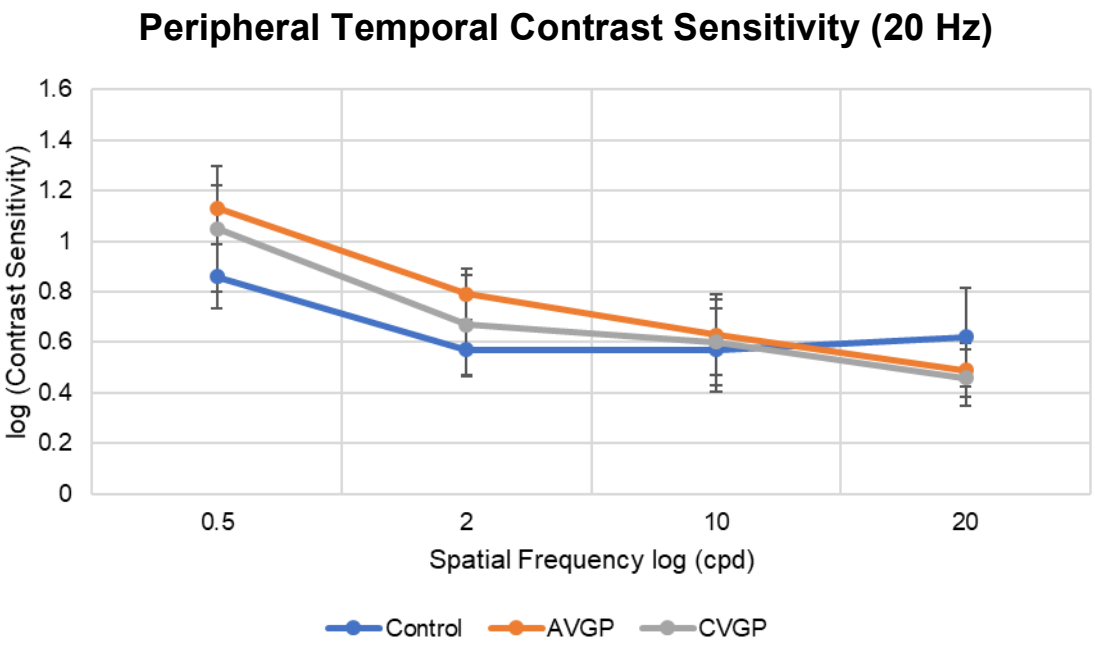

Figure 4.15 Peripheral Temporal Contrast Sensitivity 24 Hz Experiment 1

Error bars show 95% confidence intervals. The graph shows an overlap of confidence intervals at all four spatial frequencies of all three groups. cpd = cycles per degree. AVGP = action video game player. CVGP = casual video game player. AVGP n = 11; CVGP n = 6; NVGP n = 9.

Peripheral Temporal Contrast Sensitivity 24 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
AVGPs	**Mean CS**	1.13	0.79	0.63	0.49
	SD	0.15	0.17	0.27	0.18
CVGPs	**Mean CS**	1.05	0.67	0.59	0.46
	SD	0.31	0.25	0.21	0.14
Control	**Mean CS**	0.86	0.57	0.57	0.62
	SD	0.20	0.16	0.25	0.30

Table 4.9 Peripheral Temporal Contrast Sensitivity 24 Hz Experiment 1

Table showing the static peripheral contrast sensitivity results of existing video game players (action and casual) as well as controls. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players.

4.1.6.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 63) = 27.531, p = 0.00. Therefore, contrast sensitivity values change on changing spatial frequency. However, there is no significant effect of either of the three subject groups on contrast sensitivity values: F (6) = 2.114, p = 0.064. This suggests that none of the three groups differed statistically significantly from one another across all four spatial frequencies.

4.1.6.3 t – Test

Statistical analysis using an independent t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values across all four spatial frequencies between:

- Controls (mean = 0.88, SD = 0.20) and action (mean = 1.10, SD = 0.14) gamers: t (16) = 2.811, p = 0.013 at 0.5 cpd.
- Controls (mean = 0.57, SD = 0.17) and action (mean = 0.76, SD = 0.16) gamers: t (16) = 2.424, p = 0.028 at 2 cpd.

4.1.6.4 Comparing 20 Hz vs 24 Hz

A separate ANOVA was carried out to compare the results at peripheral contrast sensitivities of 20 Hz and 24 Hz. The ANOVA reported that there is a significant effect of spatial frequency: F (3, 69) = 95.040, p = 0.00. This indicates that the contrast sensitivity values differ on changing spatial frequency. Additionally, there is a significant difference of contrast sensitivity values between the two varying spatial frequencies (20 Hz and 24 Hz) across the spatial frequencies F (3, 69) = 13.223, p = 0.00. Therefore, the two different temporal frequencies will result in different peripheral contrast sensitivity values from each other as they each measure different flicker rates.

4.1.7 Discussion

Visual function experiments were conducted on existing action and casual video game players and controls (non-video game players) to identify whether there is an improvement in visual function after a minimum of 6 months of video game play. Statistical analysis using ANOVA established whether there was a statistically significant difference between the three groups, whilst an independent samples t – test identified which gaming group had the highest contrast sensitivity value and at which

spatial frequency. Below is a summary of the results produced by the repeated measures ANOVA for all six experiments (Table 4.7).

Experiment	Statistical Significance (ANOVA)
Central Static CS	Effect of spatial frequency (p = 0.000) No effect of either subject group CS on spatial frequency (p = 0.607)
Central Temporal CS 20 Hz	Effect of spatial frequency (p = 0.000) No effect of either subject group CS on spatial frequency (p = 0.698)
Central Temporal CS 24 Hz	Effect of spatial frequency (p = 0.000) Effect of a subject group CS on spatial frequency **(**p = 0.006)
Peripheral Static CS	Effect of spatial frequency (p = 0.000) No effect of either subject group CS on spatial frequency (p = 0.748)
Peripheral Temporal CS 20 Hz	Effect of spatial frequency (p = 0.000) No effect of either subject group CS on spatial frequency (p = 0.687)
Peripheral Temporal CS 24 Hz	Effect of spatial frequency (p = 0.000) No effect of either subject group CS on spatial frequency (p = 0.064)

Table 4.10 ANOVA Results Experiment 1

Table indicates which visual tests resulted in a statistical significance as well as non – statistical significance. CS = contrast sensitivity.

4.1.7.1 Central Static and Peripheral Static Contrast Sensitivity

Contrast sensitivity results for central static central vision did not differ between the three groups (p = 0.607) yet there was a statistically significant difference of contrast sensitivity values across all four spatial frequencies. The significant effect means that contrast sensitivity is different for each of the four spatial frequency values, as that is expected. This is expected as higher spatial frequency results in a lower contrast sensitivity, which is evident on the graphs. Yet, there was no difference between the three groups in terms of contrast sensitivity. This is likely because attention does not affect the shape of the static central contrast sensitivity curve (Carrasco *et al.,* 2000). This is likely to be the reason why AVGPs did not have higher contrast sensitivity for this experiment, which one may expect. In fact, none of the experiments in this thesis, in which central static contrast sensitivity was examined, provided a significant

difference in contrast sensitivity values. This is a good indicator that the psychophysical tests worked due to the significance across all the visual tests.

4.1.7.2 Temporal and Peripheral Contrast Sensitivity 20 & 24 Hz

To comprehend any changes in temporal vision (the ability of an individual to perceive motion), it is important to initially understand how moving images are produced on a screen. General video presented on screen is composed of still images (frames) that are captured repeatedly and then played back in fast sequence (frame rate). In video games, the frame rate refers to often the image on screen is updated with a new frame (image) and is measured as frames per second (fps). Games are generally played at 30 fps as a lower frame rate would result in a ‘choppy’ and ‘slow’ game play. Doom 3 has a maximum performance frame rate of 60 fps whilst Civilization 4 has a maximum performance frame rate of 20 – 60 fps (average of 40 fps). The frame rate of a casual game will be dependent on how much movement occurs in the game as the player must initiate steps to cause movement, compared to an action game which has constant movement. Due to Civilization 4 not being an action game, it requires a lower frame rate due to reduced playback frequency of images. If an action game is played using a frame rate of less than 30 fps this would result in ‘tearing’ in the game play,

All games are played on a screen which has a refresh rate and that depends on the screen that it is displayed on. Refresh rate is measured in Hertz (Hz) and 1 Hz is equivalent to one cycle per second as it is the exact number of times that the image displayed screen refreshes per second. The monitor used for the experiment had a refresh rate of 120 Hz. The two refresh rates measured for temporal and peripheral contrast sensitivity flicker were 20 Hz and 24 Hz, 24 Hz being a higher flicker rate.

Thus, the subjects could detect the flicker as it is a lower refresh rate compared to the screen refresh rate of 120 Hz.

Statistical analysis of temporal contrast sensitivity (24 Hz) using ANOVA indicated that there was a significant effect of differing subject group on contrast sensitivity 24 Hz (p = 0.006). Further analysis using the t – Test reported that there was a significant difference between the controls and the action gamers at 0.5 cycles per degree (cpd) (p = 0.000493) 1 cpd (p = 0.048) for central temporal contrast sensitivity 24 Hz. Therefore, there was a difference in the contrast sensitivity results between the controls (non – video game players) and the action gamers with the action gamers having a higher contrast sensitivity value. Furthermore, statistical analysis indicated that that there was a significant difference between the control and action gamers at 0.5 cycles per degree (p = 0.013) as well as a difference between the control and action gamers at 2 cycles per degree (p = 0.028) for the peripheral contrast sensitivity 24 Hz. These may be due to a large amount of attention used in action gaming, as visual attention increases contrast sensitivity (Motoyoshi, 2011). A summary table below indicates the statistically different contrast sensitivity values between controls and action gamers (Table 4.8).

Measurement	**Group & Significant Difference (t-Test)**	
	Action	**Casual**
Temporal CS 24 Hz	Control vs Action 0.5 cpd Control vs Action 2 cpd	-
Peripheral CS 24 Hz	Control vs Action 0.5 cpd Control vs Action 2 cpd	-

Table 4.11 t - Test Results Experiment 1

Table indicates which groups were statistically different from one another in terms of contrast sensitivity values. CS = contrast sensitivity. Cpd = cycles per degree.

During action gaming, more attentional capacity is required (Green *et al.,* 2012) which results in AVGPs performing the best at 24 Hz, which has a higher flicker rate than 20 Hz. During action gaming, the gamer constantly guesses where the enemy will appear on the screen, and when (Green & Bavelier, 2012) resulting in the gamer constantly predicting temporal events. Although not significantly different, casual gamers displayed higher mean sensitivity results compared to non-gamers for the temporal frequency of 24 Hz; this could be as casual gaming does require a certain amount of visual attention, yet significantly less than required in action gaming.

Additionally, the action gamers performed the best at peripheral contrast sensitivity 24 Hz, as proven by the statistical analysis. The peripheral test examined temporal vision at 10 degrees from fixation. 10 degrees is beyond the normal playing range, which is 0 – 5 degrees from fixation (Green & Bavelier 2003, 2007). Action video game players are also known to locate peripheral targets when they are presented on a field of distracting stimuli, compared to non-video game players.

4.1.7.3 Alternative Explanations

Alternative explanations for enhanced visual improvement in AVGPs include enhanced eye-hand motor coordination in AVGPS (Griffith *et al.,* 1983) as poor hand – eye motor coordination may result in the selection of the wrong side of the mouse during psychophysical testing.

Another alternative explanation is that AVGPs may have excellent vision compared to the casual and non-gamers, which results in the initiation of game play. An individual with poor vision may not want to play games as they will be unable to participate in the game play efficiently. To prevent this from occurring, participants' visual acuity will be tested before visual training in further experiments.

Thirdly, during game play, the action gamer will initiate a reward system which releases endogenous dopamine into the striatum (Koepp *et al.,* 1998). This is because the action video game is goal orientated and results in a reward when the goal is completed (Green & Bavelier, 2012). Casual gaming has a slower pace and thus the reward would take a longer time to achieve, compared to an action game which is fast paced.

Lastly, an enhanced visual function in AVGPs may be due to an increased amount of overall computer usage. Constant use of the Internet and other visual targets on screen improves the visual search speed. This allows the AVGP to perform at a much faster pace when attentional tasks are required (Owsley, 2011).

4.2 Three Month Training (120 hours)

As video game play has resulted in improvements in visual function, it is important to establish if a controlled visual training study can replicate the results. The experiment was conducted to identify whether playing video games for three months (120 hours) will result in an improvement in visual function. The visual function of four subjects was tested before and after video game training, also known as visual training. Participants undertook the training for a total of three months and over 120 hours (10 hours per week). The action game (n = 2) used was 'Doom 3' whilst the casual game (n = 2) used was 'Civilization 4'. A total of five subjects acted as controls. The visual function parameters assessed were for:

- Central static contrast sensitivity
- Temporal contrast sensitivity (20 Hz and 24 Hz)
- Peripheral static contrast sensitivity (5 degrees eccentricity)
- Peripheral contrast sensitivity (20 Hz and 24 Hz)

The results were presented as contrast sensitivity (log) across four spatial frequencies (0.5, 2, 10, and 20 cycles per degree). Statistical analysis was carried out using a repeated measures ANOVA with a 95% confidence interval. Statistical significance is noted as being $p = <0.05$.

The repeated measures ANOVA compared the results of all three groups in each visual function parameter (control, casual, and action gamers). For each parameter that showed a significant difference, the t – Test was used to compare the means of two groups (casual vs action) to establish which groups were statistically different from each other.

4.2.1 Three Month Training: Central Static Contrast Sensitivity

A graph (Figure 4.7) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.9).

4.2.1.1 Graph

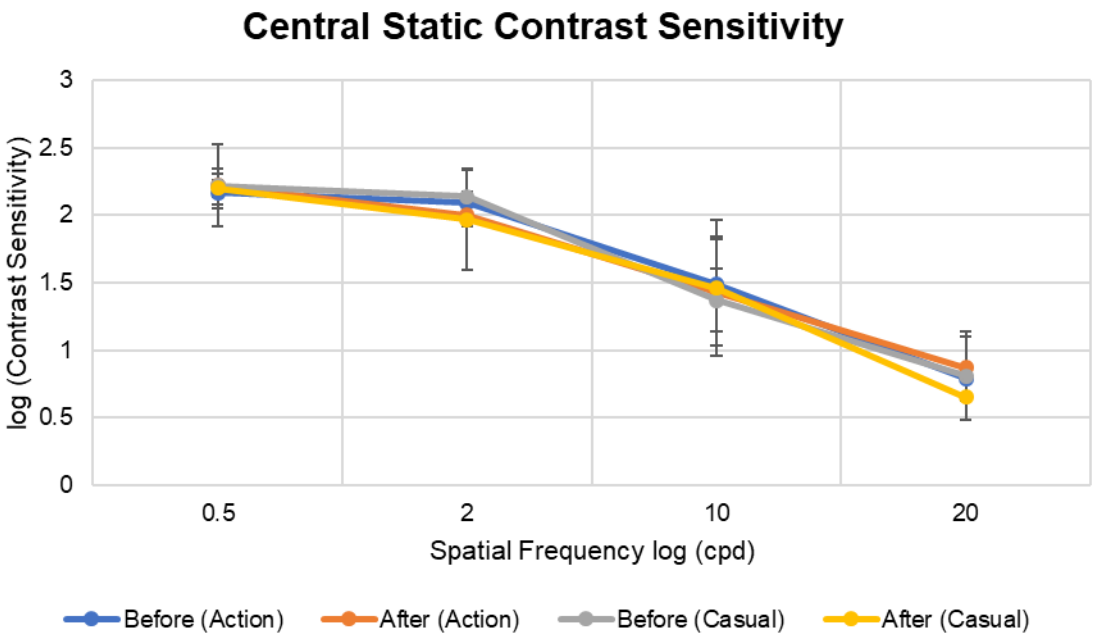

Figure 4.16 Central Static Contrast Sensitivity Experiment 2

bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Central Static Contrast Sensitivity (log)					
Group		Spatial Frequency log (cpd)			
		0.5	2	10	20
Before (AVGP)	Mean CS	2.17	2.09	1.49	0.79
	SD	0.06	0.06	0.26	0.22
After (AVGP)	Mean CS	2.22	2	1.42	0.86
	SD	0.06	0.06	0.28	0.18
Before (CVGP)	Mean CS	2.22	2.14	1.37	0.81
	SD	0.22	0.14	0.17	0.24
After (CVGP)	Mean CS	2.20	1.97	1.46	0.65
	SD	0.11	0.27	0.36	0.02

Table 4.12 Central Static Contrast Sensitivity Experiment 2

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Action n = 2, casual n = 2.

4.2.1.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 18) = 122.203, p = 0.00. Therefore, contrast sensitivity values change on changing spatial frequency. However, there is no significant effect of either of the three subject groups on contrast sensitivity values after visual training: F (1, 6) = 0.095 p = 0.768. This suggests that none of the groups differ from one another across all four spatial frequencies.

4.2.2 Three Month Training: Central Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.8) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.10).

4.2.2.1 Graph

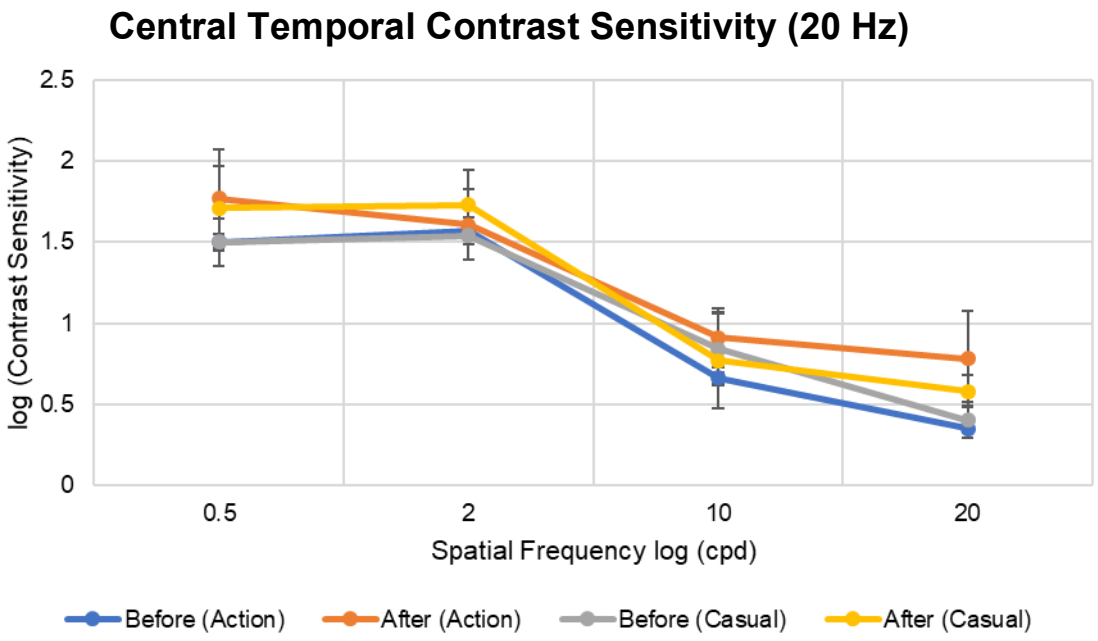

Figure 4.18 Temporal Contrast Sensitivity 20 Hz Experiment 2

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Central Temporal Contrast Sensitivity for 20 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.51	1.57	0.66	0.35
	SD	0.11	0.06	0.03	0.02
After (AVGP)	**Mean CS**	1.77	1.61	0.91	0.78
	SD	0.22	0.16	0.13	0.21
Before (CVGP)	**Mean CS**	1.50	1.54	0.84	0.40
	SD	0.04	0.04	0.16	0.08
After (CVGP)	**Mean CS**	1.71	1.73	0.76	0.58
	SD	0.19	0.16	0.21	0.07

Table 4.13 Central Temporal Contrast Sensitivity 20 Hz Experiment 2

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Action n = 2, casual n = 2.

4.2.2.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 18) = 69.294, $p = 0.00$. Therefore, contrast sensitivity values change on changing spatial frequency. However, there is no significant effect of either of the three subject groups on temporal contrast sensitivity (20 Hz) values after visual training: F (1, 6) = 5.837, $p = 0.052$. Thus, visual training did not enhance contrast sensitivity significantly for the participants. Thus, overall, there is no effect of visual training before and after across all four spatial frequencies.

4.2.3 Three Month Training: Central Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.9) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.11).

4.2.3.1Graph

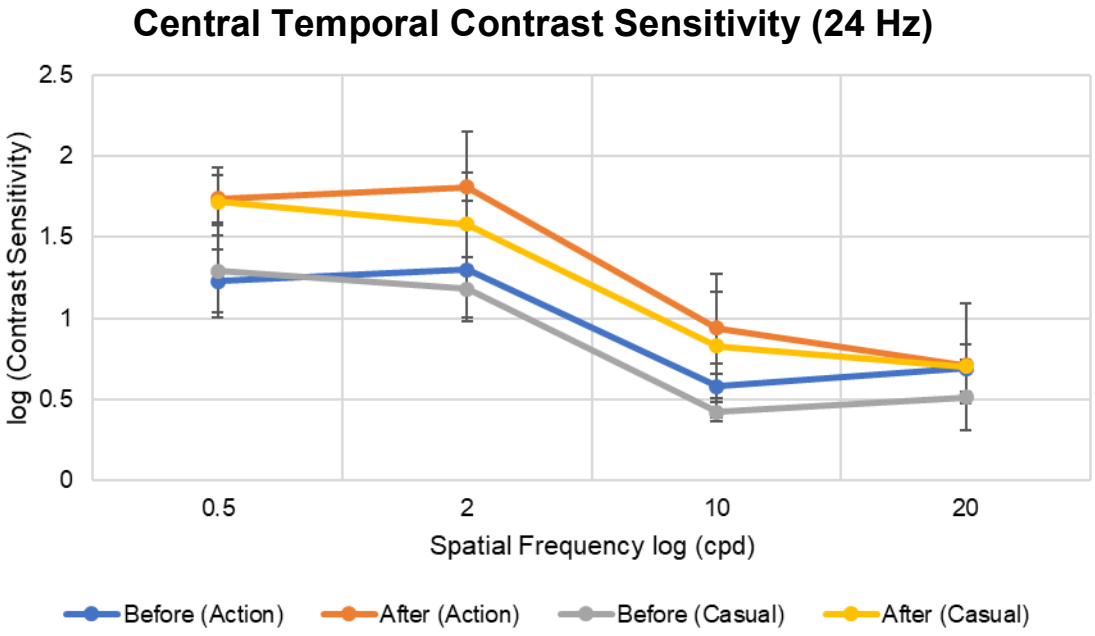

Figure 4.20 Central Temporal Contrast Sensitivity 24 Hz Experiment 2

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Central Temporal Contrast Sensitivity for 24 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	**2**	**10**	**20**
Before (AVGP)	**Mean CS**	1.22	1.30	0.58	0.69
	SD	0.14	0.02	0.05	0.12
After (AVGP)	**Mean CS**	1.74	1.81	0.94	0.71
	SD	0.11	0.06	0.16	0.03
Before (CVGP)	**Mean CS**	1.29	1.18	0.42	0.51
	SD	0.20	0.14	0.04	0.03
After (CVGP)	**Mean CS**	1.72	1.58	0.83	0.70
	SD	0.15	0.42	0.32	0.28

Table 4.14 Central Temporal Contrast Sensitivity 24 Hz Experiment 2

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Action n = 2, casual n = 2.

4.2.3.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 18) = 79.116, *p*= 0.00. Therefore, contrast sensitivity values change on changing spatial frequency. Additionally, there is a significant difference before and after video game play F (1, 6) = 42.644, *p* = 0.001 as well as a significant effect of the subject group on the contrast sensitivity values before and after training F (2) = 13.554, *p* = 0.006. This means that there was an improvement in visual function after visual training as well as certain groups visual training resulting in visual improvement. To confirm which group resulted in a visual improvement a t – Test is required.

4.2.3.3 t – Test

Statistical analysis using a paired t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values after visual training:

- Before (mean = 1.30, SD = 0.02) and after (mean = 1.81, SD = 0.6) action video game training at 2 cpd: t (1) = -16.200, p = 0.039.

4.2.4 Three Month Training: Static Peripheral Contrast Sensitivity

A graph (Figure 4.10) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.12).

4.2.4.1 Graph

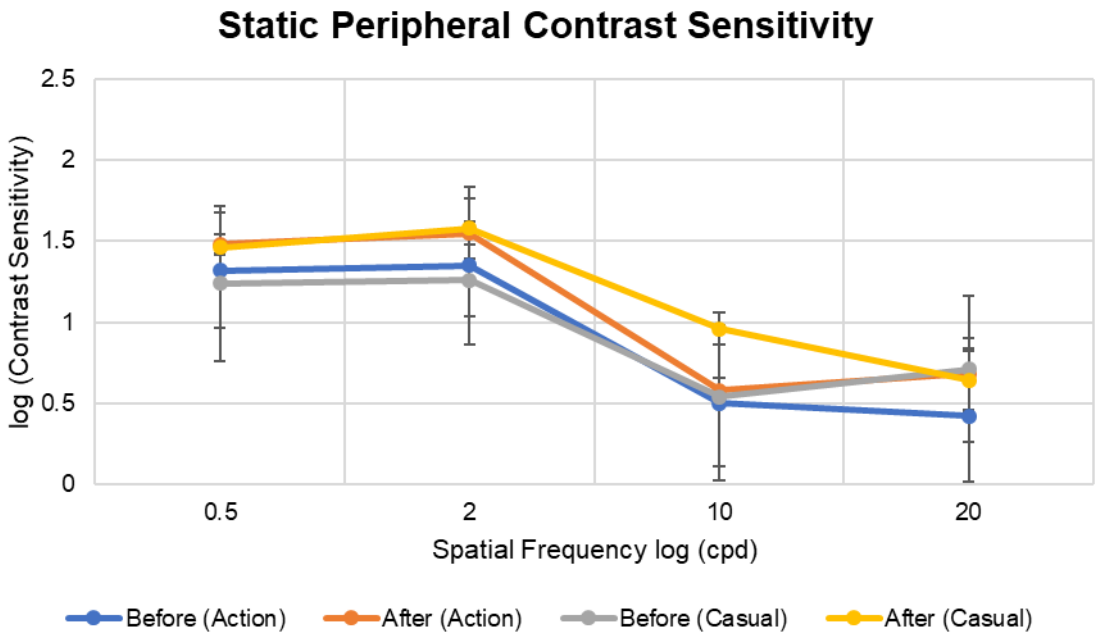

Figure 4.21 Static Peripheral Contrast Sensitivity Experiment 2

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Static Peripheral Contrast Sensitivity (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.32	1.35	0.49	0.42
	SD	0.26	0.35	0.34	0.29
After (AVGP)	**Mean CS**	1.48	1.55	0.58	0.68
	SD	0.06	0.07	0.07	0.22
Before (CVGP)	**Mean CS**	1.24	1.26	0.54	0.70
	SD	0.34	0.16	0.31	0.33
After (CVGP)	**Mean CS**	1.46	1.58	0.96	0.64
	SD	0.03	0.13	0.07	0.14

Table 4.15 Static Peripheral Contrast Sensitivity Experiment 2

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Action n = 2, casual n = 2.

4.2.4.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 18) = 46.653, p = 0.00. Yet, there was no overall significant difference before and after visual training F (1, 6) = 3.204, p = 0.124. Additionally, there is no significant effect of visual training on contrast sensitivity on the groups F (3, 18) = 0.732, p = 0.546. This indicates that visual training did not improve the contrast sensitivity for either groups.

4.2.5 Three Month Training: Peripheral Temporal Contrast Sensitivity for 20 Hz

A graph (Figure 4.11) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Figure 4.13).

4.2.5.1 Graph

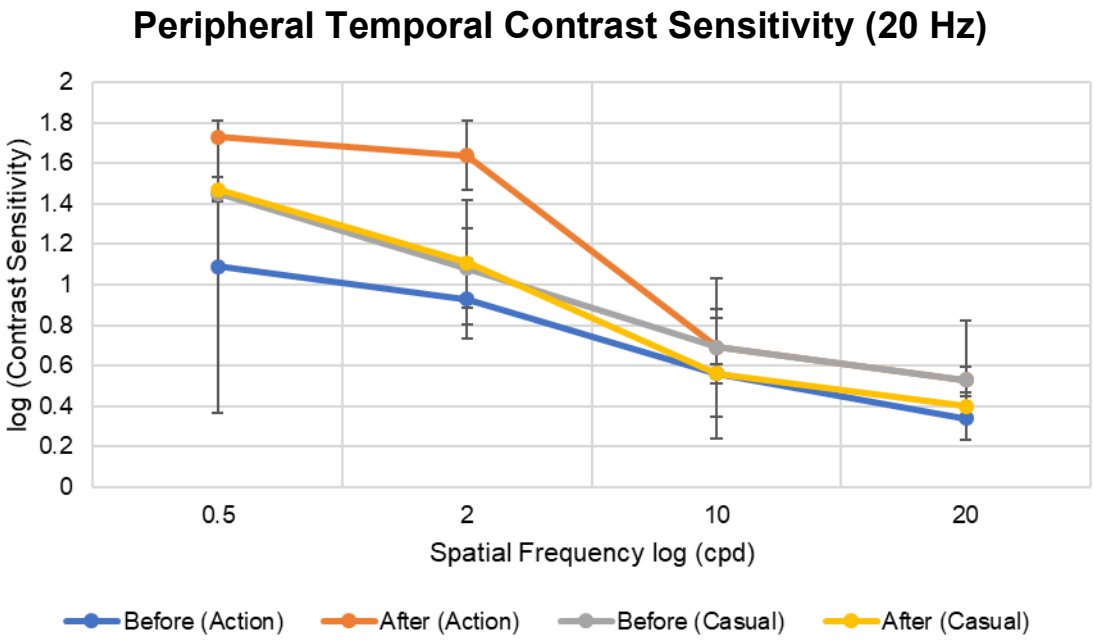

Figure 4.23 Peripheral Temporal Contrast Sensitivity 20 Hz Experiment 2

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Peripheral Temporal Contrast Sensitivity at 20 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.09	0.93	0.56	0.34
	SD	0.52	0.14	0.23	0.01
After (AVGP)	**Mean CS**	1.73	1.64	0.69	0.53
	SD	0	0.12	0.11	0.04
Before (CVGP)	**Mean CS**	1.45	1.08	0.69	0.52
	SD	0.02	0.14	0.25	0.21
After (CVGP)	**Mean CS**	1.47	1.11	0.56	0.40
	SD	0.04	0.22	0.04	0.04

Table 4.16 Peripheral Temporal Contrast Sensitivity 20 Hz Experiment 2

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Action n = 2, casual n = 2.

4.2.5.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (1.334, 8.006) = 39.065, p = 0.00. Additionally, there is no overall significant difference before and after training F (1, 6) = 5.313, p = 0.061. Yet, the analysis shows that there is a significant effect of training on the group F (3, 18) = 4.680, p = 0.014. To distinguish which group resulted in a statistically significant change after visual training, a t – Test is required.

4.2.5.3 t – Test

Statistical analysis using an independent t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values after visual training:

- After visual training between action (mean = 1.73, SD = 0.003) and casual (mean = 1.47, SD = 0.04) groups at 0.5 cycles per degree, t (2) = 8.247, *p* = 0.014.

4.2.6 Three Month Training: Peripheral Temporal Contrast Sensitivity at 24 Hz

A graph (Figure 4.12) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.14).

4.2.6.1 Graph

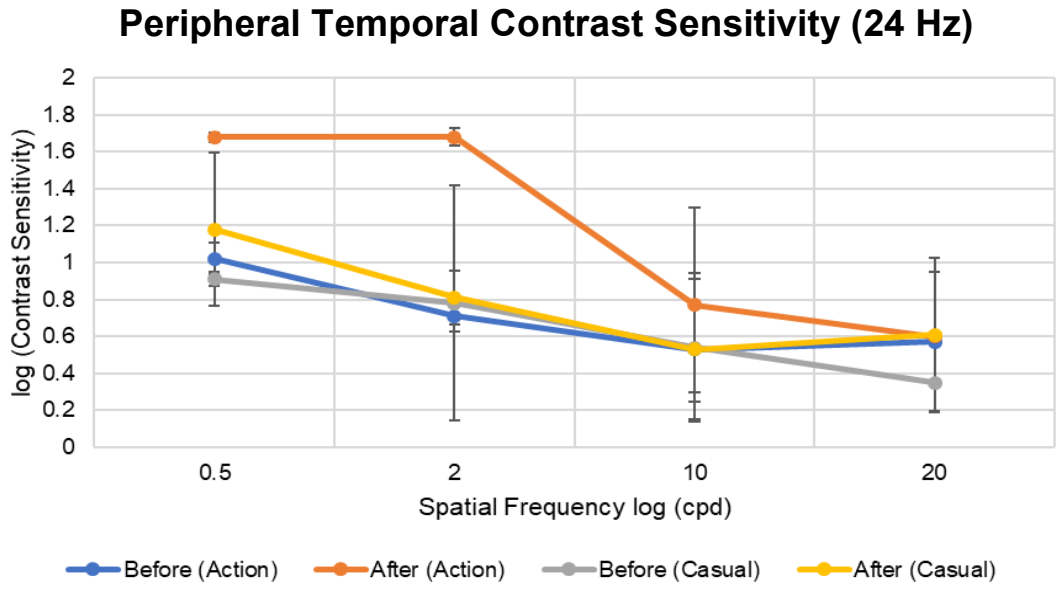

Figure 4.25 Peripheral Contrast Sensitivity 24 Hz Experiment 2

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Peripheral Temporal Contrast Sensitivity at 24 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	**2**	**10**	**20**
Before (AVGP)	**Mean CS**	1.02	0.71	0.53	0.57
	SD	0.06	0.06	0.28	0.28
After (AVGP)	**Mean CS**	1.68	1.68	0.77	0.57
	SD	0.02	0.04	0.38	0
Before (CVGP)	**Mean CS**	0.91	0.78	0.54	0.35
	SD	0.03	0.46	0.29	0
After (CVGP)	**Mean CS**	1.18	0.81	0.53	0.61
	SD	0.30	0.11	0.17	0.30

Table 4.17 Peripheral Temporal Contrast Sensitivity 24 Hz Experiment 2

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Action n = 2, casual n = 2.

4.2.6.2 Repeated Measures ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 18) = 12.208, p = 0.00. Additionally, there is an overall statistically significant difference before and after training F (1, 6) = 17.509, p = 0.006 as well as a significant effect of the subject group on contrast sensitivity before and after training F (6) = 2.966, p = 0.034. This means that visual training did improve the contrast

sensitivity and the improvement is dependent on the group. In order to find out which group resulted in a statistically significant contrast sensitivity value, a t – Test is required.

4.2.6.3 t – Test

Statistical analysis using a paired and independent samples t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values after visual training:

- Before (mean = 1.02, SD = 0.06) and after (mean = 1.68, SD = 0.02) action visual training at 0.5 cycles per degree, t (1) = -21.000, *p* = 0.030 (paired t – Test)
- before (mean = 0.71, SD = 0.06) and after (mean = 1.68, SD = 0.04) action visual training at 2 cycles per degree, t (1) = -51.667, *p* = 0.012 (paired t – Test)
- Contrast sensitivity results after visual training between action (mean = 1.68, SD = 0.04) and casual (mean = 0.81, SD = 0.11) groups at 2 cycles per degree, t (2) = 10.910, *p* = 0.008 (independent t – Test)

4.2.7 Discussion

Measurement	Statistical Significance				
	ANOVA	**t- Test 0.5 cpd**	**t – Test 2 cpd**	**t – Test 10 cpd**	**t – Test 20 cpd**
Static Central CS	-	-	-	-	-
Central Temporal CS 20 Hz	-	-	-	-	-
Central Temporal CS 24 Hz	p = 0.001 (training) p = 0.006 (group)	-	Action, p=0.039 (before vs after)	-	-
Peripheral CS	-	-	-	-	-
Peripheral Temporal CS 20 Hz	p = 0.014 (group)	Action vs Casual, p=0.014 (after vs after)	-	-	-
Peripheral Temporal CS 24 Hz	p = 0.006 (training) p = 0.034 (group)	Action, p=0.03 (before vs after)	Action, p=0.012 (before vs after) Action vs Casual, p=0.008 (after vs after)	-	-

Table 4.18 Statistical Results Experiment 2

Table shows the statistically significant results using both the repeated measures ANOVA and the independent t – Test. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. '-'signifies no statistical significance found.

As the controls did not take part in any visual training over the three-month period, it was possible to examine whether visual function stays the same over that period for a healthy individual. None of the tests resulted in a significance for the controls, thus their visual function was stable throughout the three – month period. Therefore, any change in contrast sensitivity is not due to visual function fluctuating, but rather due to visual training. In result, we can proceed to examine the contrast sensitivity results after the visual training period as we have now established that they will be due to training and not due to chance.

The results have shown that visual training using an action game resulted in more visual improvements compared to the use of a casual game (Table 4.15). Action

games resulted in a statistical improvement of visual function in temporal contrast sensitivity at 24 Hz, peripheral contrast sensitivity at 20 Hz and 24 Hz whereas casual gaming did not result in any improvements of visual function.

4.3 One Month Training (40 hours)

As three-month (120 hour) training has proven to be effective in the improvement of visual function, it is important to establish whether that improvement can be noticed in a shorter training period. The visual function of 16 subjects was tested before and after video game training. Participants undertook the training for a total of one month and over 40 hours. The action game used was Doom (n = 5) and the casual game used was Civilization 4 (n = 6). The remaining 4 participants were controls who did not undertake any visual training during the 1-month period. The visual function parameters assessed were for:

- Central static contrast sensitivity
- Temporal contrast sensitivity (20 Hz and 24 Hz)
- Static peripheral static contrast sensitivity (5° eccentricity)
- Peripheral contrast sensitivity (20 Hz and 24 Hz)

The results were presented as contrast sensitivity (log) across four spatial frequencies (0.5, 2, 10, and 20 cycles per degree). Statistical analysis was carried out using a repeated measures ANOVA with a 95% confidence interval. Statistical significance is noted as being $p = <0.05$. The repeated measures ANOVA compared the results of all three groups in each visual function parameter (control, casual, and action gamers). For each parameter that showed a significant difference, the independent samples T -test was used to compare the means of two groups (casual vs action) to establish which groups were statistically different from each other.

4.3.1 One Month Training: Central Static Contrast Sensitivity

A graph (Figure 4.13) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.16).

4.3.1.1 Graph

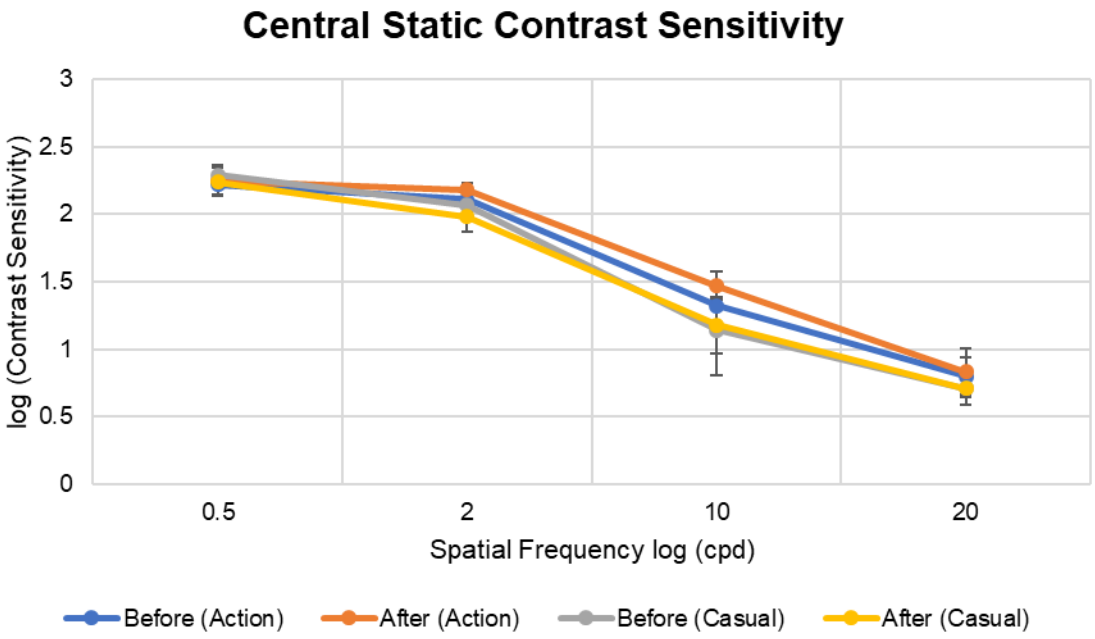

Figure 4.26 Central Static Contrast Sensitivity Experiment 3

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Doom n = 5, Civilization n = 6.

Central Static Contrast Sensitivity (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	**2**	**10**	**20**
Before (AVGP)	**Mean CS**	2.22	2.11	1.32	0.80
	SD	0.10	0.12	0.20	0.17
After (AVGP)	**Mean CS**	2.25	2.18	1.47	0.83
	SD	0.12	0.06	0.13	0.22
Before (CVGP)	**Mean CS**	2.29	2.07	1.14	0.71
	SD	0.09	0.12	0.38	0.07
After (CVGP)	**Mean CS**	2.24	1.98	1.18	0.71
	SD	0.03	0.12	0.24	0.14

Table 4.19 Central Static Contrast Sensitivity Experiment 3

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Doom n = 5, Civilization n = 6.

4.3.1.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 39) = 255.261, p = 0.000. Therefore, contrast sensitivity values change on changing spatial frequency. Yet, there is no significant effect of visual training on the contrast sensitivity values F (1, 13) = 2.750, p = 0.121. In result, visual training did not improve the contrast sensitivity values of central static vision which is expected.

4.3.2 One Month Training: Central Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.14) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.17).

4.3.2.1 Graph

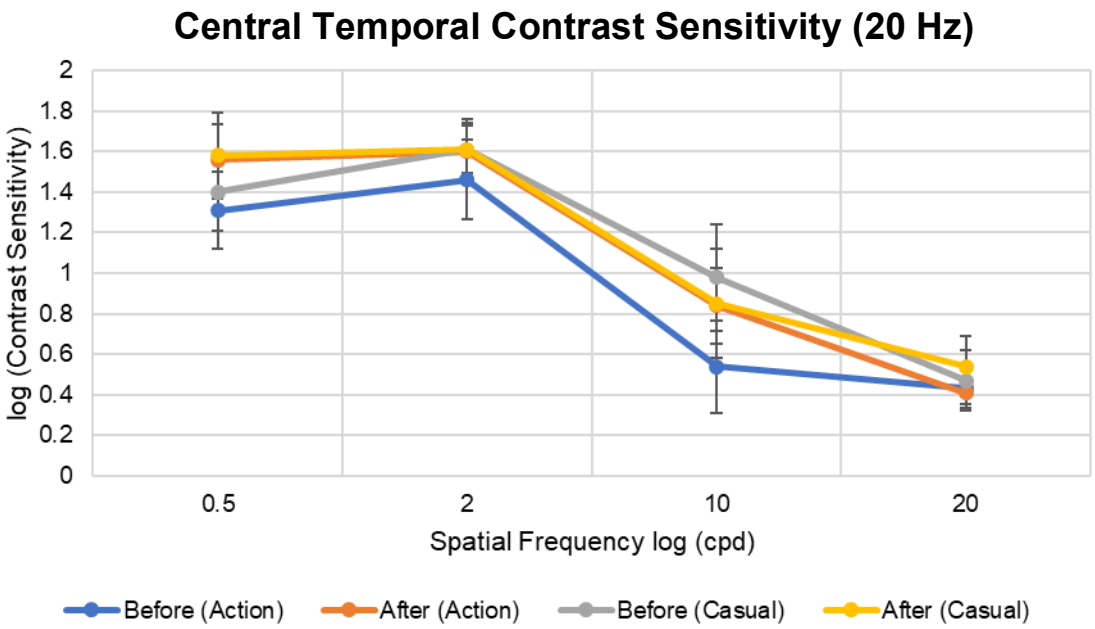

Figure 4.28 Central Temporal Contrast Sensitivity 20 Hz Experiment 3

Confidence bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Doom n = 5, Civilization n = 6.

Central Temporal Contrast Sensitivity 20 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	**2**	**10**	**20**
Before (AVGP)	**Mean CS**	1.31	1.46	0.55	0.43
	SD	0.24	0.25	0.28	0.12
After (AVGP)	**Mean CS**	1.56	1.60	0.84	0.41
	SD	0.22	0.18	0.21	0.06
Before (CVGP)	**Mean CS**	1.40	1.63	0.98	0.47
	SD	0.22	0.13	0.30	0.17
After (CVGP)	**Mean CS**	1.58	1.61	0.85	0.54
	SD	0.24	0.15	0.31	0.17

Table 4.20 Central Temporal Contrast Sensitivity 20 Hz Experiment 3

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Doom n = 5, Civilization n = 6.

4.3.2.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 39) = 128.435, p = 0.00. However, there was an effect of the subject group on the contrast sensitivity values before and after training F (2) = 5.415, p = 0.019. This suggests that the two groups differed statistically in their values. Yet, there is no overall significant effect of training on the contrast sensitivity values F (1, 13) = 3.470, p = 0.085.

4.3.3 One Month Training: Central Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.15) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.18).

4.3.3.1 Graph

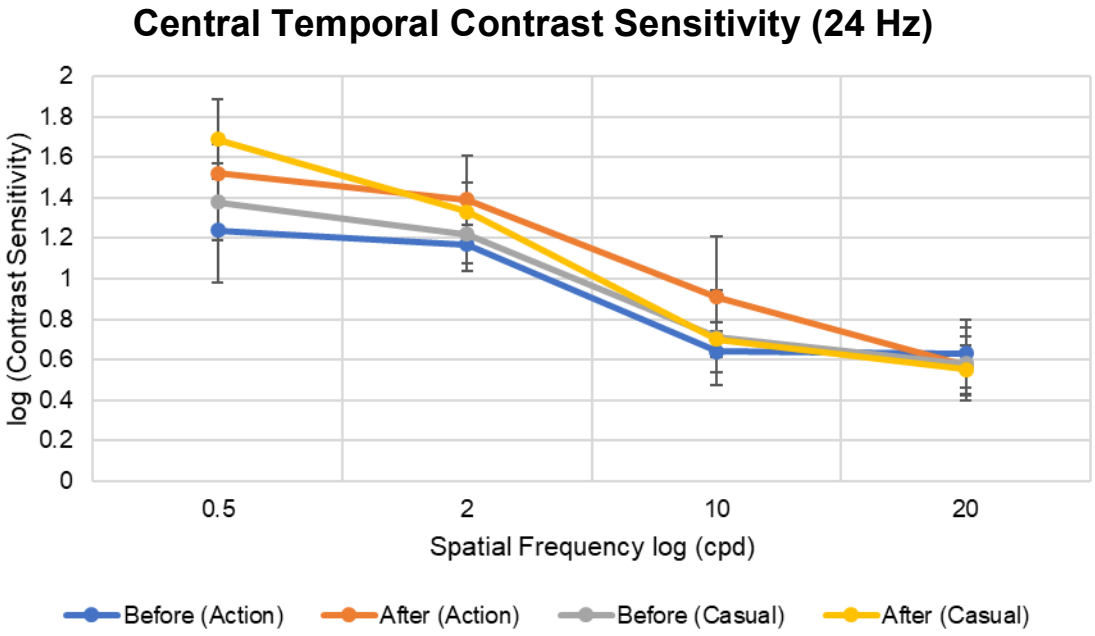

Figure 4.30 Central Temporal Contrast Sensitivity 24 Hz Experiment 3

(Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Doom n = 5, Civilization n = 6.

Central Temporal Contrast Sensitivity 24 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	**2**	**10**	**20**
Before (AVGP)	**Mean CS**	1.24	1.17	0.64	0.63
	SD	0.32	0.12	0.13	0.21
After (AVGP)	**Mean CS**	1.52	1.39	0.91	0.57
	SD	0.24	0.23	0.30	0.22
Before (CVGP)	**Mean CS**	1.38	1.22	0.71	0.58
	SD	0.22	0.21	0.27	0.21
After (CVGP)	**Mean CS**	1.69	1.33	0.70	0.55
	SD	0.22	0.16	0.10	0.13

Table 4.21 Central Temporal Contrast Sensitivity 24 Hz Experiment 3

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Doom n = 5, Civilization n = 6.

4.3.3.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (1.966, 25.562) = 132.400, p = 0.000. Additionally, there is an overall improvement of contrast sensitivity after the visual training F (1, 13) = 7.950, p = 0.014. As well, there is a change of contrast sensitivity values after the visual training which is significant in value across all four spatial frequencies F (2.645, 34.390) = 3.057, p = 0.047. In order to specify which group resulted in a change of contrast sensitivity, a t - Test is conducted.

4.3.3.3 t – Test

Statistical analysis using s paired samples t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values after visual training:

- Before (mean = 1.15, SD = 0.13) and after (mean = 1.44, SD = 0.24) action visual training at 2 cycles per degree, t (4) = -3.770, p = 0.020.

4.3.4 One Month Training: Static Peripheral Contrast Sensitivity

A graph (Figure 4.16) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.19).

4.3.4.1 Graph

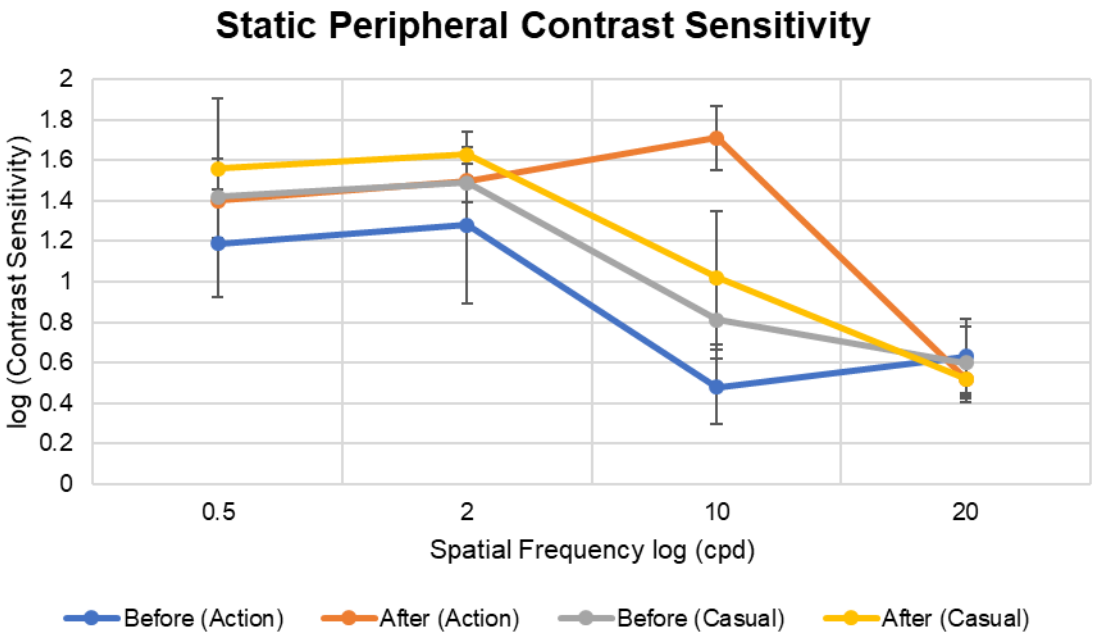

Figure 4.31 Static Peripheral Contrast Sensitivity Experiment 3

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Doom n = 5, Civilization n = 6.

Static Peripheral Contrast Sensitivity					
Group		Spatial Frequency (cpd)			
		0.5	2	10	20
Before (AVGP)	Mean CS	1.19	1.28	0.48	0.63
	SD	0.34	0.49	0.23	0.23
After (AVGP)	Mean CS	1.40	1.50	0.71	0.52
	SD	0.26	0.12	0.18	0.13
Before (CVGP)	Mean CS	1.42	1.49	0.81	0.60
	SD	0.04	0.11	0.21	0.20
After (CVGP)	Mean CS	1.56	1.63	1.02	0.52
	SD	0.39	0.13	0.38	0.10

Table 4.22 Static Peripheral Contrast Sensitivity Experiment 3

Table showing the static contrast sensitivity results before and after video game training after three months in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Doom n = 5, Civilization n = 6.

4.3.4.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies: F (3, 39) = 113.182, p = 0.000. Additionally, there is a significant change in contrast sensitivity values across the spatial frequencies after the visual training F (3, 39) = 3.277, p = 0.031. A t -Test indicates which group resulted in a significant change after visual training.

4.3.4.3 t – Test

Statistical analysis using an independent t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values after visual training:

- Contrast sensitivity before visual testing for action (mean = 0.41, SD = 0.15) and casual (mean = 0.80, SD = 0.22) groups at 10 cycles per degree, t (9) = -3.343, p = 0.009.

4.3.5 One Month Training: Peripheral Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.17) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.20).

4.3.5.1 Graph

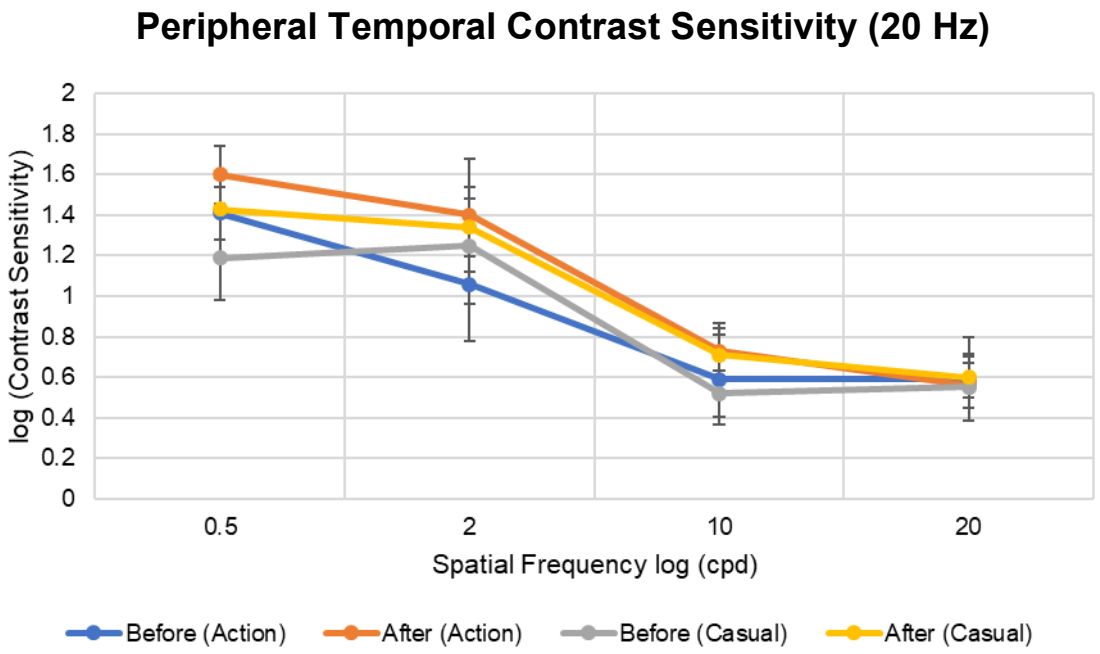

Figure 4.33 Peripheral Temporal Contrast Sensitivity 20 Hz Experiment 3

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Doom n = 5, Civilization n = 6.

Peripheral Temporal Contrast Sensitivity 20 Hz					
Group		Spatial Frequency (cpd)			
		0.5	2	10	20
Before (AVGP)	Mean CS	1.41	1.06	0.59	0.59
	SD	0.16	0.35	0.28	0.26
After (AVGP)	Mean CS	1.60	1.40	0.73	0.56
	SD	0.18	0.32	0.16	0.12
Before (CVGP)	Mean CS	1.19	1.25	0.52	0.55
	SD	0.24	0.33	0.13	0.19
After (CVGP)	Mean CS	1.43	1.34	0.71	0.60
	SD	0.18	0.16	0.15	0.11

Table 4.23 Peripheral Temporal Contrast Sensitivity 20 Hz Experiment 3

Table showing the static contrast sensitivity results before and after video game training after one month in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players.

4.3.5.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (1.722, 22.384) = 90.522, *p* = 0.000. Additionally, there is a significant overall difference before and after visual training F (1, 13) = 8.098, *p* = 0.014. As well, there is a significant interaction between the subject group and the visual training F (2) = 3.787, *p* = 0.05. To identify the group which resulted in a statistically significant change, a t – Test is required.

4.3.5.3 t – Test

Statistical analysis using a paired t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values after visual training:

- Before (mean = 0.52, SD = 0.12) and after (mean = 0.70, SD = 0.12) casual visual training at 10 cycles per degree, t (5) = -2.669, p = 0.024.

4.3.6 One Month Training: Peripheral Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.18) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Figure 4.21).

4.3.6.1 Graph

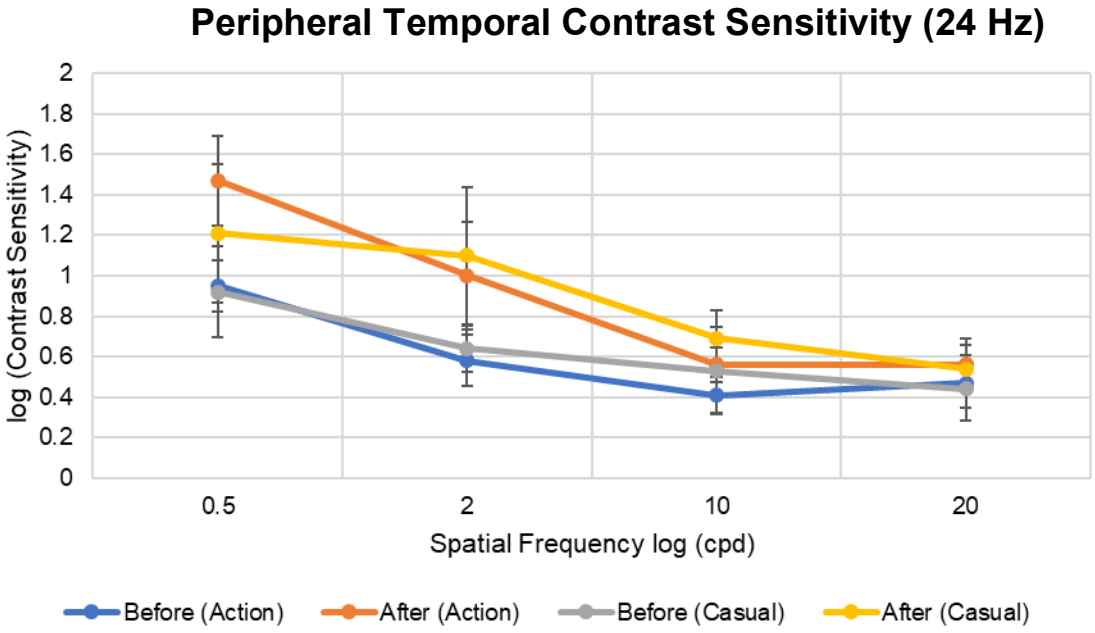

Figure 4.35 Peripheral Contrast Sensitivity 24 Hz Experiment 3

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Doom n = 5, Civilization n = 6.

Peripheral Temporal Contrast Sensitivity 24 Hz					
Group		**Spatial Frequency (cpd)**			
		0.5	**2**	**10**	**20**
Before (AVGP)	**Mean CS**	0.95	0.58	0.41	0.47
	SD	0.16	0.16	0.11	0.23
After (AVGP)	**Mean CS**	1.47	1.00	0.56	0.56
	SD	0.28	0.31	0.10	0.15
Before (CVGP)	**Mean CS**	0.92	0.64	0.53	0.44
	SD	0.26	0.13	0.25	0.10
After (CVGP)	**Mean CS**	1.21	1.10	0.68	0.54
	SD	0.39	0.39	0.16	0.08

Table 4.24 Peripheral Temporal Contrast Sensitivity 24 Hz Experiment 3

Table showing the static contrast sensitivity results before and after video game training after one month in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Doom n = 5, Civilization n = 6.

4.3.6.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (3, 39) = 31.907, p = 0.00. Additionally, there is a significant difference in contrast sensitivity values before and after the visual training F (1, 13) = 30.743, p = 0.000. As well, there is a significant improvement across all four spatial frequencies after visual training F (3, 39) = 3.853, p = 0.017. Lastly, there is a significant improvement across all four spatial frequencies after visual training and a difference between the subject groups F (6) = 2.423, p = 0.044.

4.3.6.3 t – Test

Statistical analysis using a paired samples t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values after visual training:

- Before (mean = 0.96, SD = 0.17) and after (mean = 1.53, SD = 0.28) action visual training at 0.5 cycles per degree, t (4) = -4.976, *p* = 0.008
- Before (mean = 0.57, SD = 0.18) and after (mean = 1.04, SD = 0.32) action visual training at 2 cycles per degree, t (4) = -3.286, *p* = 0.030
- Before (mean = 0.64, SD = 0.12) and after (mean = 1.05, SD = 0.37) casual visual training at 2 cycles per degree, t (5) = -3.102, *p* = 0.027
- Before (mean = 0.43, SD = 0.09) and after (mean = 0.56, SD = 0.08) casual visual training at 20 cycles per degree, t (5) = -2.623, *p* = 0.047

4.3.7 Summary

The results have shown that both action and casual gaming resulted in improvement of visual function (Table 4.22). Action gaming resulted in improvements in temporal contrast sensitivity (24 Hz) and in peripheral contrast sensitivity (24 Hz). Casual gaming resulted in improvements in peripheral contrast sensitivity, peripheral contrast sensitivity (20 Hz and 24 Hz). Additionally, there was a significant difference in the contrast sensitivity scores before visual training for both action and casual gamers for peripheral contrast sensitivity.

Test	Statistical Significance				
	ANOVA	**T- Test 0.5 cpd**	**T – Test 2 cpd**	**T – Test 10 cpd**	**T – Test 20 cpd**
Static CS	-	-	-	-	-
Central Temporal CS 20 Hz	p = 0.019 (group)	-	-	-	-
Central Temporal CS 24 Hz	p = 0.014 (training)	-	Action, p=0.020 (improvement)	-	-
Peripheral Static CS	p = 0.031 (training)	-	-	Action vs Casual p = 0.009 (before)	-
Peripheral Temporal CS 20 Hz	p = 0.014 (training) p = 0.05 (group)	-	-	Casual, p=0.024 (improvement)	-
Peripheral Temporal CS 24 Hz	p = 0.000 (training) p = 0.044 (group)	Action, p=0.008 (improvement)	Action, p=0.030 (improvement) Casual, p=0.022 (improvement)	-	Casual, p=0.047 (improvement)

Table 4.25 Statistical Results Experiment 3

Table shows the statistically significant results using both the repeated measures ANOVA and the independent t – TEST. SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players.

4.3.8 Visual Training Three Month vs One Month Discussion

4.3.8.1 Visual Training (Three Month vs One Month)

Visual training for non – reading difficulty subjects was completed over two different time training periods, which includes a total of 3 months (120 hours) and 1 month (40 hours). Noticeable visual training improvements were detected during these two training periods, which also included differences. This was established by completing statistical analysis using a repeated measures ANOVA to identify whether there is an improvement, and t – Tests to identify which gaming group resulted in a significant improvement and at which cycle per degree.

4.3.8.2 Three Month vs One Month Statistical Analysis

After the 3-month (120 hour) training period, subjects significantly improved after visual training in temporal contrast sensitivity 24 Hz (p = 0.001) and peripheral contrast

sensitivity 24 Hz (p = 0.006) with an effect of the group on temporal contrast sensitivity 24 Hz (p = 0.006) and peripheral contrast sensitivity 20 Hz (p = 0.014).

On the other hand, training over 1 month (40 hours) resulted in improvements after visual training in temporal contrast sensitivity 24 Hz (p = 0.014), static peripheral contrast sensitivity (p = 0.031, temporal peripheral contrast sensitivity 20 Hz (p = 0.014) and 24 Hz (p = 0.00). Additionally, there was an effect of the group at temporal contrast sensitivity 20 Hz (p = 0.019) and peripheral contrast sensitivity 20 Hz (p = 0.05) and 24 Hz (p = 0.044).

4.3.8.3 Action vs Casual

Further analysis identified the type of game training which resulted in the improvement as well as at which spatial frequency. The 3-month (120 hour) training period resulted in improvements of visual function, specifically due to action game training. Action game training caused an improvement in temporal contrast sensitivity 24 Hz at 2 cycles per degree (cpd) (p = 0.039), peripheral contrast sensitivity 24 Hz at 0.5 cpd (p = 0.030) and 2 cpd (p = 0.012). Additionally, there was a difference of contrast sensitivity after training between the action and casual gamers for peripheral contrast sensitivity 20 Hz at 0.5 cpd (p = 0.014) and peripheral contrast sensitivity 24 Hz at 2 cpd (p = 0.008). Lastly, there was a difference between the action and casual group contrast sensitivity values after training at peripheral contrast sensitivity 24 Hz of 2 cpd (p = 0.008).

The 1-month (40 hour) training period resulted in improvements of visual function both due to action and casual game training. Action game training resulted in an improvement in temporal contrast sensitivity 24 Hz at 2 cpd (p = 0.020), peripheral contrast sensitivity 24 Hz at 0.5 cpd (p = 0.008) and 2 cpd (p = 0.030). Additionally,

casual game training resulted in an improvement in peripheral contrast sensitivity 20 Hz at 10 cpd ($p = 0.024$) and 24 Hz ($p = 0.022$). Lastly, there was a difference between the action and casual group contrast sensitivity values before training at peripheral contrast sensitivity of 10 cpd ($p = 0.009$).

4.3.8.4 Improvements and Spatial Frequencies

Improvements were obtained from the t - Tests from both training periods were mainly noticed at the spatial frequencies 2 cycles per degree (cpd) (4 total improvements) compared to of 0.5 cpd (1 improvement), 10 cpd (2 improvements) and 20 cpd (1 improvements). Spatial frequencies which range from 2 to 5 cycles per degree are referred to as peak sensitivity frequencies. This is most likely the reason why the most improvement was noticed at 2 cycles per degree.

Studies have been conducted on both human and non-human species which have shown that incredibly low (e.g. 0.5 cpd) and high (e.g. 20 cpd) spatial frequencies resulted in poor contrast sensitivity results (Jarvis & Wathes, 2008). As the subjects in this study prior to training already demonstrate higher contrast sensitivity around 2 cycles per degree (= peak contrast sensitivity), this would then reasonably result in more improvement at that special frequency compared to a higher or lower one (= poor contrast sensitivity).

The reason as to why differing spatial frequencies result in a change in contrast sensitivity is because of the neuronal activities present in the visual cortex. At low spatial frequencies, the contrast sensitivity increases due to lateral inhibition whilst at high spatial frequency contrast sensitivity decreases due to the optical transfer function of the eye (Rovamo *et al.,* 1993). Lateral inhibition allows neurons to inhibit neighbouring neurons which result in an overall improvement of response. This

response results in contrast enhancement, which is why the contrast increases after 0.5 cycles per degree. Optical transfer function allows the visual system to handle varying spatial frequencies.

4.3.8.5 Frame Rates in Video Games

The ANOVA reported visual improvements in contrast sensitivity after game training for both the 3-month (120 hour) and 1-month (40 hour) training periods. Additionally, there were also differences in which group displayed the specific improvements. Both the training periods resulted in an improvement of temporal contrast sensitivity 24 Hz and peripheral contrast sensitivity 24 Hz. Yet, only the 1-month (40 hour) training period resulted in improvements of static peripheral contrast sensitivity and peripheral contrast sensitivity 20 Hz. Generally, the contrast sensitivity improvements after visual training support previous research. The training did indeed result in an increased peripheral acuity and enhanced contrast sensitivity (Green & Bavelier, 2003; *Green et al.,* 2012; Huber – Wallander *et al*., 2011; Maurer & Hensch, 2012) as well as on higher flicker rates which are associated with gaming.

General video presented on screen is composed of still images (frames) that are captured repeatedly and then played back in fast sequence (frame rate). In video games, the frame rate refers to often the image on screen is updated with a new frame (image) and is measured as frames per second (fps). Games are generally played at 30 fps as a lower frame rate would result in a ‘choppy’ and ‘slow’ game play. Doom 3 has a maximum performance frame rate of 60 fps whilst Civilization 4 has a maximum performance frame rate of 20 – 60 fps (average of 40 fps). The frame rate of a casual game will be dependent on how much movement occurs in the game as the player has to initiate steps to cause movement, compared to an action game which has

constant movement. Due to Civilization 4 not being an action game, it requires less of a frame rate due to less play back of images.

The game is played on a screen which has a refresh rate and that depends on the screen that it is displayed on. Refresh rate is measured in hertz (Hz) and 1 Hz is equivalent to one cycle per second as it is the exact number of times that the image displayed screen refreshes per second. The monitor used for the experiment had a refresh rate of 120 Hz. The two refresh rates measured for temporal and peripheral contrast sensitivity flicker were 20 Hz and 24 Hz, 24 Hz being a higher flicker rate. Thus, the subjects could detect the flicker as it is a lower refresh rate compared to the screen refresh rate of 120 Hz.

As the subjects were visually trained using higher frame rates, this resulted in an improvement in their temporal contrast sensitivity at detecting flicker rates of 20 and 24 Hz in the central temporal and peripheral regions. Unexpectedly, casual gaming resulted in a significant improvement in peripheral contrast sensitivity of 20 Hz (10 cpd) and peripheral contrast sensitivity of 24 Hz (2 and 20 cpd) after the 1-month (40 hour) training. This may be explained by the gamer themselves participating more ‘actively’ in the casual game, which would result in a higher frame rate similar that of an action game. Civilization 4 is a type of ‘turn based’ casual game in which the subject must manually click for the game to progress. This would then result in movement and the ability to explore around the game map. On the other hand, 3-month (120 hour) training resulted in no significant improvement of visual function in any spatial frequency from casual gaming. Once again, this may be due to the gamer being less ‘active’ in the game and instead staring at the static image or reading what is presented on screen. This may be a suggestion as to why casual games are less reliable

compared to action games in terms of visual training. Casual gaming depends a lot on the gamer to progress the game, and a lack of progression and vice versa, and this depends on the individual's motivation in the playing the game (Figure 4.19).

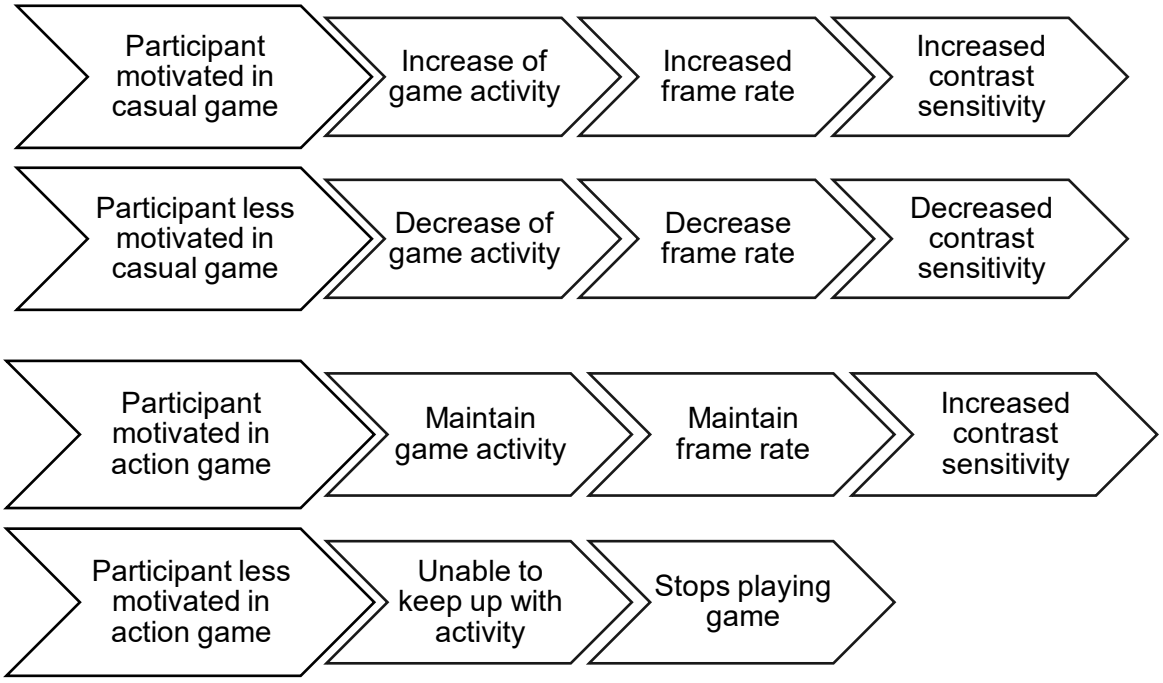

Figure 4.36 Motivation Theory in Game Play

.A subject can be motivated to play a video game, or can lack motivation. The depending motivation levels would result in a varying game activity for both game genres.

4.3.8.6 The Effect of Sample Size

A noticeable difference between the 3 Month (120 hour) and 1 Month (40 hour) training periods was that casual game training was effective on contrast sensitivity only during the 1 Month (40 hour) training period. This may be due to several reasons, one of which is sampling size. The 1 Month (40 hour) training period had a total of 16 subjects, compared to 9 subjects during the 3 Month (120 hour) training period. The larger the sample size, the more likely the case that the results will reflect the general population.

During the 3 Month (120 hour) training period only 2 subjects played the casual game whilst in the 1 Month (40 hour) training period 6 subjects received casual game training. In result, a larger sample size gives a greater chance of finding a true significant difference or effect of the casual game training. Numerous studies have conducted research on visual function using low participant numbers. This includes studies examining 20 existing gamers (Green & Bavelier, 2007), the visual training of 8 subjects using Gabor patches (Deveau *et al*., 2014), and an analysis of 1 subject using video game training for visual field loss (Wheatley *et al.,* 2011). Thus, low population studies as in my research are not a rare occurrence in vision science. Many participants receive money for their participation, such as $8 per hour (Green & Bavelier, 2007) thus low participant numbers may be due to lack of financial reward. Additionally, due to the long length of training period, not all participants are able to meet that commitment which results in a high dropout rate.

Furthermore, participants demonstrated an improvement at 20 cycles per degree during two occasions. This includes 3-month (120 hour) training of action gamers resulting in an improvement of peripheral contrast sensitivity 20 Hz at 20 cpd and 1-month (40 hour) training of casual gamers resulting in an improvement of peripheral contrast sensitivity 24 Hz at 20 cpd. As the subject number was low, this may have resulted in outliers. 20/20 vision is considered as normal visual acuity, so the participant can distinguish between small details and has clarity in their vision. This acuity is equivalent to 30 cycles per degree of the visual field. Hence, being able to distinguish gratings at 20 cycles per degree is considered a very challenging task if the subject does not have ‘eagle eyed’ vision.

4.8.3.7 Previous Study Replication

Although numerous studies have shown that video game play results in improvements of visual function a study conducted by Boot *et al.* (2008) found no improvement nor difference after action and casual game training. Boot *et al.* (2008) found no visual improvements after 20 hours of visual training using 82 subjects. Thus, Boot et al. (2008) stated that any improvement in visual function after training may rather be due prior video game experience or group differences in the ability to play a game instead of the actual game improving visual function.

Therefore, a change in visual function may however be due to chance rather than an actual improvement. Further controlled laboratory studies are required to concretely prove or disprove Boot *et al.* (2008) statement.

4.4 Stability of Visual Training

The aim of this experiment is to establish whether the visual improvement after 1 month (40 hours) of video game play remains stable one-month post training. This is important as the results can suggest whether the improvement is long lasting, and whether some game genres are more effective than others. A selection of five subjects from Experiment 3, who undertook a 1-month visual training period over 40 hours stopped all game play for a month. Their visual function was once again tested to identify whether the visual improvement stayed stable after one month. There was a total of three action and two casual gamers. The visual function parameters tested were:

- Central static contrast sensitivity
- Temporal contrast sensitivity (20 Hz and 24 Hz)
- Static peripheral contrast sensitivity (5° eccentricity)
- Peripheral temporal contrast sensitivity (20 Hz and 24 Hz)

The results were presented as contrast sensitivity (log) across four spatial frequencies (0.5, 2, 10, and 20 cycles per degree). Statistical analysis was carried out using a repeated measures ANOVA with a 95% confidence interval. Statistical significance is noted as being $p = < 0.05$. Further analysis was carried out using t – Tests.

Please note ‘’Before’’ refers to the subject’s visual function once visual training was completed, whilst ‘’After’’ refers to the visual function one-month post training. An indication of visual stability (no change in visual function) is indicated by no statistical significance whilst an indication of visual decline (a change in visual function) is showed by statistical significance.

4.4.1 Visual Stability: Central static Contrast Sensitivity

A graph (Figure 4.20) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.23).

4.4.1.1 Graph

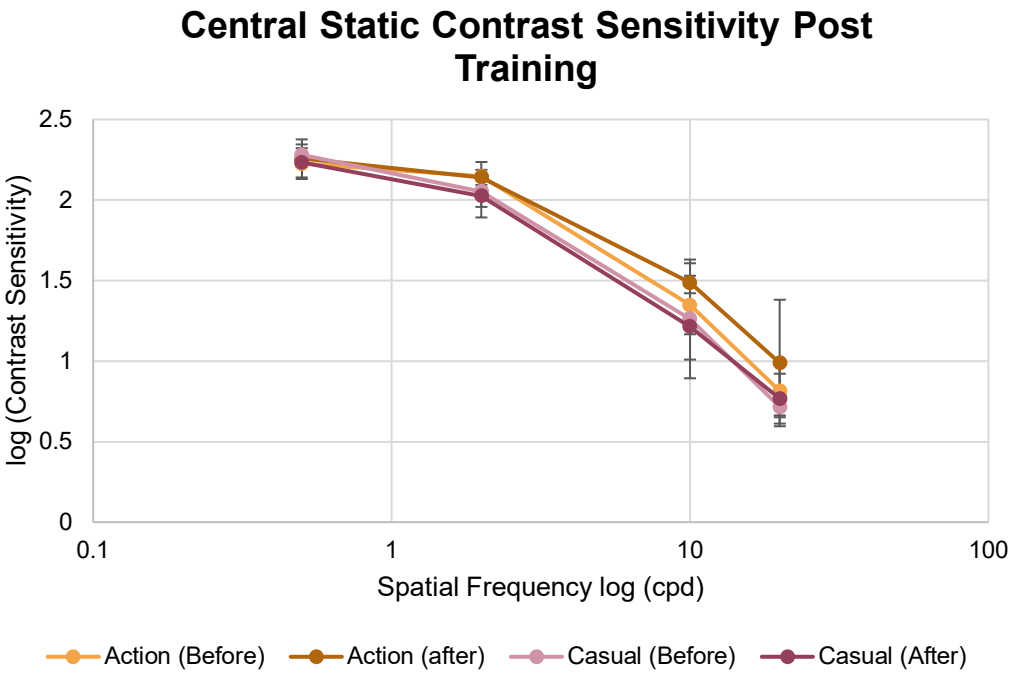

Figure 4.37 Central Static Contrast Sensitivity Experiment 4

Sensitivity post visual training. Error bars show 95% confidence intervals. Visually, the graph has considerable overlap of confidence intervals across all four spatial frequencies for both groups. Cpd=cycles per degree. n = 5.

Central Static Contrast Sensitivity (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	2.22	2.15	1.35	0.81
	SD	0.10	0.10	0.21	0.81
After (AVGP)	**Mean CS**	2.26	2.14	1.49	0.99
	SD	0.13	0.05	0.14	0.45
Before (CVGP)	**Mean CS**	2.28	2.05	1.26	0.72
	SD	0.08	0.12	0.46	0.07
After (CVGP)	**Mean CS**	2.23	2.03	1.22	0.77
	SD	0.04	0.17	0.26	0.19

Table 4.26 Central Static Contrast Sensitivity Experiment 4

Table showing the static contrast sensitivity results one month post visual training in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. n = 5.

4.4.1.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (3, 21), 62.283, $p = 0.00$. Yet, there is no significant interaction between the stability and the subject group F (2), 0.385, $p = 0.694$. Additionally, there is no significant effect of the stability F (1, 7) = 4.647, $p = 0.068$. This means that there is no significant decline of contrast sensitivity in either the casual or action group one month post visual training.

4.4.2 Visual Stability: Central Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.21) displays the contrast sensitivity results from the two groups as well as a table of temporal contrast sensitivity (20 Hz) values (Table 4.24).

4.4.2.1 Graph

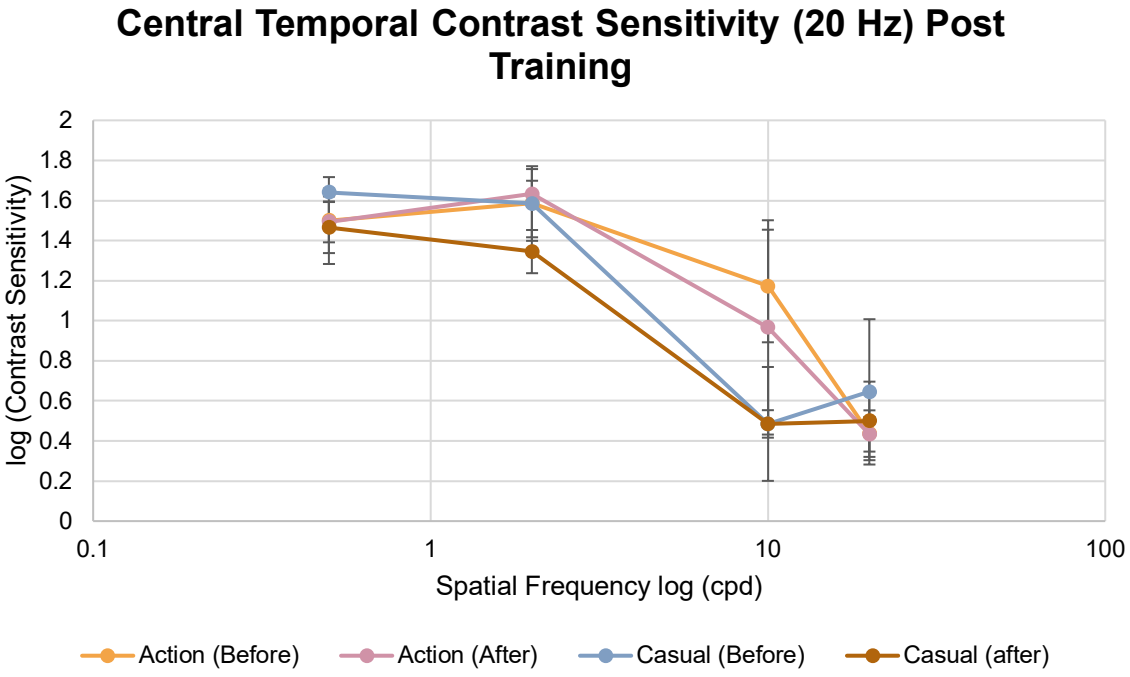

Figure 4.38 Central Temporal Contrast Sensitivity 20 Hz Experiment 4

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. n = 5.

Central Temporal Contrast Sensitivity for 20 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.50	1.59	0.17	0.44
	SD	0.19	0.15	0.25	0.10
After (AVGP)	**Mean CS**	1.49	1.63	0.97	0.43
	SD	0.09	0.06	0.47	0.08
Before (CVGP)	**Mean CS**	1.64	1.59	0.49	0.65
	SD	0.02	0.19	0.28	0.36
After (CVGP)	**Mean CS**	1.47	1.35	0.49	0.5
	SD	0.09	0.08	0.05	0.14

Table 4.27 Central Temporal Contrast Sensitivity 20 Hz Experiment 4

Table showing the static contrast sensitivity results one month post visual training in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players.

4.4.2.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (3, 21), 62.283, p = 0.00. Yet, there is no significant interaction between the stability and the subject group F (2), 0.385, p = 0.694. Additionally, there is no significant effect of the stability F (1, 7) = 4.647, p = 0.068. This means that there is no significant decline of contrast sensitivity in either the casual or action group one month post visual training.

4.4.3 Visual Stability: Central Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.22) displays the contrast sensitivity results from the two groups as well as a table of temporal contrast sensitivity (24 Hz) values (Table 4.25).

4.4.3.1 Graph

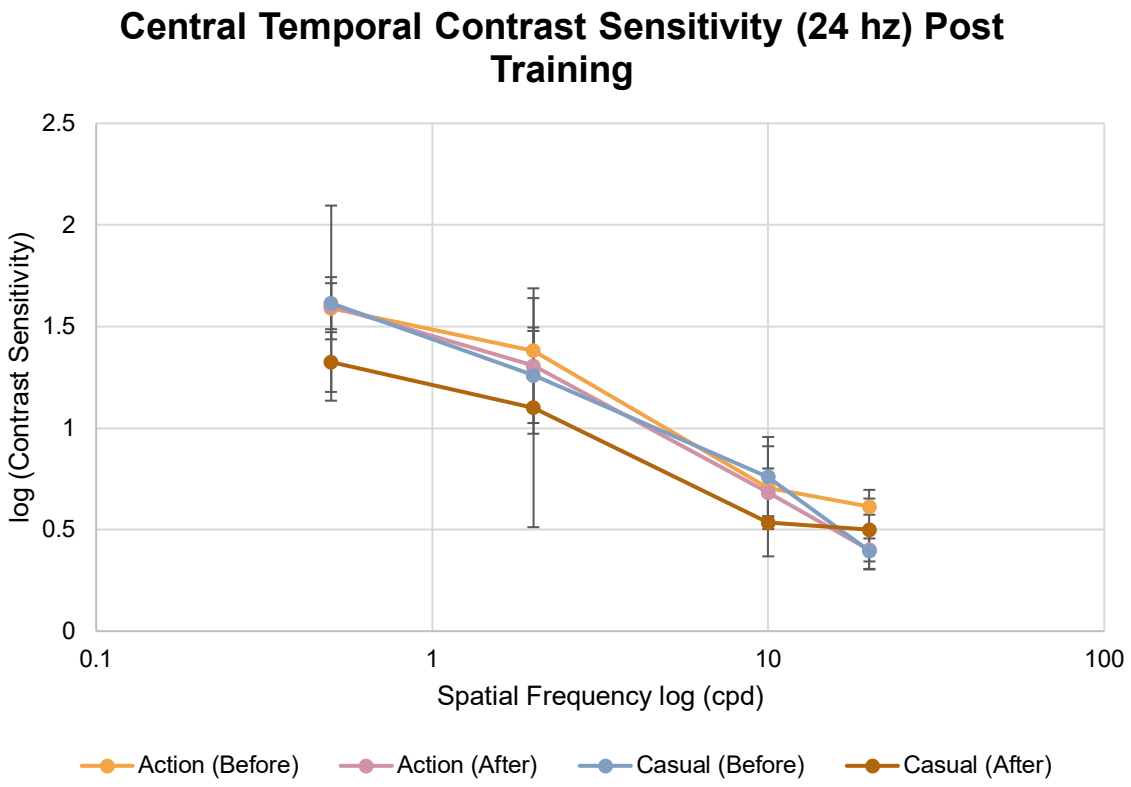

Figure 4.39 Central Temporal Contrast Sensitivity 24 Hz Experiment 4

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. n = 5.

Central Temporal Contrast Sensitivity for 24 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.59	1.38	0.71	0.61
	SD	0.15	0.09	0.18	0.04
After (AVGP)	**Mean CS**	1.6	1.31	0.68	0.40
	SD	0.10	0.30	0.10	0.05
Before (CVGP)	**Mean CS**	1.62	1.26	0.76	0.40
	SD	0.48	0.24	0.20	0.09
After (CVGP)	**Mean CS**	1.33	1.10	0.54	0.5
	SD	0.18	0.59	0.17	0.20

Table 4.28 Central Temporal Contrast Sensitivity 24 Hz Experiment 4

Table showing the static contrast sensitivity results one month post visual training in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. n = 5.

4.4.3.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (3, 21) = 93.340, p = 0.00. Additionally, there is a significant difference in contrast sensitivity values one month post visual training F (1, 7) = 7.880, p = 0.026. To identify which groups are affected, a t – Test is required comparing contrast sensitivity values within the action and casual gaming group.

4.4.3.3 t – Test

Statistical analysis using a paired samples t – Test reported that there was a statistically significant difference ($p = > 0.05$) in contrast sensitivity values post training:

- Before (mean = 0.61) and post training (mean = 0.40) in the action gaming group at 20 cycles per degree, t (2) = 8.875, p = 0.012)

4.4.4 Visual Stability: Static peripheral Contrast Sensitivity

A graph (Figure 4.23) displays the contrast sensitivity results from the two groups as well as a table of static peripheral contrast sensitivity values (Table 4.26).

4.4.4.1 Graph

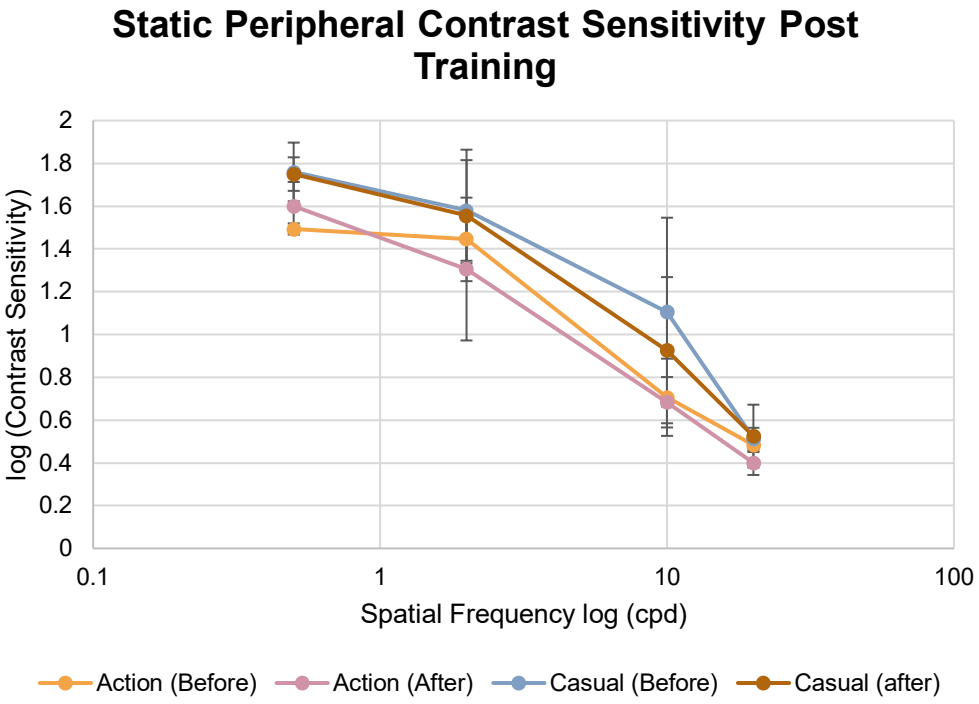

Figure 4.40 Static Peripheral Contrast Sensitivity Experiment 4

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. n = 5

Static peripheral Contrast Sensitivity (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.49	1.45	0.71	0.48
	SD	0.02	0.10	0.16	0.03
After (AVGP)	**Mean CS**	1.60	1.31	0.68	0.40
	SD	0.10	0.30	0.10	0.05
Before (CVGP)	**Mean CS**	1.60	1.31	0.68	0.40
	SD	0.10	0.30	0.10	0.05
After (CVGP)	**Mean CS**	1.75	1.56	0.93	0.53
	SD	0.06	0.22	0.25	0.11

Table 4.29 Static Peripheral Contrast Sensitivity Experiment 4

Table showing the static contrast sensitivity results one month post visual training in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. n = 5.

4.4.4.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (3, 21) = 109.935, p = 0.000. Yet, there is no significant effect of time on the contrast sensitivity values F (1, 7) = 0.264, p = 0.623. Thus, there is no significant decline in peripheral contrast sensitivity one month post visual training.

4.4.5 Visual Stability: Peripheral Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.24) displays the contrast sensitivity results from the two groups as well as a table of peripheral contrast sensitivity (20 Hz) values (Table 4.27).

4.4.5.1 Graph

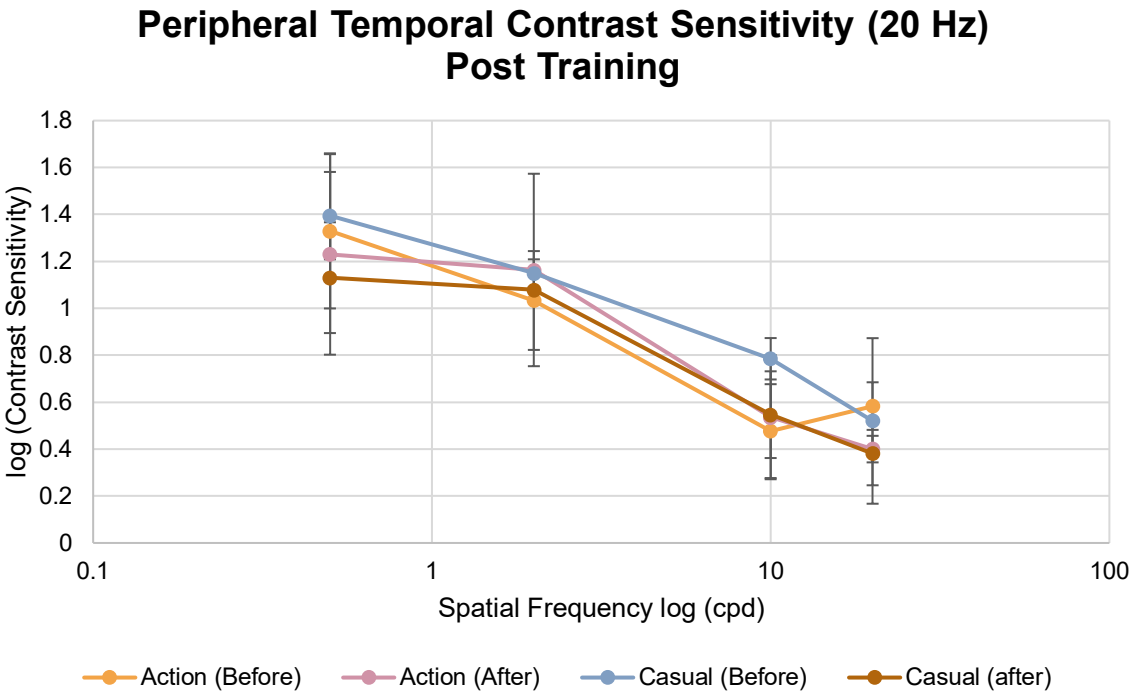

Figure 4.41 Peripheral Contrast Sensitivity 20 Hz Experiment 4

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. n = 5.

Peripheral Temporal Contrast Sensitivity 20 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.33	1.03	0.48	0.58
	SD	0.29	0.19	0.18	0.09
After (AVGP)	**Mean CS**	1.23	1.16	0.54	0.40
	SD	0.38	0.36	0.23	0.05
Before (CVGP)	**Mean CS**	1.40	1.15	0.79	0.52
	SD	0.13	0.04	0.06	0.25
After (CVGP)	**Mean CS**	1.13	1.08	0.55	0.39
	SD	0.17	0.00	0.13	0.10

Table 4.30 Peripheral Contrast Sensitivity 20 Hz Experiment 4

Table showing the static contrast sensitivity results one month post visual training in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. n = 5

4.4.5.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (3, 21) = 28.987*, p* = 0.000. Yet, there is no effect of time on the contrast sensitivity values F (1, 7) = 4.830, *p* = 0.064. Thus, there is no significant decline in peripheral vision of 20 Hz one-month post training for either group.

4.4.6 Visual Stability: Peripheral Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.25) displays the contrast sensitivity results from the two groups as well as a table of peripheral contrast sensitivity (24 Hz) values (Table 4.28).

4.4.6.1 Graph

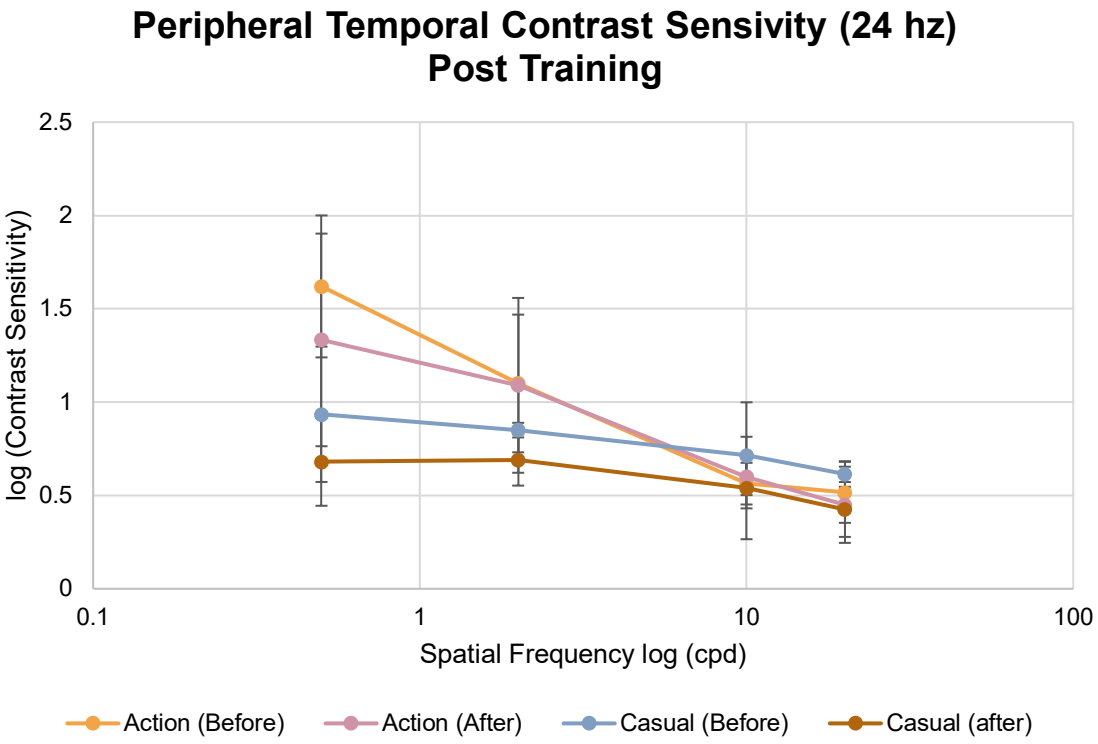

Figure 4.42 Peripheral Contrast Sensitivity 24 Hz Experiment 4

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. n = 5.

Peripheral Temporal Contrast Sensitivity for 24 Hz (log)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.62	1.1	0.56	0.52
	SD	0.34	0.33	0.10	0.14
After (AVGP)	**Mean CS**	1.33	1.09	0.60	0.45
	SD	0.57	0.47	0.10	0.20
Before (CVGP)	**Mean CS**	0.94	0.85	0.72	0.62
	SD	0.36	0.04	0.28	0.07
After (CVGP)	**Mean CS**	0.68	0.69	0.54	0.43
	SD	0.24	0.14	0.27	0.15

Table 4.31 Peripheral Contrast Sensitivity 24 Hz Experiment 4

Table showing the static contrast sensitivity results one month post visual training in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. n = 5

4.4.6.2 ANOVA

Statistical analysis using the repeated measures ANOVA reported that there is a significant difference of contrast sensitivity values across the four varying spatial frequencies F (3, 21) = 9.978, p = 0.000. Additionally, there is a significant difference between the two groups in terms of visual decline F (2) = 5.115, p = 0.043.

4.4.7 Summary

The results from the experiment indicate that there is both a stability and loss in visual function in certain games and spatial frequencies (Table 4.29). For instance, statistical analysis reported that there was no decline in visual function one – month post training for the gaming group ($p = 0.068$) for temporal contrast sensitivity 20 Hz. Yet, ANOVA reported that there was a decline in visual function one – month post training for a gaming group ($p = 0.026$) for temporal contrast sensitivity 24 Hz. The t – Test confirmed that the action group displayed a decline of visual function at 20 cycles per degree ($p = 0.012$). Static peripheral contrast sensitivity did not decline one - month post training for either gaming group ($p = 0.623$). Additionally, peripheral contrast sensitivity 20 Hz did not decline one – month post training for either gaming group ($p = 0.064$). Yet there was a decline in visual function one – month post training for peripheral contrast sensitivity 24 Hz ($p = 0.043$). However, the t – Test was not able to confirm which gaming group displayed the decline.

Measurement	**Game Genre & Visual Function Post Training (t – Test)**	
	Action	**Casual**
Static Central CS	Stable	Stable
Temporal CS 24 Hz	Decline @ 20 cpd	Stable
Static Peripheral CS	Stable	Stable
Peripheral Temporal CS 20 Hz	Stable	Stable
Peripheral Temporal CS 24 Hz	Decline	Decline

Table 4.32 Visual Stability and Decline

Table indicating that visual function declined only at one visual parameter, whereas the other parameters remained stable. Cpd = cycles per degree.

4.5 Reading Difficulty Subjects 1 Month Training (40 hours)

Previous studies and experiments indicate that visual training results in visual improvements in non – reading difficulty adults, as well as reading – difficulty children. Thus, a controlled study is required to assess whether the visual improvement can be replicate on adults with reading difficulties. Additionally, it is important to establish whether certain types of video game genres prove to be more effective compared to others. The visual function of 4 subjects with reading difficulties was tested before and after video game training. Participants undertook the training for a total of one month, which is 40 hours. The action game used was Half Life 2 (n = 2) and the casual game used was Civilization (n = 2). The visual function parameters assessed were for:

- Temporal contrast sensitivity (20 Hz and 24 Hz)
- Static peripheral static contrast sensitivity (5° eccentricity)
- Peripheral contrast sensitivity (20 Hz and 24 Hz)

The results were presented as contrast sensitivity (log) across four spatial frequencies (0.5, 2, 10, and 20 cycles per degree). Statistical analysis was carried out using an independent samples t – Test which compares the means before and after visual training of both gaming groups. Only a t – Test is used for this experiment as there are only two groups, rather than three which is used for a repeated measures ANOVA. Statistical significance is noted as being $p = <0.05$. Additionally, the aim is to establish which game proves to be more effective as well as whether there is a difference in the two games used. The t-Test will only be displayed if a significant difference has been found.

4.5.1 Reading Difficulty 40 Hours: Central Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.26) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.30).

4.5.1.1 Graph

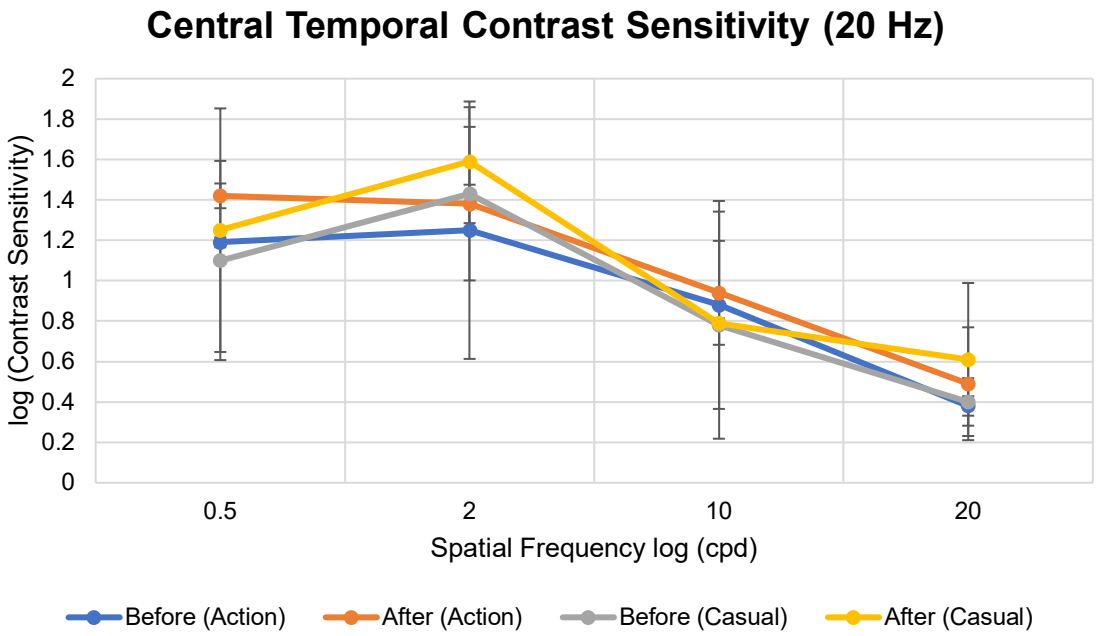

Figure 4.43 Central Temporal Contrast Sensitivity 20 Hz Experiment 5

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Central Temporal Contrast Sensitivity 20 Hz log (Subjects with RD)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.19*	1.26	0.88	0.38
	SD	0.02	0.46	0.37	0.03
After (AVGP)	**Mean CS**	1.42*	1.38	0.94	0.49
	SD	0.04	0.07	0.19	0.20
Before (CVGP)	**Mean CS**	1.10	1.45	0.78	0.40
	SD	0.36	0.31	0.41	0.08
After (CVGP)	**Mean CS**	1.25	1.59	0.79	0.61
	SD	0.44	0.12	0.02	0.27

Table 4.33 Central Temporal Contrast Sensitivity 20 Hz Experiment 5

Table showing the static contrast sensitivity results before and after video game training after one month both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. RD = Reading Difficulty. Action n = 2, casual n = 2.

4.5.1.2 t – Test

Statistical analysis using a paired t – Test reported that there was a significant difference ($p = < 0.05$) in contrast sensitivity values:

- Before (mean = 1.19, SD = 0.02) and after (mean = 1.42, SD = 0.04) action video game play at 0.5 cycles per degree, t (1) = -12.805, p = 0.049.

4.5.2 Reading Difficulty 40 Hours: Central Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.27) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.31).

4.5.2.1 Graph

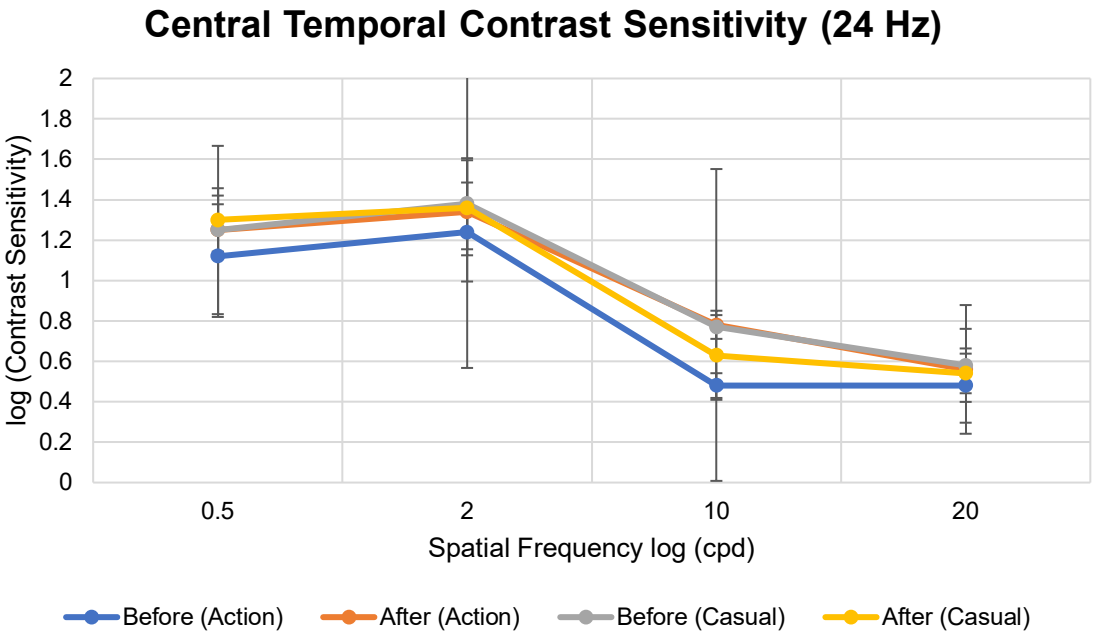

Figure 4.44 Temporal Contrast Sensitivity 24 Hz Experiment 5

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Central Temporal Contrast Sensitivity 24 Hz log (Subjects with RD)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.12	1.24	0.49	0.49
	SD	0.30	0.25	0.06	0.18
After (AVGP)	**Mean CS**	1.25	1.34	0.78	0.56
	SD	0.30	0.56	0.56	0.23
Before (CVGP)	**Mean CS**	1.25	1.38	0.77	0.58
	SD	0.13	0.23	0.06	0.18
After (CVGP)	**Mean CS**	1.30	1.36	0.63	0.54
	SD	0.16	0.24	0.22	0.01

Table 4.34 Central Temporal Contrast Sensitivity 24 Hz Experiment 5

Table showing the static contrast sensitivity results before and after video game training after one month in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. RD = Reading Difficulty. Action n = 2, casual n = 2.

4.5.3 Reading Difficulty 40 Hours: Static Peripheral Contrast Sensitivity

A graph (Figure 4.28) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.32).

4.5.3.1 Graph

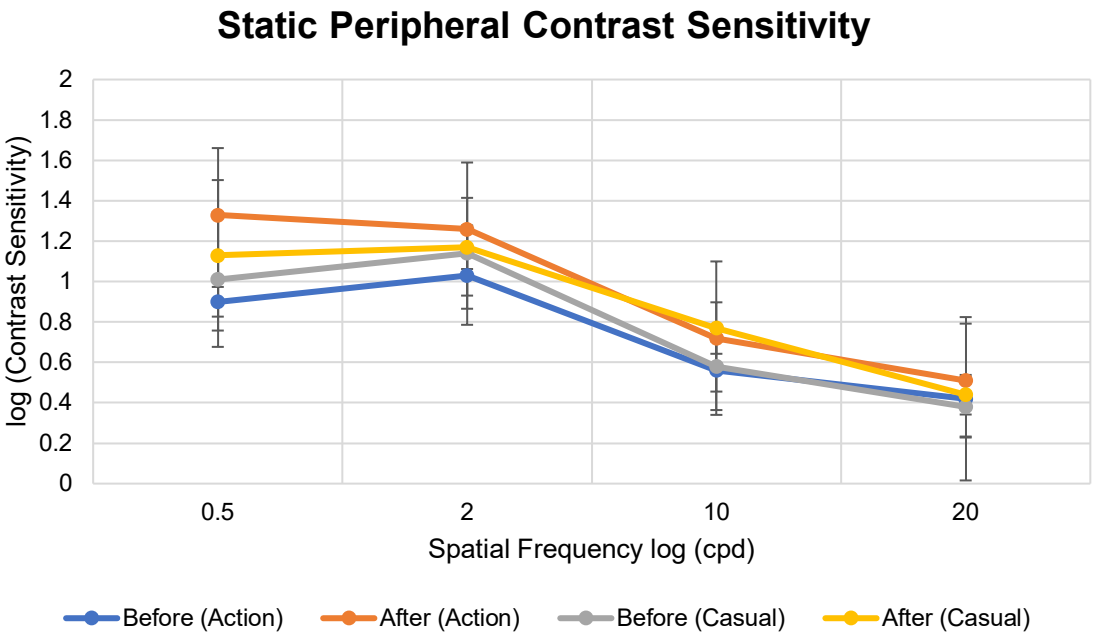

Figure 4.45 Static Peripheral Contrast Sensitivity Experiment 5

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Static Peripheral Contrast Sensitivity log (Subjects with RD)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	0.90	1.03	0.56	0.42
	SD	0.05	0.18	0.14	0.29
After (AVGP)	**Mean CS**	1.33	1.26	0.72	0.51
	SD	0.24	0.24	0.27	0.20
Before (CVGP)	**Mean CS**	1.01	1.14	0.58	0.38
	SD	0.33	0.27	0.12	0.15
After (CVGP)	**Mean CS**	1.13	1.18	0.77	0.44
	SD	0.37	0.11	0.13	0.09

Table 4.35 Static Peripheral Contrast Sensitivity Experiment 5

Table showing the static contrast sensitivity results before and after video game training after one month in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. Action n = 2, casual n = 2.

4.5.4 Reading Difficulty 40 Hours: Peripheral Temporal Contrast Sensitivity 20 Hz

A graph (Figure 4.29) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.33).

4.5.4.1 Graph

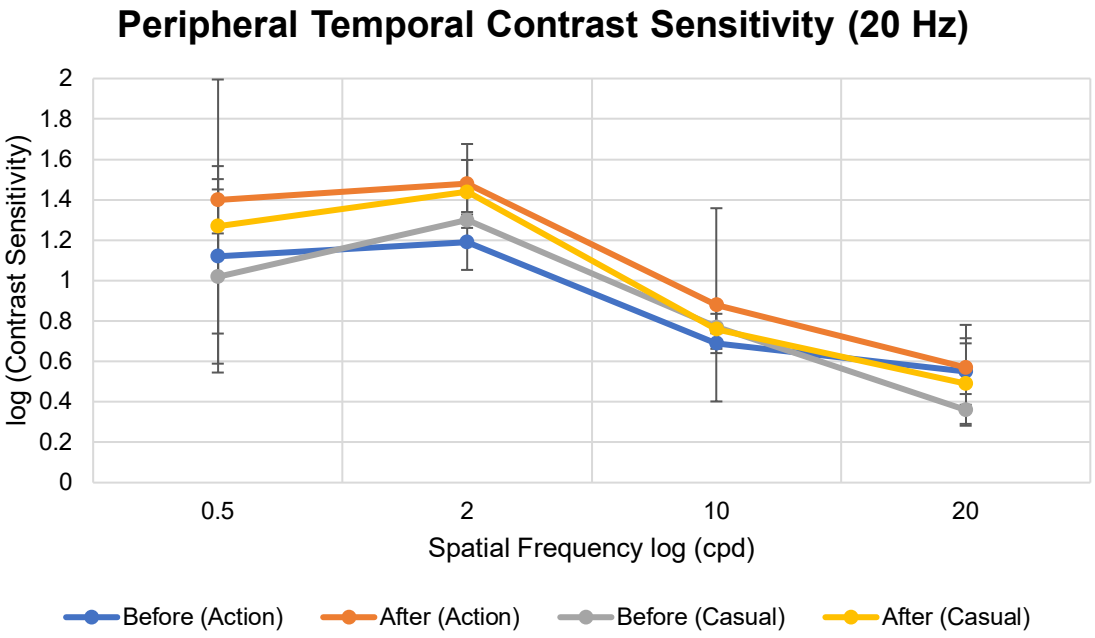

Figure 4.46 Peripheral Temporal Contrast Sensitivity 20 Hz Exp 5

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Peripheral Temporal Contrast Sensitivity 20 Hz (Subjects with RD)					
Group		**Spatial Frequency (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.12	1.19	0.69	0.55
	SD	0.38	0.14	0.05	0.16
After (AVGP)	**Mean CS**	1.40	1.48	0.88	0.57
	SD	0.17	0.20	0.48	0.21
Before (CVGP)	**Mean CS**	1.02	1.3	0.77	0.36
	SD	0.31	0.03	0.08	0.06
After (CVGP)	**Mean CS**	1.27	1.44	0.76	0.49
	SD	0.73	0.16	0.08	0.20

Table 4.36 Peripheral Contrast Sensitivity 20 Hz Experiment 5

Table showing the static contrast sensitivity results before and after video game training after one month in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. RD = Reading Difficulty. Action n = 2, casual n = 2.

4.5.5 Reading Difficulty 40 Hours: Peripheral Contrast Sensitivity 24 Hz

A graph (Figure 4.30) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.34).

4.5.5.1 Graph

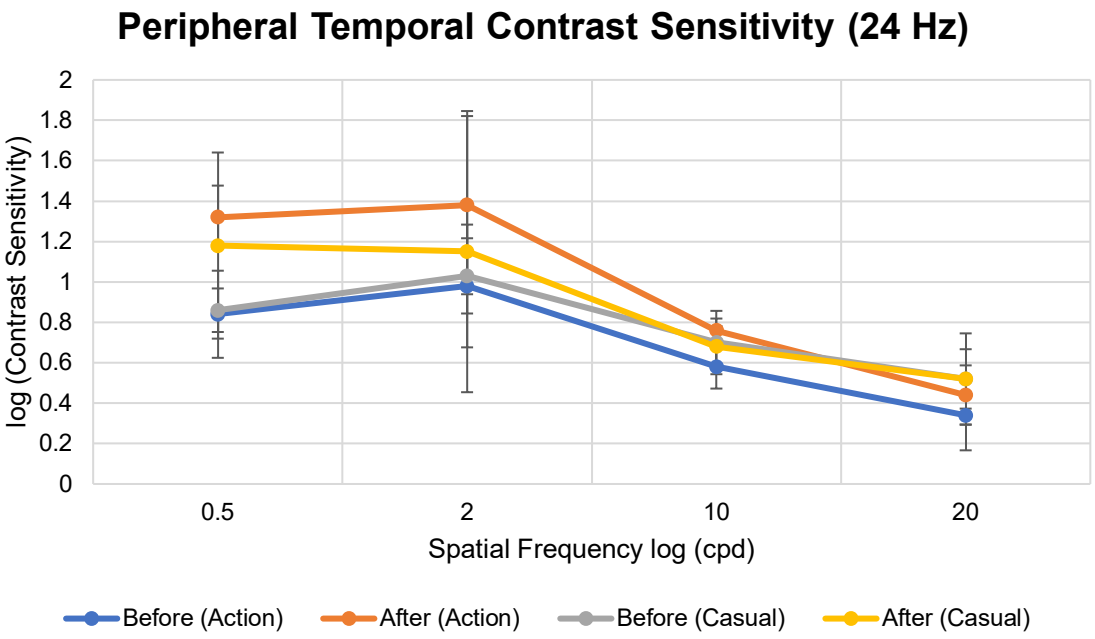

Figure 4.47 Peripheral Contrast Sensitivity 24 Hz Experiment 5

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree. Action n = 2, casual n = 2.

Peripheral Temporal Contrast Sensitivity 24 Hz log (Subjects with RD)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	0.84	0.98	0.58	0.34
	SD	0.16	0.30	0.11	0.17
After (AVGP)	**Mean CS**	1.32	1.38	0.76	0.44
	SD	0.04	0.32	0.04	0.11
Before (CVGP)	**Mean CS**	0.87	1.03	0.70	0.53
	SD	0.08	0.13	0.11	0.16
After (CVGP)	**Mean CS**	1.18	1.16	0.68	0.52
	SD	0.33	0.50	0.07	0.11

Table 4.37 Peripheral Temporal Contrast Sensitivity 24 Hz Experiment 5

Table showing the peripheral contrast sensitivity 24 Hz results before and after video game training after one month in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. RD = Reading Difficulty. Action n = 2, casual n = 2.

4.5.6 Summary

In summary, one-month (40 hour) training resulted in an improvement of temporal contrast sensitivity of 20 Hz at 0.5 cycles per degree (Table 4.35). Aside from that, there were no further improvements in visual function. Compared to non – reading difficulty (NRD) subjects, NRD subjects improved far greater, with the improvement being over four visual parameters rather than just one.

This may be due to varying participant numbers, as well as a difference in the game used. A further study over 20 hours will examine whether a shorter gaming period would result in greater visual improvements.

Measurement	Training Paired *t* – Test analysis	
	1 Month NRD	**1 Month RD**
Central Temporal CS 20 Hz	-	0.5 cpd: *p*=0.049 (Action)
Central Temporal CS 24 Hz	2 cpd: *p* = 0.020 (Action)	-
Static Peripheral CS	-	-
Peripheral Temporal CS 20 Hz	10 cpd: *p*=0.024 (Casual)	-
Peripheral Temporal CS 24 Hz	0.5 cpd: *p*=0.008 (Action) 2 cpd: *p*=0.030 (Action) 2 cpd: *p*=0.022 (Casual) 20 cpd: *p*=0.047 (Casual)	-

Table 4.38 t -Test Results

The table compares results from both non- reading difficulty subjects and reading difficulty subjects from t – Test results. CS = Contrast Sensitivity. CPD = cycles per degree. RD = Reading difficulty. All significant values for the t – test are p = <0.05.

4.6 Reading Difficulty: 2 Week Training (20 Hours)

The previous experiment suggested that visual training of 1 month (40 hours) resulted in improvements of visual function. Therefore, it is necessary to examine whether a shorter training period of 2 week (20 hours) provides a similar visual improvement. The visual function of 6 subjects with reading difficulties was tested before and after video game training. Participants undertook the training for a total of one month, which is 40 hours. The action game used was Half Life 2 (n = 3) and the casual game used was Civilization (n = 3). The visual function parameters assessed were for:

- Central Temporal contrast sensitivity (20 Hz and 24 Hz)
- Peripheral static contrast sensitivity
- Peripheral temporal contrast sensitivity (20 Hz and 24 Hz)

The results were presented as contrast sensitivity (log) across four spatial frequencies (0.5, 2, 10, and 20 cycles per degree). Statistical analysis was carried out using an t – Tests which compares the means before and after visual training of both gaming groups. Only a t – Test is used for this experiment as there are only two groups, rather than three which is used for a repeated measures ANOVA. Statistical significance is noted as being $p = <0.05$. Only significant t – Test results will be presented.

4.6.1 Central Temporal Contrast Sensitivity 20 Hz (RD 2 Week Training)

A graph (Figure 4.31) displays the contrast sensitivity results from the two groups as well as a table of central temporal contrast sensitivity (20 Hz) values (Table 4.36).

4.6.1.1 Graph

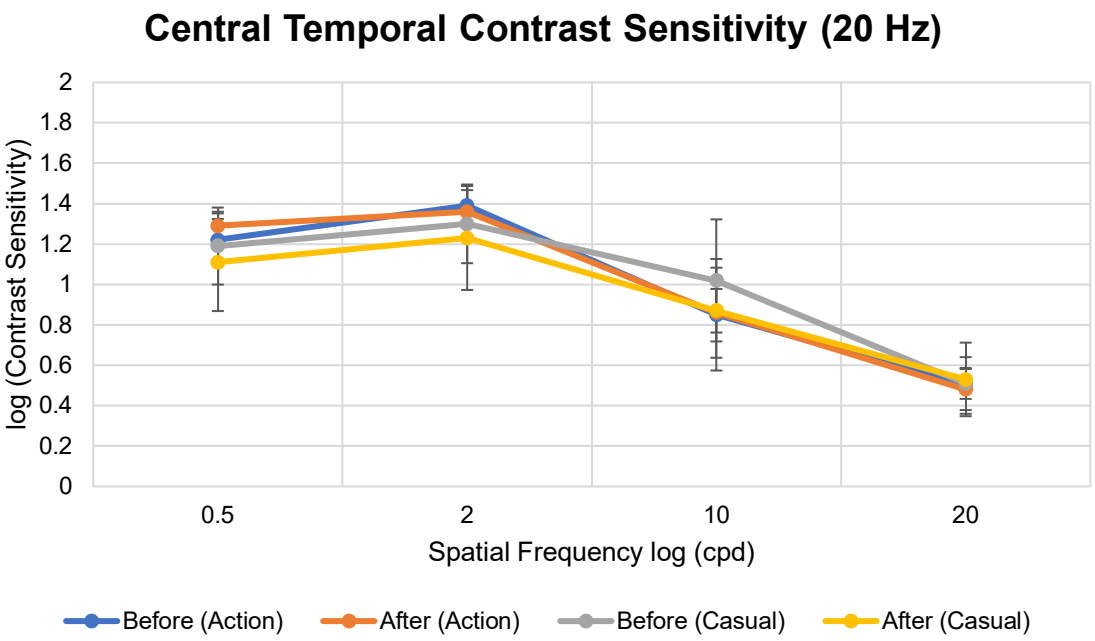

Figure 4.48 Central Temporal Contrast Sensitivity 20 Hz Experiment 6

Graph before and after 2-week training. Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree.

Central Temporal Contrast Sensitivity 20 Hz log (Subjects with RD)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.22	1.39	0.85	0.50
	SD	0.09	0.07	0.24	0.12
After (AVGP)	**Mean CS**	1.29	1.36	0.86	0.48
	SD	0.06	0.11	0.20	0.09
Before (CVGP)	**Mean CS**	1.19	1.30	1.02	0.51
	SD	0.17	0.17	0.27	0.06
After (CVGP)	**Mean CS**	1.11	1.23	0.87	0.51
	SD	0.21	0.23	0.10	0.16

Table 4.39 Central Temporal Contrast Sensitivity 20 Hz Experiment 6

Table showing the contrast sensitivity results before and after video game training after 20 hours in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players.

4.6.2 Central Temporal Contrast Sensitivity 24 Hz (RD 2 Week Training)

A graph (Figure 4.32) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.37).

4.6.2.1 Graph

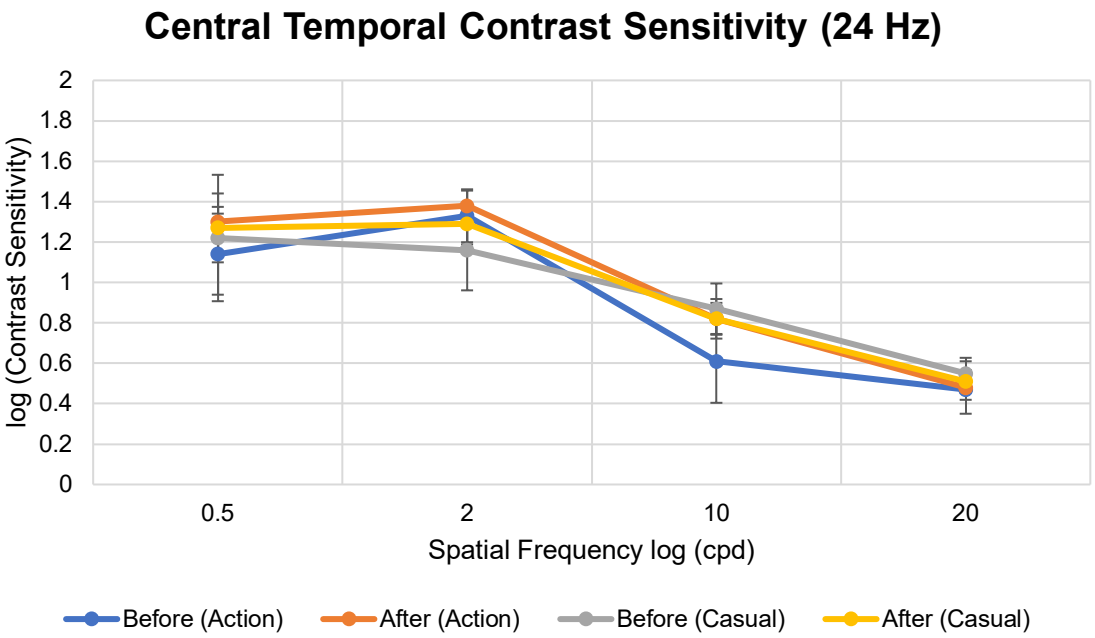

Figure 4.49 Central Temporal Contrast Sensitivity 24 Hz Experiment 6

Graph before and after 2-week training. Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree.

Central Temporal Contrast Sensitivity 24 Hz log (Subjects with RD)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.14	1.33	0.61	0.47
	SD	0.20	0.13	0.18	0.04
After (AVGP)	**Mean CS**	1.30	1.38	0.82	0.48
	SD	0.07	0.07	0.09	0.11
Before (CVGP)	**Mean CS**	1.22	1.16	0.87	0.55
	SD	0.28	0.18	0.11	0.07
After (CVGP)	**Mean CS**	1.27	1.29	0.82	0.51
	SD	0.15	0.09	0.07	0.05

Table 4.40 Central Temporal Contrast Sensitivity 24 Hz Experiment 6

Table showing the contrast sensitivity results before and after video game training after 20 hours in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. RD = Reading difficulty.

4.6.3 Reading Difficulty 20 Hours: Peripheral Contrast Sensitivity 20 Hz

A graph (Figure 4.33) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.38).

4.6.3.1 Graph

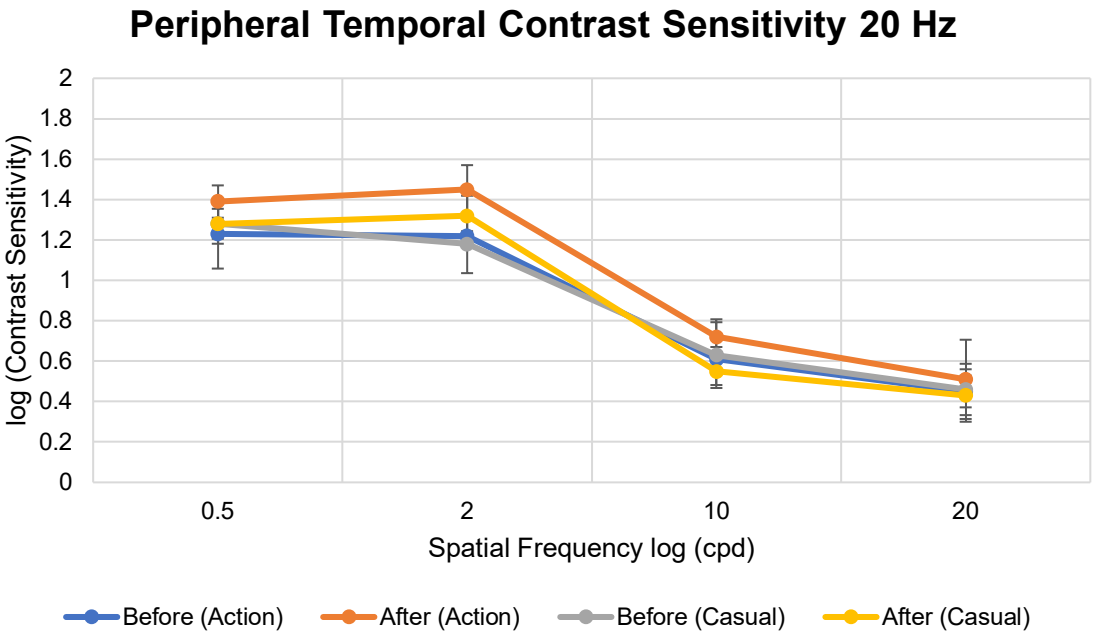

Figure 4.33 Peripheral Temporal Contrast Sensitivity 20 Hz Experiment 6

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree.

Peripheral Temporal Contrast Sensitivity 20 Hz log (Subjects with RD)					
Group		**Spatial Frequency log (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	1.23	1.22	0.61	0.45
	SD	0.15	0.02	0.05	0.07
After (AVGP)	**Mean CS**	1.39	1.45	0.72	0.51
	SD	0.07	0.11	0.08	0.17
Before (CVGP)	**Mean CS**	1.28	1.18	0.63	0.46
	SD	0.09	0.13	0.14	0.11
After (CVGP)	**Mean CS**	1.28	1.32	0.55	0.43
	SD	0.07	0.09	0.06	0.11

Table 4.38 Peripheral Temporal Contrast Sensitivity 20 Hz Experiment 6

Table showing the contrast sensitivity results before and after video game training after 20 hours in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players. RD = Reading difficulty.

4.6.4 Reading Difficulty 20 Hours: Peripheral Temporal Contrast Sensitivity 24 Hz

A graph (Figure 4.34) displays the contrast sensitivity results from the two groups as well as a table of central static contrast sensitivity values (Table 4.39).

4.6.4.1 Graph

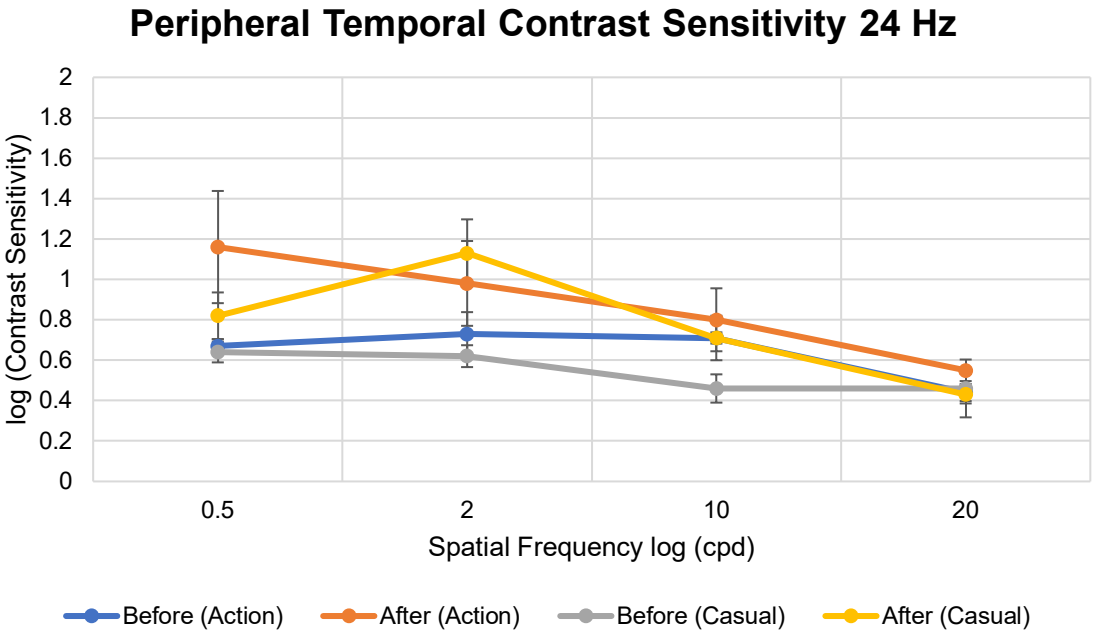

Figure 4.34 Peripheral Temporal Contrast Sensitivity 24 Hz Experiment 6

Error bars show 95% confidence intervals. The graph displays an overlap of confidence intervals across all four spatial frequencies. cpd = cycles per degree.

Peripheral Temporal Contrast Sensitivity 24 Hz (Subjects with RD)					
Group		**Spatial Frequency (cpd)**			
		0.5	2	10	20
Before (AVGP)	**Mean CS**	0.67	0.73	0.71	0.44
	SD	0.03	0.10	0.10	0.04
After (AVGP)	**Mean CS**	1.16	0.98	0.81	0.55
	SD	0.25	0.19	0.14	0.05
Before (CVGP)	**Mean CS**	0.64	0.62	0.46	0.46
	SD	0.05	0.05	0.06	0.07
After (CVGP)	**Mean CS**	0.82	1.13	0.71	0.43
	SD	0.12	0.17	0.03	0.11

Table 4.41 Peripheral Temporal Contrast Sensitivity 24 Hz Experiment 6

Table showing the static contrast sensitivity results before and after video game training after 20 hours in both action and casual gamers.SD = Standard deviation. CS = Contrast Sensitivity. CPD = cycles per degree. AVGPs = Action video game players. CVGPs = Casual video game players.

4.6.4.2 t – Test

Statistical analysis using a paired t – Test reported that there was a statistically significant difference ($p = < 0.05$) in contrast sensitivity values:

- Before (mean = 0.62, SD = 0.06) and after (mean = 1.13, SD = 0.18) casual video game training at 2 cycles per degree, t (2) = -4.296, p = 0.049
- Before (mean = 0.46, SD = 0.08) and after (mean = 0.71, SD = 0.03) casual video game training at 10 cycles per degree, t (2) = -5.500, p = 0.031.

4.6.6 Summary

In summary the results indicate that visual training after only two weeks (20 hours) is more effective than one month (40 hours). This supports previous research which suggests that shorter training periods are as affective and can be used in visual training. A further explanation will be provided in Chapter 5 (Discussion).

Chapter 5 Discussion

5.1 Applying the Four Theories of Reading Difficulties

As the subjects used for the visual training suffered from self-reported reading difficulties (RD) they were initially screened to establish the extent of their reading difficulties, as well as whether their reading scores differed from subjects without self – reported reading difficulties. The results indicated that the subjects do indeed suffer from reading difficulties and that their scores highly correlate to the reading scores of those who have developmental dyslexia. It is estimated that the most common cause of reading difficulties is dyslexia, accounting for 70 – 80% of reading difficulty cases (University of Michigan, 2017). Thus, the current theories of dyslexia will be examined using the results obtained from the RD subjects in this study.

To establish whether the RD subjects do indeed display traits in common with either of the four theories (the magnocellular deficit, the phonological, the visual deficit, and the cerebellar dysfunction theory), their scores were compared to subjects without any self – reported reading difficulties (NRD) (please see Chapter 3).

5.1.1 Magnocellular Deficit Theory

In the magnocellular deficit theory, a deficit in either the magnocellular or the parvocellular stream leads to dyslexia symptoms (Fisher & Chekaluk, 2015). A magnocellular deficit will affect low spatial frequencies whilst a parvocellular deficit will affect high spatial frequencies. Low spatial frequencies are less than 2 cpd whilst high spatial frequencies are above 10 cpd. Statistical analysis comparing 10 RD and 20 NRD subjects before visual training showed that:

- NRD subjects have a higher temporal contrast sensitivity at

    - 20 Hz in 0.5 cycles per degree (cpd)
    - 20 Hz in 2 cpd
    - 24 Hz in 0.5 cpd
- RD subjects have a higher temporal contrast sensitivity at 24 Hz in peripheral vision in 2 cpd.

There were no other significant differences found in other visual parameters and spatial frequencies.

The scores indicate that RD subjects had lower contrast sensitivity scores, compared to NRD subjects, in three occasions affecting temporal vision 20 and 24 Hz at generally low spatial frequencies, which would support the underlying cause as being consistent with the magnocellular deficit theory. However, to confirm that the reduced contrast sensitivity is due to a magnocellular defect, the reduction must be consistent in all visual parameters (Skottun, 2000) and not just in a small number. Additionally, a deficit in the magnocellular system would manifest itself in spatial frequencies which are lower than 1.5 cycles per degree (Merigan *et al.,* 1991) and only two out of the three spatial frequencies showing a significant difference in RD subjects in this study were lower than 1.5 cycles per degree.

Additionally, to confirm that the defect is indeed due to a magnocellular deficit, the lower contrast sensitivity must not be consistent with a parvocellular deficit (Skottun, 2000). In temporal contrast sensitivity 20 Hz, RD subjects had a lower contrast sensitivity at 2 cycles per degree, which would be predicted to be due to a deficit in the parvocellular system. Furthermore, NRD subjects displayed higher contrast sensitivity values affecting temporal sensitivity 24 Hz in peripheral vision.

Therefore, the results are contradictory in terms of supporting the magnocellular theory throughout.

Yet, the current results in this thesis do support previous studies investigating the relationship between the magnocellular deficit and spatial frequency. Lovegrove *et al*. (1980) found that subjects had lower contrast sensitivity values compared to controls, though at spatial frequencies which are thought to be mediated by the parvocellular system. A study conducted by Lovegrove *et al.* (1982) reported that subjects with reading disabilities displayed higher contrast sensitivities above 1.5 cycles per degree, which would dispute the magnocellular deficit theory overall. In general, there are 22 studies which examine the relationship between spatial frequency and visual function in dyslexics. Four studies suggest that dyslexia is due to the magnocellular defect, 11 studies in total are in conflict with the theory, and 7 studies are inconclusive (Figure 5.1).

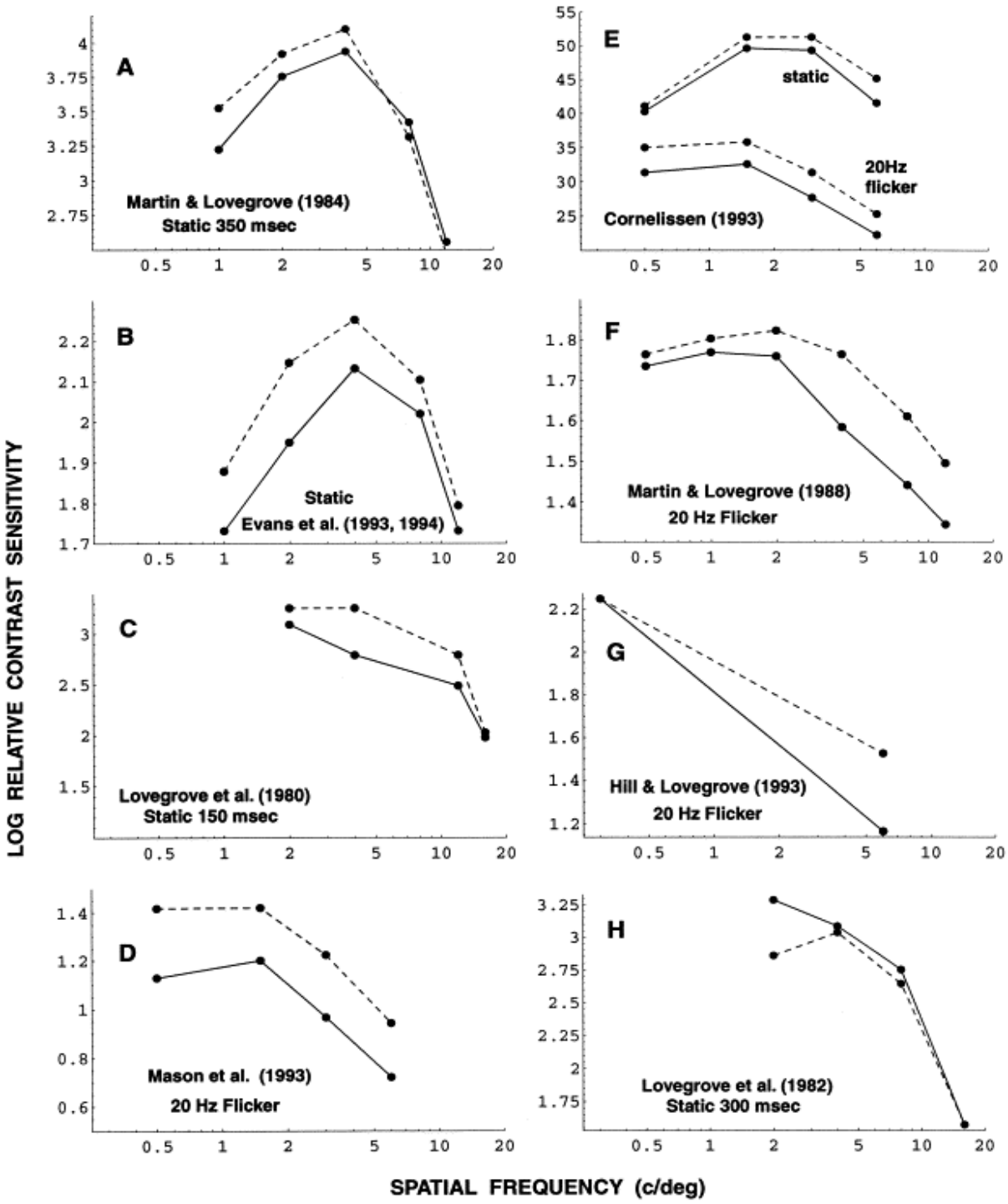

Figure 5.1 Magnocellular Deficit Theory Disputing Studies

Graphs obtained from Skottun (2000). A comparison of a selection of 8 studies investigating the relationship between dyslexics and controls in terms of contrast sensitivity across six spatial frequencies. The studies suggest varying results and neither is conclusive in terms of which group displays higher contrast sensitivity values. (Dyslexics = Solid Lines, Controls = Dashed Lines).

The results in this thesis suggest that the reading difficulty subjects examined in this study had both poor and elevated contrast sensitivity values at differing spatial frequencies This contradicts the magnocellular deficit theory, and consequently my research suggests that it is inconclusive whether subjects with dyslexia, or reading difficulties, do indeed have a magnocellular deficit. This supports previous research which proposes that there is no strong link. It is also suggested that magnocellular defects may occur in only one type of dyslexia among individuals (Borsting *et al.,* 1996). The disorder may only be present in the dysphoneidetic dyslexic group, which is a form of dyslexia which results in a combination of deficits in brain function in the Wernicke's Area and angular gyrus of the brain. My study included participants who had general reading difficulties, rather than being grouped in reading difficulty subtypes. Thus, my results do not support the magnocellular theory of dyslexia.

Moreover, the conflicting values may be due to 'negative results' present in human experiments. Negative results are due to incorrect techniques and faulty experimental design (Stein & Walsh, 1997). There are several studies which have resulted in negative results (Martin & Lovegrove, 1988, Walther – Muller, 1995, Cornelissen *et al.,* 1995) thus it is important for the experimental design to be consistent among all the studies examining the visual function of dyslexic and non – dyslexic individuals. To prevent negative results, studies would be required using diagnosed dyslexic subjects, preferably those who have been diagnosed as adults. Therefore, they have an impairment which is still present, compared to diagnosis as a child in which the impairment may have already passed. This would require a qualified psychologist trained in dyslexia assessment to assess the participants for dyslexia, which is more demanding and would have required more resources than were available during this study, considering a trained psychologists and adult dyslexia

charges around £800 per diagnosis. Additionally, a higher participant number is required to provide results which could be applicable to the general dyslexic population.

5.1.2 Additional Theories

As well as the magnocellular deficit theory, there are three other theories of dyslexia which are the phonological, cerebellar dysfunction, and visual deficit theory. The theories state that an individual is unable to read correctly either due to a lack of phonological awareness, cerebellar abnormality, or oculomotor abnormalities, respectively. It is not possible to test the effectiveness of the theories with psychophysics alone, as further research is required for each theory, such as eye tracking. Eye tracking was conducted on participants for this research, yet due to the lack of a specialist in the software as well as inaccurate software installed, there was no possibly to analyse and interpret the results. Future research can incorporate the eye tracking results in order to assess the additional theories.

However, non – invasive neuroimaging techniques are being developed with the aim of studying the dyslexic brain. This will help provide the most valid theory of dyslexia as well as help formulate successful interventions (Kershner, 2015).

5.2 Visual Training Time Comparison

It is important to distinguish the differences between training times, whether certain training times result in a greater visual improvement. (Table 5.1). This is important as it allows the investigator to determine whether a shorter training period is more beneficial.

Measurement	Group & Improvement (t – Test)			
	1 Month		2 Week	
	Action	Casual	Action	Casual
Central Temporal CS 20 Hz	Improvement at 0.5 cpd	-	-	-
Central Temporal CS 24 Hz	-	-	-	-
Static Peripheral CS	-	-	-	-
Peripheral CS 20 Hz	-	-	-	-
Peripheral CS 24 Hz	-	-	-	Improvement at 2 & 10 cpd

Table 5.1 Comparison of Training Durations

Reading difficulty (RD) subjects underwent visual training using two training periods of 1 – month (40 hour) and 2 – weeks (20 hour). After 1 month (40 hours) of action game visual training, RD subjects improved in temporal contrast sensitivity 20 Hz at 0.5 cycles per degree. After 2 weeks (20 hours) of action game visual training, RD subjects improved in peripheral contrast sensitivity at 24 Hz at 2 and 10 cycles per degree.

There was an improvement in temporal contrast sensitivity from both action and casual gaming. Temporal vision is the eye's ability to distinguish between the changes in luminance over time, such as flicker produced by light. Studies have shown that video game players have a greater temporal sensitivity when using attentional blink tasks and flanker tasks (Green & Bavelier, 2006). Action and casual games have differing image and motion parameters (frames rate) which results in the movement of an image on screen. However, there was a difference in the training periods and the visual effects which resulted from these two game trainings. This suggests that non – reading difficulty subjects can improve far greater than reading – difficulty subjects over a period of 40 hours (Table 5.2). However, as there were less training subjects in

the RD group (n = 4) compared to the NRD group (n = 11), so a smaller sample size may have had an effect.

Measurement	Training Type		
	1 Month NRD	**1 Month RD**	**2 Week RD**
Central Temporal CS 20 Hz	-	Action (0.5 cpd)	-
Central Temporal CS 24 Hz	Action (2 cpd)	-	-
Static Peripheral CS	-	-	-
Peripheral Static CS 20 Hz	Casual (10 cpd)	-	
Peripheral Static CS 24 Hz	Action (0.5 & 2 cpd) Casual (2 & 20 cpd)	-	Casual (2 & 10 cpd)

Table 5.2 Training Duration and Subject Types

Results indicate that subjects without any reading difficulties performed better compared to subjects with reading difficulties, over the same period. NRD = Non – reading difficulty, RD = Reading – Difficulty

5.3 Visual Attention Improvement

The reason for the lack of improvement across parameters may be due to a low participant number, of four, compared to the 2 – week (20 hour) training, of six. Due to the participant numbers being low, it was important to recruit the same number of subjects in both groups to prevent errors. Consequently, if the participant has results which would be classed as outliers, they can easily skew the overall results. Additionally, participants may have played their hours not equally rather than evenly throughout the one month. The participants were told to play an equal number of hours per week. But due to the study not taking place in a lab, it is not possible to establish that the participant was truthful. Therefore, they may have played all their hours a few days prior to testing, or even a few days into visual training. If the subject plays their hours well before the visual testing using MATLAB, this may result in a decline of that improvement which may explain why subjects did not perform as well after 40 hours of game training.

The training period of 2 weeks (20 hours) resulted in less improvements across more visual parameters. This may be due to a small sample size, as well as a short training period. Before training, reading difficulty subjects were poor at peripheral contrast sensitivity 24 Hz at 2 and 2 and 10 cycles per degree, respectively. Yet, after 2-week (20 hour) action visual training, they significantly improved at that specific spatial frequency. This improvement of visual function after video gaming may be due to an internal additive noise reduction (within the brain), or external noise exclusion (outside of the brain) (Li, 2010). Generally, noise exclusion and signal enhancement lead to an improvement of perception and attention (Sperling et al, 2006). During signal enhancement, signal integrity is constantly maintained during processing whilst noise exclusion results in the optimization of the perceptual filter. This results in the signal being processed and the noise excluded. Sperling et al. (2006) stated that deficits in noise exclusion leads to the symptoms of dyslexia. Therefore, as dyslexic individuals have difficulty in targeting visual information during the ongoing presence of visual perceptual distractions, this leads to their inability to filter environmental distractors. In result, they are unable to distinguish and separate sensory information that is deemed relevant and irrelevant.

Visual attention is important in terms of distinguishing between noise as it allows the individual to process information that they are confronted with, and to prioritize important information whilst ignoring others (Carrasco, 2011). Thus, visual training could likely result in the improvement of visual attention, as attention is generally impaired in subjects who have poor reading skills (Stein, 2014). Additionally, this improvement in these parameters after visual training would support the new theory that dyslexia is due to deficits in noise exclusion (Sperling *et al*., 2006) and that can be trained and improved.

5.4 Reading Therapy in Video Games

Casual gaming led to improvements in peripheral contrast sensitivity 24 Hz after 2 weeks (20 hours) of visual training at 2 and 10 cycles per degree. Civilization is a turn-based game and requires the player to constantly read to proceed to the next stages (Figure 5.2). Examples include reading leader's traits, city and empire histories, and enemy civilization summaries. The improvement due to casual gaming may therefore be due to the individual reading and playing, rather than only playing the casual game. As reading is a form of therapy for dyslexia, it helps the individual to read better and results in language activity of the brain (Narayana & Xiong, 2003).

Figure 5.2 Screenshot of Civilization 4

In this casual game, reading is required to progress to the next stages, such as selecting the next leader. If the player is unable to read the text, they will not be able to succeed in the game, and therefore gameplay will end abruptly.

Studies have been conducted which demonstrated that reading therapy led to both an improvement in visual function and reading ability. Narayana & Xiong (2003) tested 10 children who underwent reading therapy for 28 hours. This resulted in an improvement in reading ability, and therefore this may also result in contrast sensitivity improvements. Franceschini *et al.* (2017) conducted a study examining dyslexic children who took part in visual training playing either an action or non – action game. Visual training using action games resulted in improved word reading ability, phonological decoding, and visual function specifically attention. This is important as my results suggest that a combination of both reading therapy and visual training using video game play may improve deficits associated with reading difficulties There were no visual nor reading improvements using non – action games, but this difference to the results found in this thesis may be due to the type of non – action (casual) game used.

Figure 5.3 Screenshot of 'Bunnies Don't Give Gifts'

During the game play, the bunny must run to its destination before the bomb explodes. Therefore, there is no complex reading involved, aside from the timer at the top of the screen.

Franceschini *et al.* (2017) used a casual game called ‘’Bunnies Don’t Give Gifts’’ (Figure 5.3) which is less complex compared to Civilization 4 in terms of content. The game ‘’Bunnies Don’t Give Gifts’’ is a minigame in which the main character, a rabbit, must run to its destination before a bomb explodes. There is no complex text aside from a timer which is at the top of the screen.

As Civilization 4 involves reading this could result in an improvement of visual function. Additionally, the Civilization game series is also education – focused, and has been introduced and available to play in certain schools in North America from 2017. The game will allow students to think critically about historical events as well as make decisions which can influence the future of society in the game. The creator of Civilization, Sid Meier, stated that ‘’For the past 25 years, we’ve found that one of the fun secrets of Civilization is learning while you play’’. So, as it is an educational game, learning may result in greater attention. However, previous research has been conducted using casual games and suggests that casual games can improve visual attention, whilst other research suggests the opposite, as mentioned in Chapter 2. This may be due to the difference in the game, as casual games have many subtypes.

Additionally, ‘reading therapy video games’ are readily available online as well as to purchase (www.thedyslexiashop.co.uk). The video games and board games claim to improve spelling, letter reversals, concentration, and so on. Reading therapy may be beneficial to subjects with reading difficulties who have never experienced reading therapy before. Therefore, a video game should be created which can contain the movement of an action game and the word content as in reading therapy. This may result in further improvements in visual function for subjects with reading difficulties as both therapy types are applied in one video game.

5.5 Future Research Directions

Future improvements are required to establish whether video gaming does indeed improve visual function in adults with reading difficulties, and whether a game with reading results in a larger improvement. My study suggested that action and casual video game training did improve the visual function of those with reading difficulties. However, the improvements were not seen across all visual parameters and the improvements in high spatial frequencies may not be reliable. This outcome may be due to a variation and a low number of participants. A large-scale study is required using adult – diagnosed subjects preferably from the NHS, rather than a private psychologist as their testing methods vary.

Also, as the problems experienced from reading difficulties vary along a spectrum, some subjects may have been higher on the spectrum, whilst others lower. Thus, subjects higher on the spectrum may require additional training time or a different and more intense game to produce visual improvements. Furthermore, some subjects may not react as well to video games compared to others, due to boredom or their general personality.

Additionally, as the improvement were both due to action and casual gaming, this would suggest that the type of game used is important during visual training. Games which include aspects of reading therapy as well as moving image may lead to more improvements, compared to simple casual games with less content, such as ‘Candy Crush’. Thus, a wider selection of games must be used in the future, as well as popular video games to identify whether they hold any potential.

Moreover, different action games were used for the RD and NRD subjects. The RD subjects had difficulty with the initial game play, as the game was ‘too dark’

(Doom). Thus, the game had to be changed to a 'brighter' but similar game (Half – Life). Therefore, any changes in visual improvement may also be because two separate games were used for the RD and NRD subjects even though they were both action games. An explanation of why the RD subjects found the prior game to be too dark may be due to their contrast sensitivity already being impaired, compared to NRD subjects.

5.6 Amblyope vs Adult RD Improvements

As amblyopia is also a condition of the visual system, there is also possibility to train and enhance that system through visual training. Li *et al.* (2008) reported that amblyopia requires more than 50 hours of training to show a 5-fold improvement of visual function. The results from the RD subjects indicate that less visual training is required, as only 40 and 20 hours of training produced significant effects. In support, a study conducted on training dyslexic children using only 12 hours of training over 2 weeks also produced significant improvements in visual function (Franceschini *et al.* 2013, 2017).

As there are cases of adults who have both amblyopia and dyslexia (Barban *et al.,* 2010), visual training may improve the visual function and reading ability for those adults. A future study is required to assess this type of treatment. Yet, it is important to establish how many amblyopes do indeed have dyslexia and research on this is scarce. A study conducted by Koklanis *et al.* (2006) reported that only 5% of the amblyopic children assessed had a specific reading difficulty. The reading difficulty resulted in a lack of phonological awareness and decoding words. Moreover, Koklanis *et al.* (2006) suggested that amblyopia may be associated with a deficit in rapid automatized naming, which is the ability to name aloud random objects, letters, or

colors. Rapid automatized naming differentiates dyslexic children from controls (Denckla & Rudel, 1976) as it is an important indicator of dyslexia (Bexkens *et al*., 2015).

An amblyopic experiment was attempted during this study; however, it was not possible to replicate the exact methods as in previous research. The subjects were not able to see through their amblyopic eye and thus were not able to train visually. A specially designed study is required for amblyopic subjects which could also apply to reading difficulty subjects to compare the visual improvements of both disorders. This requires a specialist optometrist who can assist in the design of a study investigating amblyopic vision.

The aim of this research was to eventually establish whether visual training improves visual function in subjects with self – reported reading difficulties. Experimental steps were initially taken to show whether visual training can indeed improve visual function in adults with and without reading difficulties. A generally summary of the dissertation is outlined in Section 5.7.

5.7 Summary of the Work

In Experiment 1, existing video game players were analysed to establish whether they do indeed have superior visual function, compared to controls, as reported in previous research. The results reported that action gamers do have a higher contrast sensitivity in temporal vision at a higher flicker rate of 24 Hz. Additionally, compared to controls, the action video game players had higher contrast sensitivity levels at low frequencies of 0.5 and 2 cycles per degree in both temporal and peripheral vision of 24 Hz. These results indicate that action video game play does improve contrast sensitivity and that video game play is beneficial for vision in healthy adults.

In Experiment 2, subjects took part in 120 hours of visual training over 3 months to establish whether a longer training period produces larger visual improvements. There was a change of contrast sensitivity in both temporal and peripheral contrast sensitivity 24 Hz. Further analysis revealed that solely action game training resulted in these improvements in a total of five spatial frequencies across three visual parameters. Thus, it is possible to train the human visual system to enhance contrast sensitivity. This further supports action video games as a beneficial and superior type of game, due to the effects which result from its game play.

In Experiment 3, subjects took part in 40 hours of visual training over 1 month to establish whether a shorter training period produces similar improvements to that of 120 hours. Training over a shorter period results in a total of four contrast sensitivity changes in temporal and peripheral contrast sensitivity 24 Hz, static peripheral contrast sensitivity, and peripheral contrast sensitivity 20 Hz. Further analysis revealed that both action and casual game training resulted in visual improvements. This is the first experiment in which casual games prove to be effective in visual training. The reason for the improvement because of casual gaming may be due to the subject participating more actively in the game play, and thus resulting in a higher frame rate. Additionally, training over a shorter period is more effective compared to a longer period. Therefore, short training periods may be as effective as long training periods.

In Experiment 4, trained visual function was assessed one-month post-game play. This was required to identify whether the visual improvements are long lasting. The results reported that the decline was only present in two occasions (temporal and peripheral contrast sensitivity 24 Hz) from action game training and at a high spatial frequency of 20 cycles per degree. This suggests that visual training is long lasting

and only deteriorates at the high spatial frequencies. Therefore, video game training may only be required occasionally, rather than periodically, as the improvement in long lasting.

In Experiment 5, subjects with reading difficulties had visual training over a period of 1 Month (40 hours). Training resulted in an improvement in temporal contrast sensitivity 20 Hz at a low spatial frequency of 0.5 cycles per degree, due to action gaming. The lack of further improvements may be due to the small sample size and the varying degrees of reading impairment, and thus visual impairment.

In Experiment 6, reading difficulty subjects had visual training over a period of 2 weeks (20 hours) to assess whether a shorter training period results in similar improvements. Visual training resulted in improvements from both action and casual gaming in peripheral contrast sensitivity 20 and 24 Hz. The improvement from casual gaming may be due to the type of casual game used, as it differs from the simple casual games used in previous research. Furthermore, the results do not support the controversial magnocellular deficit theory, which is highly disputed. In addition, the improvement of visual function may be due to attentional capacity training. Visual attention is impaired in those with poor reading skills (Stein, 2014) and visual attention can be trained using video games (Green and Bavelier 2003; Huber – Wallander et al., 2011).

Indeed, visual attention is an important parameter of visual function. It is improved in those who play video games, and impaired in those who have reading difficulties. Visual attention allows the subject to concentrate on the task ahead and to ignore irrelevant information and process relevant information. Reading difficulties prevents the visual attentional processes to be allocated correctly due to external

noise, as supported by Lu and Dosher (1997). The visual training results in a reduction of internal additive noise and an exclusion of external noise. Thus, the video game player can improve channels related to the task whilst reducing irrelevant channels, both of which are present in the cortical level. In result, due to this concentration, this results in active perceptual learning both for subjects with and without reading difficulties.

5.8 Main Contribution to Knowledge

Visual training improved visual function in adults who suffer from reading difficulties, using both action and casual video games. Yet, due to the unexpected improvement from the casual game, this may be due to the game itself rather than the genre. Thus, it is of interest to compare different subtypes of casual games to establish whether some casual games are more beneficial than others. Game training can therefore be used as a form of visual therapy for those with self – reported visual difficulties to complete at home. This is highly optimistic as not everyone has access to healthcare and the availability of a dyslexia assessment, either due to geographical location or financial burden. Video game play may also be used by adults who have both amblyopia and reading difficulties (or dyslexia), as both share a deficit in automatized naming (Bexkens *et al.,* 2015). Action video game play remains the gold standard gaming genre for visual improvement in people with reading difficulties, as supported by previous research.

In conclusion, video game play may improve certain aspects of visual function in adults with reading difficulties. Video game play has already shown to prove more effective than reading therapy alone. Reading therapy costs £8,236 (North West Reading Clinic prices, 2018) compared to £18 for Civilization, which is a total saving

of £8,218 per year. Thus, video games are cheaper, more enjoyable, and easily accessible for the wider population throughout the world and for all ages. Future research is required using a larger sample size and diagnosed adult dyslexics. Additionally, the training must take place in a controlled situation to prevent false positives and false negatives. It is also of interest to apply the visual training to reading improvements, not just in visual function improvements. In general, video gaming is an excellent tool for perceptual learning and brain plasticity.

Acronyms

AVGP Action video game player

CPD Cycles per degree

CREST Comparative rate of reading test

CS Contrast sensitivity

CSF Contrast sensitivity function

CVGP Casual video game player

FrACT Freiburg visual acuity and contrast test

HZ Hertz

LGN Lateral geniculate nucleus

M Magnocellular

MATLAB matrix laboratory (created by Mathworks)

NRD Non – reading difficulty

NVGP Non – video game player

P Parvocellular

RD Reading difficulty

SD Standard deviation

SF Spatial frequency

VA Visual acuity

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APPENDIX A: Ethical Approval Form

APPLICATION FORM FOR ETHICAL REVIEW RE4 FOR RESEARCH INVOLVING HUMAN PARTICIPANTS

Project title:

Assessing different styles of video game play as suitable visual training tasks for amblyopes and people with reading difficulties.

Name of the lead applicant:

Name (Title / first name / surname):	Agne Mikailionyte
Position held:	PhD Student
Department/School/Faculty:	SEC
Telephone:	07432086955
Email address:	K1011131@kingston.ac.uk

Name of co-applicants:

Name (Title / first name / surname):	Prof. Barbara Pierscionek
Position held:	Associate Dean - Research and Enterprise
Department/School/Faculty:	Faculty Wide
Telephone:	0208 417 4821
Email address:	B.Pierscionek@kingston.ac.uk

Name (Title / first name / surname):	Dr Jan S. Lauritzen
Position held:	Senior Lecturer
Department/School/Faculty:	Life Sciences/ SEC
Telephone:	Ext 62935
Email address:	j.lauritzen@kingston.ac.uk

Is the project:	Student research	Yes	X	No	
	KU Staff research	Yes	X	No	
	Research on KU premises	Yes	X	No	

If it is STUDENT research:

Course title	PhD
Supervisor/DoS	Dr Jan S. Lauritzen

Provide a brief project description (max. 150 words). This should be written for a lay audience

A reading difficulty (RD) is a major drawback in society as it prevents the individual from accessing information and this could lead to social disadvantage. This condition occurs in around 5 – 10% of the population. Children with RD also have more visual impairments compared to those without RD. RD may be due to impairment in reading comprehension preventing the individual from understanding what they read. Additionally, RD has been shown to present with visual function deficits such as a decreased sensitivity to motion, contrast, and flicker. The aim of this study is to identify whether video game playing improves visual function that is deficient in adults with RD. This will be compared to individuals with amblyopia, who are known to experience difficulties with a range of basic visual functions and who would benefit from visual training. Different types of video game will be used to assess whether the nature of the interaction with the visual stimulus impacts on its suitability as a training task.

Estimate duration of the project (months)	24
State the source of funding	Kingston University PhD Studentship

Briefly describe the procedures to be used which involve human participants

- Participants will be recruited using a poster which will be placed around Kingston University. The poster will ask the individual whether they perceive themselves to have a reading difficulty or whether they have amblyopia. Additionally, the research will be advertised using Facebook on the study page.

- Informed consent will be sought from the participants. The information form as well as the following questionnaire may be read out to the participant if they require. The study will take place in a closed room ensuring privacy.

- A questionnaire will be used to assess the frequency of game play of the participant and their visual experience.

- Participants will have their visual acuity tested using the Freiburg Visual Acuity and Contrast Test, which involves the participant using a mouse in order to respond to the stimuli presented on the screen.

- A series of psychophysical tests will be conducted (static and temporal contrast sensitivity, peripheral contrast sensitivity, isoluminant chromatic contrast sensitivity, and motion detection and discrimination). These tests require a response using a mouse, corresponding to stimuli presented on the screen. If the participant requires, they may take a break during the tests or complete the tests in two different visits.

- After the experiments, the individuals will be given a training schedule with an action video game (Doom 3) or a casual game (Civilization 4) to play using their personal computer. The training period is 10 hours per week over the period of 1 month, thus totalling 40 hours. This training period was identified by completing a pilot study which has indicated an improvement in visual function in healthy participants. Additionally, it is a reasonable training period that does not require a lengthy time commitment. The participant will have to play the selected video game regularly over the defined training period.

Summarise the data sources to be used in the project

- Information that is disclosed in the questionnaire by the participant.
- Visual acuity results from the Freiburg Visual Acuity and Contrast Test.
- Psychophysical measures of visual performance.

Storage, access and disposal of data

Describe what research data will be stored, where, for what period of time, the measures that will be put in place to ensure security of the data, who will have access to the data, and the method and timing of disposal of the data.

All data collected will be anonymized and stored on a password protected computer system. The data will also be encrypted and password protected.

All documentation permitting individual subjects to be linked to a particular set of results or questionnaire responses will be stored in a locked cabinet that only the principal investigators have access to, and these records will be kept for the duration of the project. Afterwards, the data will be kept in order to publish the research as raw data is required. Data will be kept for a period of 5 years after the end of the study.

There is no foreseeable risk associated with accidental disclosure of this data.

Risk Assessment Questionnaire: Does the proposed research involve any of the following?

		YES	NO
0.	The use of human biological material?		X
1.	Children or young people under 18 years of age?		X
1.a	If YES, have you complied with the requirements of the DBS?		
2.	People with an intellectual or mental impairment, temporary or permanent?		X
3.	People highly dependent on medical care, e.g., emergency care, intensive care, neonatal intensive care, terminally ill, or unconscious?		X
4.	Prisoners, illegal immigrants or financially destitute?		X
5.	Women who are known to be pregnant?		X
6.	Will people from a specific ethnic, cultural or indigenous group be targeted in the proposed research, or is there potential that they may be targeted?		X
7.	Assisted reproductive technology?		X
8.	Human genetic research?		X
9.	Epidemiology research?		X
10.	Stem cell research?		X
11.	Use of environmentally toxic chemicals?		X
12.	Use of ionizing radiation?		X
13.	Ingestion of potentially harmful or harmful dose of foods, fluids or drugs?		X
14.	Contravention of social/cultural boundaries?		X
15.	Involves use of data without prior consent?		X
16.	Involves bodily contact?		X
17.	Compromising professional boundaries between participants and researchers?		X
18.	Deception of participants, concealment or covert observation?		X
19.	Will this research significantly affect the health* outcomes or health services of subjects or communities?		X
20.	Is there a significant risk of enduring physical and/or psychological harm/distress to participants?		X
21.	Does your research raise any issues of personal safety for you or other researchers involved? (especially if taking place outside working hours or off KU premises)		X

22.	Will the research be conducted without written informed consent being obtained from the participants?		X
23.	Will financial/in kind payments (other than reasonable expenses and compensation for time) be offered to participants? (Indicate in the proposal how much and on what basis)		X
24.	Is there a potential danger to participants in case of accidental unauthorised access to data?		X

[**Note** *health is defined as not just the physical well-being of the individual but also the social, emotional and cultural well-being of the whole community].

SECTION D ***(To be signed by all applicants)***
Declaration to be signed by the applicant(s) and the supervisor (in the case of a student):

- I confirm that the research will be undertaken in accordance with the Kingston University *Guidance and procedures for undertaking research involving human participants.*

- I will undertake to report formally to the relevant Faculty Research Ethics Committee for continuing review approval where required.

- I shall ensure that any changes in approved research protocols or membership of the research team are reported promptly for approval by the relevant Faculty Research Ethics Committee.

- I shall ensure that the research study complies with the law and University policy on Health and Safety.

- I confirm that the research study is compliant with the requirements of the Disclosure and Barring Service where applicable.

- I am satisfied that the research study is compliant with the Data Protection Act 1998, and that necessary arrangements have been, or will be made with regard to the storage and processing of participants' personal information and generally, to ensure confidentiality of such data supplied and generated in the course of the research.
  (Further advice may be sought from the Data Protection Officer, University Secretary's Office)

- I shall ensure that the research is undertaken in accordance with the University's Single Equality Scheme.

- I will ensure that all adverse or unforeseen problems arising from the research project are reported immediately to the Chair of the relevant Faculty Research Ethics Committee.

- I will undertake to provide notification when the study is complete and if it fails to start or is abandoned;

- (For supervisors, *if the applicant is a student)* I have met and advised the student on the ethical aspects of the study design, and am satisfied that it complies with the current professional (*where relevant),* departmental and University guidelines. I accept responsibility for the conduct of this research and the maintenance of any consent

documents as required by this Committee.

- I understand that failure to provide accurate information can invalidate ethical approval.

Is this an application for fast-track ethical approval?	**Yes**	X	**No**	

Please sign and date	*Signature*	*Date*
Lead applicant	Agne Mikailionyte	20/11/2014
Co-applicant	Dr Jan S. Lauritzen	20/11/014

APPENDIX B: Email/ Letter Provided to Participants

Dear Participant,

Study of whether different styles of video game play act as a suitable visual training task for amblyopes and people with reading difficulties.

Computer gaming could potentially serve as an enjoyable and low cost treatment for individuals with amblyopia or reading difficulties. We are conducting a study to find out whether certain types of game play can improve vision in people with either amblyopia or reading difficulties. We are asking you if you would help us with a study that involves completing a questionnaire on your video game usage and whether you have amblyopia (Lazy eye) or a reading difficulty. Afterwards, you would take part in a series of computerized measurements of visual function that require you to respond to what you see on a screen using a mouse. There is no contact or administration of any medication involved in any of these tests. You would then be randomly allocated to one of three training groups (action gaming, casual gaming, no gaming / control) and given a specific free of charge action or casual game that we would ask you to play regularly over a specified training period (games value of approx. £10). If you are assigned to the control group, you may choose a copy of either game at the end of the study. The training period will be 10 hours per week for a total of 40 month (thus 40 hours overall). We will then repeat the computerized measurement test to see whether there has been a change in any measures of visual function. If you agree to participate in this study, we would ask you to come to the psychophysics laboratory in Kingston University on several occasions (before and after your training), at your convenience, where you will be asked to complete a questionnaire and to participate in the computerized visual tests.

There are no side effects of this study but some participants may experience tired eyes. You can interrupt testing to take a break at any time and we can arrange testing sessions as best suits you. In the very unlikely case of experiencing further visual discomfort, you may be advised to see your optometrist or GP. If you agree to take part in this study, you can leave it at any time.

All data we obtain will be treated in a strictly confidential manner. The only people who will have access to the information will be Dr Jan Lauritzen and PhD student Agne Mikailionyte. After the project all raw data will be kept for the duration of 5 years for research publication. In the reporting of the project, no information will be released that will enable the reader to identify who the respondents were. If you have any questions or problems, please contact me. The telephone number to Dr Jan Lauritzen is 020 8417 2935.

Yours sincerely

Agne Mikailionyte

Contact details:

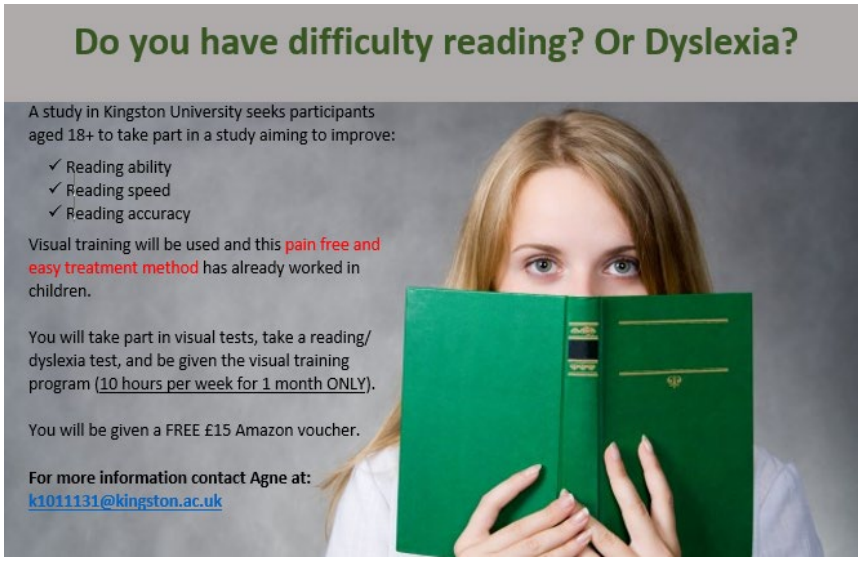
1. Researcher contact details in case of query:

Agne Mikailionyte, School of Life Science, Faculty of Science, Engineering and Computing, Kingston University. E-mail: k1011131@kingston.ac.uk

2. In case of complaint:

Dr Lucy Jones, Acting Dean, Faculty Wide, Kingston University. E-mail: L.Jones@kingston.ac.uk

APPENDIX C: Poster Adverts



APPENDIX D: MATLAB Script

```
% Setup PTB with some default values

PsychDefaultSetup(2);

% Set the screen number to the external secondary monitor if there is one

% connected

screenNumber = max(Screen('Screens'));

% Define black, white and grey

white = WhiteIndex(screenNumber);

grey = white / 2;

% Skip sync tests for demo purposes only

Screen('Preference', 'SkipSyncTests', 2);

% Open the screen

[window, windowRect] = PsychImaging('OpenWindow', screenNumber, grey, [], 32, 2,...

    [], [],  kPsychNeed32BPCFloat);

%--------------------

% Gabor information

%--------------------

% Dimension of the region where will draw the Gabor in pixels

gaborDimPix = windowRect(4) / 2;



% Sigma of Gaussian

sigma = gaborDimPix / 7;
```

```
% Obvious Parameters

orientation = 0;

contrast = 0.8;

aspectRatio = 1.0;

phase = 0;

% Spatial Frequency (Cycles Per Pixel)

% One Cycle = Grey-Black-Grey-White-Grey i.e. One Black and One White Lobe

numCycles = 5;

freq = numCycles / gaborDimPix;

% Build a procedural gabor texture (Note: to get a "standard" Gabor patch

% we set a grey background offset, disable normalisation, and set a

% pre-contrast multiplier of 0.5.

% For full details see:

% https://groups.yahoo.com/neo/groups/psychtoolbox/conversations/topics/9174

backgroundOffset = [0.5 0.5 0.5 0.0];

disableNorm = 1;

preContrastMultiplier = 0.5;

gabortex = CreateProceduralGabor(window, gaborDimPix, gaborDimPix, [],...

    backgroundOffset, disableNorm, preContrastMultiplier);

% Randomise the phase of the Gabors and make a properties matrix.

propertiesMat = [phase, freq, sigma, contrast, aspectRatio, 0, 0, 0];

%----------------------------------------
```

```
%    Draw stuff - button press to exit
%----------------------------------------
% Draw the Gabor. By default PTB will draw this in the center of the screen
% for us.
Screen('DrawTextures', window, gabortex, [], [], orientation, [], [], [], [],...
    kPsychDontDoRotation, propertiesMat');
% Flip to the screen
Screen('Flip', window);
% Wait for a button press to exit
KbWait;
% Clear screen
sca;
```

Adapted from Grating Demo in Psychtoolbox (Psychtoolbox/PsychDemos/GratingDemo.m) (Brainard, 1997; Pelli, 1997)