Optimization of Sweep Visually Evoked Potential (sVEP) in Adults

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Science
in
Vision Science

Waterloo, Ontario, Canada, 2008

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Purpose and hypothesis: The purpose of this study was to optimize and standardize the following parameters of sweep Visually Evoked Potential (sVEP) in adults: criteria for fitting the regression line to estimate threshold, luminance, electrode placement, temporal frequency, sweep direction, presence of fixation target and stimulus area. The hypothesis is that the parameters chosen will have an impact on the measured visual acuity, contrast threshold and on the number of viable sVEP plots.

Methods: The Power Diva software, Version 1.9 was used for this study. Five gold cup active electrodes, one reference electrode and one ground electrode were used to measure the Electroencephalography (EEG) signals. Six adult participants (aged 17 to 35 years), with corrected to normal visual acuity and no history of ocular disease took part in each experiment, except for the repeatability experiment in which 3 subjects participated. Four criteria for regression line fitting were compared. Psychophysical thresholds were used to validate the sVEP measures for the different criterion and repeatability of sVEP was estimated for 10 sessions. The effect of luminance (25 cd/m^2, 50 cd/m^2, 100 cd/m^2), electrode placement (Power Diva and ISCEV), temporal frequency (6 Hz, 7.5 Hz, 10 Hz), sweep direction, fixation target and stimulus area were investigated. A repeated measure ANOVA statistical method was used to analyze the average threshold and the number of viable plots out of five active channels for all subjects.

Results: Criterion 2 and 3 gave better visual acuity, higher contrast sensitivity, better repeatability and gave results that were closer to the psychophysical threshold than criterion 0 and 1. Luminance of 25 cd/m^2 gave significantly fewer viable readings than 50 and 100

cd/m^2 while measuring visual acuity (F = 5.11, df = 2, p = 0.0295). Temporal frequency of 7.5 Hz gave significantly more viable readings than 6 and 10 Hz while measuring visual acuity (F = 50.53, df = 2, p < 0.0001) and contrast threshold (F = 9.87, df = 2,p = 0.0043). There was a highly significant interaction of criterion with temporal frequency (F = 1536.98, df = 6, p < 0.0001) while measuring contrast threshold. There was a significant interaction of criterion with sweep direction (F = 4.26, df = 3, p = 0.0231) and for the number of readings (F = 3.75, df = 3, p = 0.0343) while measuring visual acuity. There was an interaction of criterion with sweep direction (F = 4.97, df = 3, p = 0.0136) while measuring contrast threshold at a spatial frequency of 1 cpd. There was a significant effect of fixation target (F = 7.64, df = 1, p = 0.0396) while measuring visual acuity. There was a significant effect of stimulus area (F = 11.78, df = 4, p < 0.0001) on the number of readings while measuring contrast threshold.

Conclusion: The sVEP parameters chosen do have a significant effect on visual acuity, contrast threshold and on the number of viable readings. The following parameters are recommended in adults on the basis of results; Criterion 2 or 3 for fitting regression line (C2 - regression line fitted from the signal peak amplitude to the last data point with a signal to noise ratio (SNR) >1; C3 – similar to criterion 2, but the threshold should be within sweep range used), luminance of 50 or 100 cd/m^2 , either Power Diva (PD) or International Society for Clinical Electrophysiology of Vision (ISCEV) electrode placement, temporal frequency of 7.5 Hz, either sweep direction, measurement with the central fixation target, larger stimulus area.

Acknowledgements

I am indebted to my supervisors Dr. Susan J. Leat and Dr. Elizabeth L. Irving for their guidance and invaluable suggestions. Gratitude is also expressed to my committee members Dr. Trefford L. Simpson and Dr. Marlee Spafford for their suggestions in formulating this research and in drafting this manuscript. I thank the Graduate Officers Dr. Thomas Singer and Dr. Natalie Hutchings and the Graduate coordinator Krista Parson for their help and for keeping me on track. I thank my fellow graduate students, staff and faculty of the School of Optometry for providing a pleasant work environment.

Dedication

This thesis is dedicated to my loving parents and my family members whose constant support helped me in this endeavor.

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Chapter 1: Introduction

1.1 Visual acuity and contrast threshold

Visual acuity - Visual acuity is defined as the resolving power of the eye. There are at least two types of visual acuity: recognition acuity and resolution acuity (Leat et al., 1999). Recognition acuity is the smallest size of a letter, number or shape that can be recognised or discriminated and resolution acuity is the smallest separation between dots or between bars in a grating that can be resolved. Visual acuity is a very important factor for an individual, as it helps in reading (Legge, 1990), face recognition (Bullimore et al., 1991) and identification of objects.

Contrast threshold - Contrast threshold is defined as "the lower contrast detectable for a given size of stimulus" (Leat et al., 1999). The measurement of contrast sensitivity has emerged as "the most complete single measure of human spatial vision" (Adams and Courage, 2002). Contrast sensitivity is the reciprocal of contrast threshold (Contrast sensitivity = 1/contrast threshold). Contrast threshold is expressed in contrast, in a logarithmic$_{10}$ scale or in a linear scale. For example, contrast threshold of 0.1 is a log contrast threshold of – 1 and gives a contrast sensitivity of 10, and a log contrast sensitivity of 1. The contrast sensitivity across a range of spatial frequencies gives the measure of contrast sensitivity function (CSF). The human psychophysical CSF peaks in the region of 4 cycles/degree (cpd).

1.2 Visual Evoked Potential (VEP)

VEP can be used to measure changes in electrical potentials in the striate occipital cortex in response to visual stimulation. Other electrophysiological tests such as electro-oculogram (EOG) and electroretinogram (ERG) measure activities in the retina or retinal ganglion cells. To measure VEPs, cup shaped silver or gold electrodes are placed on the scalp in the occipital region. These electrodes are used to measure Electroencephalography (EEG) signals from the visual cortex. To separate the VEP response from other EEG signals/electrical noise, repeated evoked responses are averaged. The VEP is a time-locked response to the stimulus i.e. the changes in the electrical activity of the visual cortex, occur at a particular time after each stimulus presentation. Therefore, by averaging these responses, the responses that are not in synchrony with the stimulus (EEG and noise) cancel and the VEP waveform can be extracted. Standards for some VEP recording have been developed by the International Society for Clinical Electrophysiology of Vision (ISCEV). These standards were modified in 2004 (Odom et. al., 2004).

1.2.1 Physiological pathway of VEP

To elicit a VEP response, the stimulus has to reach the photoreceptors and then on to the retinal ganglion cells. From retinal ganglion cell through the optic nerve and optic chiasma it reaches the lateral geniculate nucleus (LGN) and then to the optic radiations. The primary visual cortex receives visual projections from the optic radiations. The VEP is considered to be due to neuronal electrical activity in the primary visual cortex in response to the stimulus. The primary visual cortex, also called the striate cortex, is designated as V1. It is not a flat surface but it folds inwards to form the calcarine sulcus. There are thought to be three

physiological categories of retinal ganglion cells i.e. the parvocellular (P) pathway, the magnocellular (M) pathway and the koniocellular pathway (Hendry and Reid, 2000; Rodieck and Watanabe, 1993) which carry information from the retinal ganglion cells to the LGN to the primary visual cortex to elicit a VEP response. The magnocellular pathway carries information from the large ganglion cells and the parvocellular pathway carries information from smaller retinal ganglion cells. The M pathway is believed to be primarily responsible for the mediation of information regarding movement of objects, high temporal frequencies, low spatial frequencies and very low contrast targets. The P pathway is considered to be the main carrier of high contrast, color information and high spatial frequency information, especially at lower temporal frequency. The koniocellular pathway is related to form (Lam. B. L, 2005).

1.2.2 Types of VEP covered by ISCEV standard

The description of the pattern VEP and flash VEP mentioned below are taken from Odom et. al. (2004). Both transient pattern VEP and transient flash VEP have ISCEV standards and are used in clinics for diagnostic purposes. Pattern VEP can be for pattern reversal or pattern onset/offset. A transient VEP response occurs when the stimulus is modulated at a temporal frequency of less than 5 Hz. In transient VEP, responses are produced only when the stimulus rates are slow enough to allow the brain to recover to its resting state between stimuli.

1.2.2.1 Flash VEP (fVEP)

The fVEP is elicited by a flash stimulus that subtends a visual field of at least 20 degrees. The fVEP stimulus parameters are based on the international full-field ERG standard (Marmor et. al., 2004; Odom et. al., 2004). In the fVEP, a white flash stimulus is flashed in a full-field dome in the presence of a light adapting background. According to the ERG standards, the flash should have a brightness of 1.5-3 cd/m^2 with a background of 15-30 cd/m^2 and the flash should be presented less than 1.5 times per second. fVEP waveforms are much more variable among subjects than the pattern VEP (pVEP). The nomenclature consists of designating peaks as negative or positive followed by the typical mean peak latency (Figure 1.1), P being a positive peak and N being a negative peak or trough. This nomenclature is recommended to differentiate the fVEP from the pVEP. In fVEP, the most prominent components are the N2 and P2 peaks. The amplitude of the P2 is measured vertically from the preceding negative peak N2 to the positive peak P2. The latency of the P2 peak is around 100-120 msec in visually normal subjects. fVEP is used for patients with poor visual acuity due to dense media opacities or poor fixation due to nystagmus (Odom et. al., 2004; Lam. B. L, 2005).

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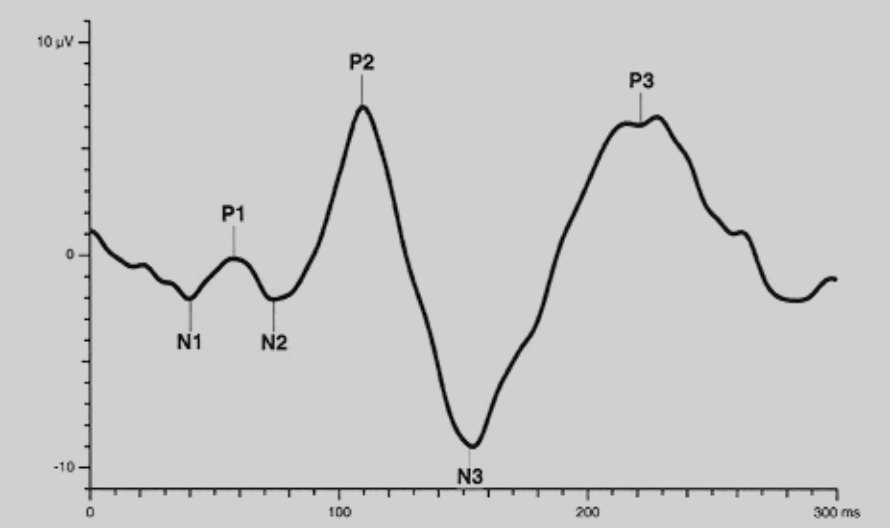


Figure 1.1: A normal flash VEP (Graph taken from Odom et al., 2004, Permission obtained from the Springer Link publisher, as shown in Appendix A.4)

1.2.2.2 Pattern reversal VEP

In pattern VEP, a checkerboard pattern, horizontal or vertical grating pattern stimulus can be used. According to ISCEV standards (Odom et. al., 2004), the pattern reversal stimulus consists of a checkerboard-like alternating black and white square check pattern, that changes in a regular frequency (black to white and white to black). The pattern reversal stimulus consists of equal number of alternating black and white squares. The pattern stimulus can include a fixation point, which is located at the center of the stimulus at the common corner of the central four checks. According to the ISCEV standards, the luminance of the white check squares should be at least 80 cd/m^2 and the contrast should be at least 75% . The pattern stimulus rate of reversal should be between 1-3 reversals per second i.e. 0.5-1.5 Hz to elicit the transient pVEP response. The pattern stimulus is defined in terms of the visual angle. According to the ISCEV standards, 15, 30 and 60 minutes of arc check sizes are recommended for obtaining a pVEP response. The large 60 arc minutes check

stimulus will elicit the response from the parafovea and the small 15 arc minutes check stimulus will elicit the response from the fovea. The overall size of the stimulus recommended by ISCEV should be greater than 15 degrees at its narrowest dimensions. Variability of waveform and peak latency are low for pattern reversal stimulus both within a subject and over the visually normal population. Therefore, transient VEP is the preferred clinical VEP examination. The pattern reversal transient VEP waveform consists of N75, P100 and N135 peaks (Figure 1.2), P being a positive peak and N being a negative peak or trough. The amplitude of P100 is measured vertically from the preceding negative peak N75 to the peak of P100. The latency is defined as the time from stimulus onset to the peak of each component. The P100 peak has a latency close to 100 msec in visually normal subjects. However, in pattern reversal VEP, peak P100 latency is affected by parameters such as pattern size, contrast and mean luminance. It is also affected by the refractive error, poor fixation and miosis (Odom et. al., 2004; Lam. B. L, 2005).

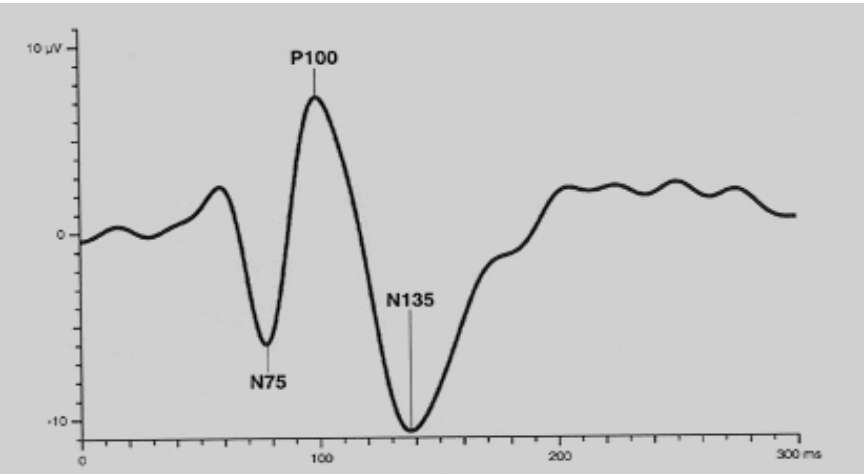


Figure 1.2: A normal pattern reversal VEP (Graph taken from Odom et al., 2004, Permission obtained from the Springer Link publisher,as shown in Appendix A.4)

1.2.2.3 Pattern onset/offset VEP

The transient pattern onset/offset VEP is similar to pattern reversal VEP. The main difference is that, in, the pattern stimulus is abruptly separated by a period of diffuse blank screen. According to the ISCEV standards, (Odom et. al., 2004) the diffuse blank screen and the patterned stimuli mean luminance must be the same so that the mean luminance is constant during the periodic change from pattern to diffuse blank screen. ISCEV recommended a standard of 100 to 200 ms pattern presentations separated by 400 ms of diffuse background. Pattern check sizes (15 or 60 minutes) and reversal rates (1 or 3 reversal per second) are similar to the pattern reversal stimulus.

The pattern onset/offset VEP waveform is more variable than the pattern reversal VEP and consists of three components; C1, C2 and C3 (Figure 1.3). The first positive peak C1 has a latency of approximately 75 msec, the negative peak C2 has a latency of approximately 125 msec, and the positive peak C3 has a latency of approximately 150 msec. The vertical amplitudes of the response are measured from the preceding negative peak. The pattern onset/offset VEP response, unlike pattern reversal VEP, is less affected by poor fixation. So it is used in clinics for measurement of potential visual acuity in preverbal children and in patients with nystagmus, as both have a tendency to poor fixation (Odom et. al., 2004; Lam. B. L, 2005).

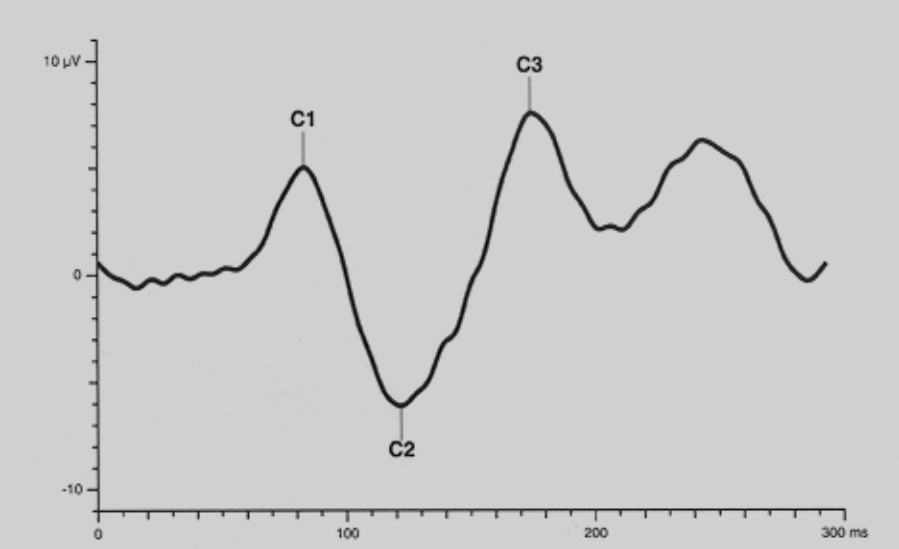


Figure 1.3: A normal pattern onset/offset VEP (Graph taken from Odom et al., 2004, Permission obtained from the Springer Link publisher, as shown in Appendix A.4)

Amplification and averaging for pVEP and fVEP recommended by ISCEV

A high pass filter of 100 Hz or more and low pass filter of 0.1 Hz or less should be used. The amplification of the input signal should be 20,000 to 50,000 for recording VEP. There should be an automatic artifact detector. It should be used to exclude EEG signals exceeding ± 50-100 µV in amplitude, caused by eye movement or body movement. According to the ISCEV standard, in clinical settings for both pVEP and fVEP measurement, the minimum number of sweeps per average should be 64. It is recommended to perform two averages to verify the repeatability of the VEP response. ISCEV recommended at least 250 ms of analysis time or sweep duration for the flash and pattern reversal VEPs and for pattern onset-offset VEP it should be at least 500 ms (Odom et al., 2004).

1.2.3 Types of VEP not covered by the ISCEV standard

Currently there are no ISCEV standards for Steady state VEP (ssVEP) and Sweep VEP (sVEP) which are used mainly in research.

1. Steady state VEP (SSVEP)
2. Sweep VEP (sVEP)

1.2.3.1 Steady state VEP (ssVEP)

Steady-state VEP recording was first introduced by Regan (1966). A ssVEP is a type of evoked potential in which a pattern stimulus is reversed in rapid succession, at a high temporal frequency of more than 5 Hz. Therefore, the evoked potentials overlap in time and the stimulus presentation rate is high enough to evoke a steady-state wave. This steady state VEP response can be separated from other EEG activity by using Fourier analysis. The frequency of the response corresponds to 2x the stimulation frequency or even higher harmonics. Harmonics are frequencies that are integer multiples of the fundamental frequency. For example, if F is the fundamental frequency, the harmonics have frequency 2F, 3F, 4F etc. The second harmonic waveform (2F) or even higher harmonics are used when the stimulus is alternated with a frequency that is symmetric in time . Since the visual system responds every time there is a reversal of the pattern, it will respond twice for every cycle of the stimulus i.e. at 2F. The plots of response amplitude versus spatial frequency describe ssVEP responses.

Regan (1977) described various advantages of ssVEP recording. For example ssVEP can provide a rapid assessment of visual function in infants and adults.

Visual acuity measurement – The ssVEP can be used to measure visual acuity. The spatial frequency of the stimulus grating varies between trials. VEP measurements are recorded for a particular spatial frequency at a temporal frequency > 5 Hz for 10 seconds. The amplitude and phase of the second or higher harmonics can be determined from the EEG signals using a Discrete Fourier analysis (Norcia and Tyler, 1985). The response amplitude for approximately 5-10 trials are averaged together and the mean amplitude of that averaged data is computed and is defined as the ssVEP response amplitude for that spatial frequency. The amplitudes for 3-5 spatial frequencies are plotted against spatial frequency and the data are fitted using linear regression. The ssVEP visual acuity threshold is defined as the spatial frequency in cycles per degree (cpd) corresponding to the x-intercept of the regression line (Simon and Rassow, 1986; Allen et al., 1992).

Contrast threshold measurement – Using ssVEP to measure contrast threshold, the contrast of the stimulus grating with a fixed spatial frequency and temporal frequency is varied between trials. The measurement of a particular contrast grating trial continues for 10 seconds. The response amplitude for approximately 5-10 trials are averaged together. The mean amplitude of that averaged data is computed and is defined as the ssVEP response amplitude for that contrast grating and plotted against log contrast. A regression line is fit to the data. The ssVEP contrast threshold is defined as the log contrast corresponding to the x-intercept of the regression line (Campbell and Maffei, 1970; Campbell and Kulikowski, 1972).

1.2.3.2 Sweep VEP (sVEP)

The sVEP which was first developed by Regan (1973) has become an important technique to measure visual functions in infants, children and adults**.** Tyler et al. (1979) further developed this technique for measuring visual acuity and Norcia et al (1986) for measuring contrast sensitivity. The sVEP is essentially the same as the steady-state pVEP used to measure a visual acuity or contrast threshold. The sVEP technique involves the recording of the steady state VEP response at a temporal frequency > 5 Hz to a grating stimulus that lasts for several seconds. For sVEP measurement the stimulus is electronically swept (increased or decreased) in spatial frequency (for measuring visual acuity) or contrast percentage (for measuring contrast threshold) over a particular range in a few seconds. The sVEP can also be used to measure vernier acuity (Skoczenski and Norcia 1999)

Visual acuity measurement - The sVEP measures visual acuity by using a rapid recording technique in which the spatial frequency of a reversing horizontal or vertical grating stimulus is increased or decreased in linear or logarithmic steps while the rate of reversal, i.e. the temporal frequency remains unchanged.

In the sVEP, the threshold is determined by extrapolation of the regression line from the signal peak to the X -axis intercept of the amplitude against spatial frequency plot (visual acuity threshold = 39.57 cpd) as shown in Figure 1.4.

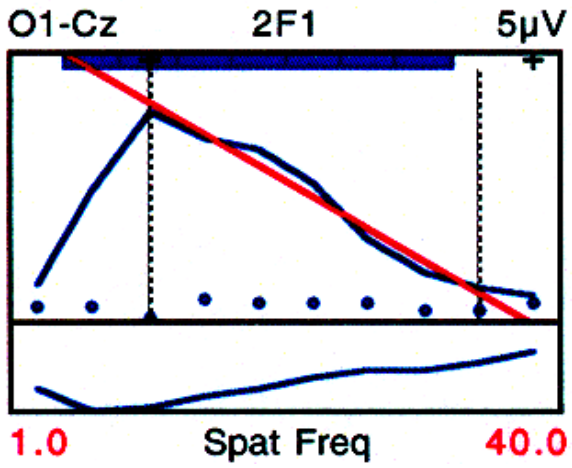


Figure 1.4: Visual acuity threshold sVEP plot

Contrast threshold measurement – Similarly for measuring contrast threshold the contrast of a reversing horizontal or vertical grating stimulus is increased or decreased in linear or logarithmic steps while the temporal frequency (rate of reversal) and spatial frequency of the grating remain unchanged.

The threshold is determined by extrapolation of the regression line from the signal peak to the X -axis intercept against percentage contrast (contrast threshold = 0.38 % contrast) as shown in the Figure 1.5.

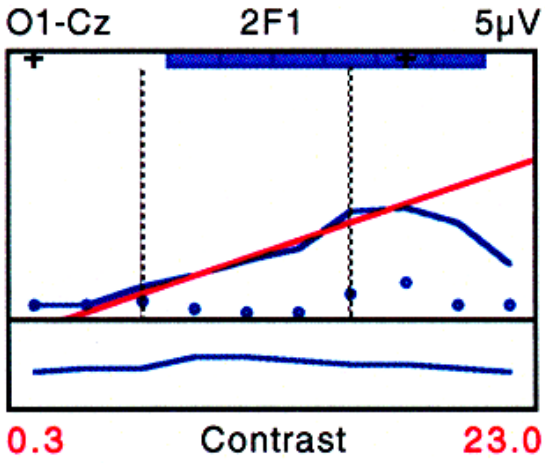


Figure 1.5: Contrast threshold sVEP plot

In the Figure 1.4 and 1.5, O1-Cz (O1 is the active electrode response with reference to the Cz electrode) is the sVEP plot of the O1 active channel. The electrode positions used in this study are described in section 3:9.3. The blue curve in the upper panel represents the signal amplitude in μV and the blue curve in the lower panel represents the phase. The details about the sVEP plots are discussed in the methods section 3.2.

Two general criteria have been used for accepting a sVEP plot as valid. First, the peak signal-to-noise ratio (SNR) should be ≥ 3 (Norcia and Tyler, 1985; Norcia and Tyler, 1985; Norcia et. al., 1985; Allen et. al., 1986; Norcia et. al., 1989;) and second, the phase or latency of the response should be constant or gradually changing (Parker and Salzen, 1977; Kulikowski, 1977; Vassilev and Strashimirov, 1979; Peli et. al., 1988; Strasburger et. al., 1988; Norcia et. al., 1989; Siepel and Holopigian, 1989). Phase is defined as the latency of the response for a particular stimulus and it is measured as an angle. Phase is measured by considering the temporal sinewave of the stimulus and comparing the timing of this with the sinusoidal response. The latency of the response changes with change in the stimulus, for example, with change in spatial frequency or contrast. As the stimulus becomes less salient, the latency increases, resulting in an increasing lag, and conversely, as the stimulus becomes more salient, the latency decreases resulting in a lead. Thus by using a sweep range from lower to higher spatial frequency or from higher to lower contrast, the phase shifts from a positive to a negative angle i.e. phase gradually lags. By using a sweep range from higher to lower spatial frequency or from lower to higher contrast, the phase shifts from a negative to a positive angle i.e. phase leads.

The sVEP trials are recorded and averaged together to determine visual acuity. A similar procedure is use to determine contrast threshold. The amplitude and phase of the second or higher harmonics can be determined from the EEG signals using a discrete Fourier transform algorithm or the Recursive Least Square (RLS) method (see Appendix A.1) as used in this study.

The main advantages of the sVEP method are that, firstly, it is an objective method and secondly, it quickly determines visual function compare to pVEP and fVEP. Therefore, it can be used to assess visual function in infants, young children, and people with special needs who cannot participate in traditional subjective vision testing. In infants, it is difficult to control fixation and attention for a long time, so sVEP is better than the pattern VEP for measuring visual function. Infants have large VEP amplitudes compared to adults and it has been suggested that this is because of the thinness of their skulls relative to those of adults. Therefore, the VEP signal is closer to the electrodes in infants relative to sources of noise extrinsic to the brain, such as muscle activity.

Many researchers have used sVEP techniques in infants and children to measure visual acuity (Norcia and Tyler, 1985; Norcia and Tyler, 1985; Norcia et al., 1990; Gottlob et al., 1990; Sokol et al., 1992; Riddel et al. 1997; Lauritzen et al., 2004; Good and Hou, 2006) and contrast threshold (Norcia et al., 1986; Norcia et al., 1988; Norcia et al., 1989; Norcia et al., 1990; Lauritzen et al., 2004). Similarly they have used the sVEP technique in adults to measure visual acuity (Regan, 1977; Tyler et al., 1979; Weiner at al., 1985; Strasburger 1988; Ridder et al., 1998; Lauritzen et al., 2004) and contrast threshold (Seiple et al., 1984; Allen et al., 1986; Seiple et al., 1988; Norcia et al., 1989; Norcia et al., 1990; Chen et al., 1990; Lopes de Faria et al., 1998; Lauritzen et al., 2004).

1.2.3.2.1 Importance of sVEP

Regan (1973) first demonstrated the sVEP technique for measuring refractive errors. Tyler et al. (1979) described some clinical uses of sVEP method i.e. it can be used to measure refractive error and to assess binocular function. The sVEP technique has been used to assess visual acuity in children with chorioretinopathy, microcephaly, cortical visual impairment (CVI), strabismus, amblyopia, nystagmus, albinism and retinitis pigmentosa (Ahmadi and Bradfield, 2007; Gottlob et al., 1990; Good, 2001) The sVEP technique is helpful in assessing visual function in special populations i.e. populations with multiple impairments (Mackie and McCulloch, 1995). Multiple impairments may be caused by cerebral palsy, complications of prematurity, hypoxic or ischemic brain injury, hydrocephalus and Down's syndrome. Visual assessment is important in these individuals because they have a high prevalence of visual disorders such as strabismus, refractive errors, cataract, defects of visual field, optic atrophy, optic nerve hypoplasia and cortical blindness (Kennerly, 1974; Black, 1982; Scheimann, 1984; Roizen et al., 1994).

As discussed earlier, the sVEP currently has no ISCEV guidelines exist. It has not become a preferred objective technique to assess visual acuity and contrast in clinics. Therefore, currently it is used mainly for research purposes. The sVEP has also been used to assess visual function in animals. For example, the sVEP was used to measure visual acuity in monkeys (Boothe et al., 2000; Glickman et al., 1991; Yildirim and Tychsen, 1999).

1.2.3.2.2 sVEP and visual development

Knowledge of human visual development is important to the clinician for the diagnosis and treatment of visual developmental disorders. There are visual development studies in infants and children using sVEP. However, there is no overall agreement as to when visual development is fully complete.

sVEP studies in infants and children - Norcia and Tyler (1985) measured visual acuity development in infants using the sVEP. Their results showed that there is an increase in visual acuity from a mean of 4.5 cpd in the first month to about 20 cpd at 8-13 months of age, at which point it is still not adult-like. Norcia et al. (1990) studied visual acuity development in a group of infants aged from 2-40 weeks and compared it with a group of 10 adults. They found that there is a gradual increase in visual acuity with age, starting at 5 cpd in the first month and reaching 16.3 cpd at 8 months of age. However, the adults mean acuity was 31.9 cpd. Similarly, Norcia et al. (1990) measured contrast sensitivity development in infants with sVEP. Their results showed that the contrast threshold development at low spatial frequency is rapid i.e. it decreases from 7% at 2-3 weeks to 0.5% contrast at 9 weeks. They mentioned that there are two phases in the development of contrast threshold in infants. The first is between 4 and 9 weeks when overall contrast threshold decreased by a factor of 4-5% at all spatial frequencies. In the second phase, contrast threshold beyond 9 weeks remained constant at low spatial frequencies but it decreased at high spatial frequencies. However, still it is not fully developed compared to adults.

Psychophysical studies in infants and children - Forced choice preferential looking (FPL) techniques have been used by different researchers (Teller, 1974; Atkinson and Braddick, 1982; Gwiazda et al., 1978; Banks and Salapatek, 1978) to measure visual acuity and contrast threshold development in infants and children. Mayer and Dobson (1982) used the Operant Preferential Looking (OPL) test to measure visual acuity development. Their results showed that grating visual acuity was fully mature at 5 years of age. However, Atkinson and Braddick (1983) showed that Snellen visual acuity does not become adult-like until 10 years of age. Atkinson et al. (1981) showed that the shape of the contrast sensitivity function is adult-like by 5 years of age, but the overall sensitivity is less than adult until 12 years of age. Bradley and Freeman (1999) showed that contrast sensitivity becomes adult like by about 7-9 years of age while Adams and Courage (2002) showed that contrast sensitivity is adult-like by 9 years of age. All of these researchers with the exception of Atkinson and Braddick (1983) used the forced choice preferential looking method to measure the visual acuity and contrast sensitivity. After reviewing the above studies, using both objective and subjective methods, it is not possible to reach a firm conclusion about the age at which visual acuity and contrast threshold become fully adult-like in children. Therefore, more studies need to be done to determine the exact age of visual acuity and contrast threshold development in children.

1.2.4 The criteria for fitting the regression line in sVEP to determine thresholds.

So far all researchers (Tyler et al., 1979; Norcia and Tyler 1985; Norcia and Tyler, 1985; Norcia et al., 1986; Allen et al., 1986; Norcia et al., 1990; Chen et al., 1990; Allen et al., 1982; Lopes de Faria et al., 1998; Lauritzen et al., 2004) have used a linear regression line fit from the signal peak to zero of the amplitude against spatial frequency or % contrast (log contrast) to determine threshold. Most of the researchers do not define the range over which the data points are included for this fit. Norcia et al. (1985) suggested an endpoint criterion to fit the regression line for determining threshold. According to the Norcia et al. (1985) endpoint criterion, the SNR of each data point starting from the below threshold (last data point) end of the sVEP plot is checked. The range is then defined as beginning at the data point where the amplitude function rises and stays above an SNR of 1.5:1.The regression line will then be fitted if there are at least three data points with an SNR of **>**1.5:1 and one of the data point has an SNR of **>** 3:1. A range of two data points will be used if both the data points exceed an SNR of 3:1. The regression line will then be fitted between the signal peak and the last data point with an SNR > 1.5:1. If the phase of that data point is inconsistent then the range is shifted to the next data point with consistent phase. The Norcia et al. (1985) endpoint criteria were used by Norcia et al. (1989) and Gottlob et al. (1990). Ridder et al., (1998) used two different criteria to fit the regression line to determine the visual acuity threshold. In the first criterion, Ridder et al. (1998) fitted the line between the peak spatial frequency and the highest spatial frequency data point which was above the noise and the linear fit was extrapolated to the zero amplitude to determine the visual acuity threshold. In a second criterion, if there were no data points between the peak spatial frequency and the

highest spatial frequency which was above the noise, then the peak spatial frequency data point was taken as the visual acuity threshold. However, Ridder et al. (1998) could not determine acuities for 29 of 384 possible plots by using these two criteria. Norcia et al. (1989), Gottlob et al. (1990) and Ridder et al. (1998) did not compare the threshold determined by the criteria they used with the psychophysical threshold, which would be one method of validating these criteria.

1.2.5 Validity of sweep VEP (sVEP) measurement

To validate sVEP visual acuity and contrast threshold measurements, many researchers have compared it with psychophysically measured visual acuity and contrast threshold.

1.2.5.1 Visual acuity

Tyler et al. (1979) used sVEP to measure the visual acuity thresholds in adults and compared them with psychophysical thresholds. They used the psychophysical method of adjustment to measure visual acuity threshold. Their results showed that the psychophysically-determined visual acuity threshold was higher than the sVEP threshold. A study done by Wiener et al. (1985) in adults showed that the correlations between sVEP grating acuity and Snellen optotype acuity were poorer than correlations between sVEP and psychophysically-determined grating acuity. Allen et al. (1992) compared the sVEP and the psychophysical visual acuity threshold in infants. They used forced choice preferential looking (FPL) to measure visual acuity in infants. Their results showed that the average sVEP acuities were higher than the FPL acuities. Sokol et al. (1992) compared the sVEP and the temporally modulated preferential looking (PL) grating acuity in infants. They used temporal

frequencies of 5, 7 and 14 Hz for both the sVEP and PL grating stimuli. They found a smaller difference between sVEP and PL visual acuities than Allen et al. (1992) but still the sVEP acuity was higher than the PL grating acuity. Sokol et al. (1992) showed that the sVEP and PL acuity difference decreased with the age. The mean octave difference between sVEP and PL was 2 octaves at 2 month of age and decreased to 0.5 octaves at 12 month of age. The study done by Riddell et al. (1997) in infants compared sVEP acuity and Teller Acuity Cards (TAC) acuity. Their study showed that sVEP acuity was generally higher than TAC acuity.

The above studies are in agreement that sVEP visual acuity is higher in infants than the psychophysically determined acuity, whereas, in adults, sVEP visual acuity is lower than the psychophysical visual acuity.

1.2.5.2 Contrast Threshold

Similar to researchers studying visual acuity, researchers have compared the sVEP and psychophysically determined contrast threshold in adults. Allen et al. (1986) used similar parameters (spatial frequencies: 1, 3, 6, 9, 12, 15 and 18 cpd; temporal frequency: 15 Hz) for contrast threshold measurement for both sVEP and psychophysical contrast threshold. They used the psychophysical method of ascending limits for measuring contrast threshold. Their results showed that contrast threshold measured with the sVEP correlates well with the psychophysical contrast threshold. The correlation coefficient between sVEP and psychophysical threshold was 0.914, with a mean discrepancy of only 12%. Chen et al. (1990) also used the method of ascending limits for measuring the psychophysical contrast threshold. For measuring the contrast threshold by sVEP, the stimulus was swept from 0.5%

to 40% contrast, over a period of 22 seconds, at five spatial frequencies (0.5, 1, 3, 7.43 and 14.9 cpd) and at a temporal frequency of 7.5 Hz. Their results showed a high correlation (correlation coefficient r = 0.816) between the sVEP and the psychophysical contrast threshold measured under the same stimulus conditions. Seipel et al. (1984) used ascending and descending methods of limits to determine psychophysical contrast threshold. The sVEP and the psychophysical grating stimuli were modulated with the same temporal frequencies. They found that the shape of contrast sensitivity function (CSF) was similar for both methods, but the sVEP CSF was consistently lower than the psychophysical method (mean of 0.4 log unit less at 7 reversal/sec).

The above studies showed a good correlation between sVEP and psychophysically measured contrast thresholds in adults, except for the Seipel et al. (1984) study in which the psychophysical contrast threshold was lower than the sVEP threshold.

1.2.6 Repeatability of sVEP measurements

Repeatability of sVEP is defined as a test-retest repeatability of sVEP measurement. Repeatability is measured by recording sVEPs using the same parameters on the same subjects but on different days or times. Lauritzen et al. (2004) measured the test-retest reliability of sVEP of 92 infants (age ranged 6-40 weeks) for visual acuity and contrast threshold, and for visual acuity of seven adult subjects. The results showed that the coefficient of variation in the sVEP visual acuity assessment of infants was 17% within each session and 8.4% between sessions. These coefficients of variation were found to be similar in adult subjects. They also found that the coefficient of variation in the sVEP contrast threshold assessment of infants was 23% within each session and 54% between sessions.

These results are in agreement with a previous study of test-retest difference done by Kelly et al. (1997). The above studies showed that that there were variations in the visual acuity and contrast thresholds of both within and between session in infants and adults measured repetitively using sVEP. Therefore, Lauritzen et al. (2004) concluded that sVEP threshold is more valid in a group of subjects than in individual subject. They also suggested that the mean of several thresholds give less variable results than using the best threshold. The test-retest results of sVEP might vary due to many factors, such as attentiveness, muscle activity and accommodative state related to the individual subjects.

1.2.7 Parameters that may affect sVEP

1.2.7.1 Luminance

sVEP studies - There are few sVEP studies, which investigated the effect of luminance on visual acuity and contrast threshold. Tyler et al. (1979) used sVEP to measure visual acuity in adults at a luminance ranging from 0.5 to 46 cd /m^2. The results showed that the visual acuity remained constant with an increase in luminance. Allen et al. (1992), using sVEP, showed that visual acuity in adults improves about 0.5 log units between a luminance of 0.01 and 10 cd/m^2 and then remains constant between 10 and 100 cd/m^2. Good and Hou (2006) used sVEP to measure visual acuity in children with normal vision and those with cortical visual impairment at two luminance levels, 20 and 109 cd/m^2. They found that there was no significant effect of luminance on visual acuity in children with normal vision. There are some psychophysical studies mentioned below which looked at the effect of luminance.

Psychophysical/subjective studies - Brown et al. (1987) used a spatial FPL method to measure visual acuity in adults at seven luminance levels between -1.3 and 2.7 log cd/m^2. They found that visual acuity in adults improved with increasing luminance until 0.0 log cd/m^2 and then remained constant above that luminance. Rabin (1994) measured visual acuity and contrast sensitivity for small letters in adults with computer-generated letter charts at luminances ranging from 0.23 cd/m^2 to 116 cd/m^2 and found that both visual acuity and contrast sensitivity improved with increasing luminance. Increasing the luminance from 0.23 cd/m^2 to 116 cd/m^2 caused a 3x increase in visual acuity and a 17x increase in contrast sensitivity. Johnson and Casson (1995) measured visual acuity in adults using Landolt C targets at varying background luminance from 0.075 to 75 cd/m^2. They also found that visual acuity increased with increasing luminance.

The preceding studies showed that visual acuity remains constant at a luminance between 10 and 100 cd/m^2 in adults with sVEP. However, psychophysical studies showed improvement in visual acuity and contrast threshold in adults with increasing luminance. To date no study has looked at the effect of luminance on contrast threshold in adults using sVEP.

1.2.7.2 Effect of electrode placement

The ISCEV standard (Odom et al., 2004) for pVEP and fVEP measurements recommends using either three or five active electrodes channels. By using only one or two electrodes, there is a chance that chiasmal or retrochiasmal disease might be missed (Odom et al. 2004). Previous studies of sVEPs used either one or two active channel electrodes (Tyler et al., 1979; Nelson et al., 1984; Seipel et al., 1984; Norcia and Tyler, 1985; Norcia and Tyler, 1985; Seipel et al., 1988; Norcia et al., 1989; Norcia et al., 1990; Chen et al., 1990; Gottlob

et al., 1990; Riddel et al., 1997; Lopes de Faria et al., 1998; Ridder et al., 1998). Allen et al. (1986) studied the effect of two different single active electrode placements on contrast threshold.. The reference electrode was placed 1 cm above the inion and the ground electrode was placed on the ear. In one trial, the active electrode was placed 3 cm above the inion (channel 1). In the second trial, the active electrode was placed 3 cm above and 3 cm lateral to the inion (channel 2). Their results showed a small difference (0.0012 ± 0.168 log units) in the sVEP derived contrast threshold using the two different electrode placements. However, the correlation coefficient between the two contrast thresholds was 0.905. Currently there is no study, which has looked at the effect of five differently placed active electrodes on the visual acuity and contrast threshold. .

1.2.7.3 Effect of temporal frequency

Norcia and Tyler (1985) measured visual acuity in infants using sVEP at two temporal frequencies, 6 and 10 Hz. Their results showed "that the change in temporal frequency accounts for only 3% of the total variation and 14% of the variation in acuity estimates within-subjects" i.e. there was little effect of these temporal frequencies on visual acuity. Another study was done by Gottlob et al. (1990) in which they measured the visual acuity in children (aged from 3 weeks to 11 years) using sVEP at temporal frequencies of 4, 6, 7.5 and 12 Hz. Their study showed that the temporal frequency of 4 Hz gave better visual acuity than 12 Hz. Siepel et al. (1984) measured the contrast threshold in adults at the temporal frequencies of 1.5, 3.5 and 21.5 Hz. Their results showed that the temporal frequencies of 1.5 and 3.5 Hz gave lower contrast thresholds than 21.5 Hz. Several authors (Fagan et al., 1985; Mast and Victor, 1991; Pigeau and Fram, 1992) recommended using stimulation

frequencies outside the alpha band or alpha rhythm (8 to 13 Hz). These authors suggested, "Stimulating at alpha frequencies has the disadvantage of confounding the visual stimulus signal with instability in the spontaneous alpha signal". The alpha rhythm is electromagnetic waves that are evoked at a frequency range from 8 to 13 Hz. These waves are the EEG response of the occipital lobe when the person is awake and relaxed with eyes closed. These waves can also occur with open eyes when the visual cortex is in a resting state.

Table 1.1: Summary of temporal frequencies used in different studies for visual acuity and contrast threshold measurement by using sVEP.

Study	**Infants/children/ adults**	**Temporal Frequency (Hz)**	**Visual acuity/contrast threshold.**
1. Tyler et al. (1979)	Adults	12 Hz	Visual acuity
2. Norcia and Tyler (1985)	Infants	6 and 10 Hz	Visual acuity
3. Norcia and Tyler (1985)	Infants	6 Hz	Visual acuity
4. Wiener et al. (1985)	Adults	3.5 Hz	Visual acuity
5. Norcia et al. (1986)	Infants	6 Hz	Contrast threshold
6. Norcia et al. (1989)	Infants and adults	6 Hz	Contrast threshold
7. Norcia et al. (1990)	Infants and adults	6 Hz	Contrast threshold

Study	Infants/children/ adults	Temporal Frequency (Hz)	Visual acuity/contrast threshold.
8. Gottlob et al. (1990)	Children	4, 6, 7.5 and 10 Hz	Visual acuity
9. Chen et al. (1990)	Adults	7.5 Hz	Contrast threshold
10. Allen et al.(1992)	Infants and adults	6 Hz	Visual acuity
11. Ridder et al. (1998)	Adults	7.5 Hz	Visual acuity
12. Lopes de Faria et al. (1998)	Adults	6 Hz	Contrast threshold
13. Lauritzen et al. (2004)	Infants and adults	6 Hz	Visual acuity
14. Good and Hou (2006)	Children	3.76 Hz	Visual acuity

Table 1.1 shows that a range of temporal frequency has been employed, although most of the sVEP studies used a temporal frequency of 6 Hz for measuring the visual acuity and the contrast threshold. This is equal to a response frequency of 12 Hz , which falls within the range of the alpha rhythm. None of these researchers explained the reason for choosing a particular temporal frequency for the stimulus to measure visual acuity and contrast threshold. Currently there is no study, which has examined the effect of temporal frequency on visual acuity and contrast threshold in adults using sVEP.

1.2.7.4 Effect of sweep direction

There are few studies, which have investigated the effect of sweep direction on visual acuity and contrast threshold.

Visual acuity

Nelson et al. (1984) looked at the effect of sweep direction on the visual acuity threshold. They measured visual acuity in adult subjects by sweeping spatial frequencies from 5-30 cpd for 20 seconds, from seeing to non-seeing and vice versa. They showed that sweeping spatial frequencies from non-seeing to seeing (high to low spatial frequency) causes no adaptation effect on visual acuity threshold compared to spatial frequencies sweeping from seeing to non-seeing (low to high spatial frequency). They showed that superior visual acuity was always obtained by sweeping the spatial frequencies from non-seeing to seeing rather than seeing to non-seeing. They suggested that with the sVEP method, visual acuity assessment should be done by sweeping the spatial frequencies from non-seeing to seeing. However, Tyler et al. (1979) suggested that an overestimation of the visual acuity threshold is avoided by sweeping the spatial frequencies from seeing to non-seeing i.e. there is disagreement about whether sweeping non-seeing to seeing over-estimates or gives an accurate estimation of acuity.

Contrast threshold

Nelson et al. (1984) also looked at the effect of sweep direction on contrast thresholds. They measured contrast threshold in adult subjects by sweeping contrast between 0.1-20 % for 20 seconds, from seeing to non-seeing and vice versa. They found that sweeping the

contrast from seeing to non-seeing (high to low contrast) caused more adaptation effect compared to sweeping contrast from non-seeing to seeing (low to high contrast). They showed that the contrast thresholds were significantly higher on sweeping the contrast from seeing to non-seeing. They suggested that with the sVEP method, contrast threshold assessment should be done by sweeping the contrast from non-seeing to seeing. Studies done by Seipel et al. (1988) and Briggel et al. (1987) in adults found similar results. Nelson et al. (1984) also suggested that the adaptation effect is smaller with spatial frequency sweeps than with contrast sweeps. Xin et al. (1983), in their study abruptly changed the contrast with time. They presented a 1 cpd grating stimulus at a low contrast of 3% for 8 seconds, followed by a step change in contrast to either 15, 20, 30 or 40% for another 8 seconds. Then the contrast was abruptly reduced back to 3% for the final 8 seconds. Their results showed an effect of contrast change on the VEP amplitude and phase. They explained that the VEP amplitude and phase do not immediately stabilize when the stimulus contrast changes abruptly because both are dependent on the size and direction of the contrast change and on the spatial frequency of the grating stimulus. The above studies showed that the measured visual acuity and contrast threshold changes with the sweep direction and this is probably due to adaptation effects.

1.2.7.5 Effect of stimulus area

Tyler et al. (1979) measured sVEP visual acuity in adults at a test distance of 37 cm with different stimulus sizes. The test stimulus consisted of a circular vertical grating with a field size of 2, 4, 6, 8, 10, 12 and 15 degrees and spatial frequency was swept from 0.2 to 16 cpd. The results showed that visual acuity remained constant with all the stimulus areas.

Hagemans and Wildt (1979) measured the contrast sensitivity function in adults by using a forced choice psychophysical procedure in the amblyopic and the non-amblyopia eye of each subject. The stimulus area they used was varied from 0.25 to 8 degrees of visual angle at a spatial frequency from 0.1 to 12 cycles/degree. They found that in subjects' dominant eye's contrast sensitivity function increased linearly with increasing stimulus area. There is no study which has looked at the effect of different stimulus area on contrast threshold using sVEP in adults.

In summary, most studies have shown, that there is an effect of different parameters on visual acuity and contrast threshold in infants, children and adults using sVEP. The studies on luminance showed that there is no effect of luminance on visual acuity between 10 cd/m^2 and 100 cd/m^2. There is no study using sVEP which has examined the effect of luminance on contrast threshold. Allen et al's. (1986) study is the only one, which has examined the effect of differently placed active electrodes on contrast threshold using sVEP. The study needs to be done in adults to investigate the effect of five differently placed active electrodes on visual acuity and contrast threshold. Some studies showed that there are some effects of temporal frequency on visual acuity and contrast threshold. A study needs to be done to show the effect of different temporal frequencies on visual acuity and contrast threshold. Previous studies also showed that there is an effect of sweep direction on visual acuity and contrast threshold. However, there is a disagreement between the studies on the optimum sweep direction for visual acuity assessment. Therefore, more studies are needed to determine which sweep direction gives the best assessment of visual acuity. Tyler et al. (1979) have assessed the effect of different stimulus areas in adults on visual acuity using

sVEP. Studies are required to investigate the effect of different stimulus areas on contrast threshold.

Chapter 2: Purpose and hypothesis

2.1 Purpose

The primary purpose of this study is to optimize and standardize the parameters of sVEP in adults. The effect of changing the following parameters of the sVEP on visual acuity and contrast threshold are considered in this study: criterion for fitting the regression line to estimate threshold, luminance, electrode placement, temporal frequency, sweep direction, stimulus area and presence or absence of a fixation target. The long-term purpose of this study is to investigate the effects of similar parameters in children from age 6 to 8 years old and to compare these parameters with adults. These optimized sVEP parameters in children will be used to measure the development of visual acuity and contrast threshold in children, to determine when they becomes fully adult-like and to compare with visual development measured psychophysically.

2.2 Hypothesis

To measure visual acuity and contrast threshold using sVEP requires optimized parameters. The hypothesis of this study is that the parameters studied will have an impact on the measured visual acuity and contrast threshold and on the number of acceptable plots. Therefore, the hypotheses are that

1. The different criteria for fitting the regression line will affect the sVEP threshold. A more objectively determined criteria for fitting would result in better repeatability and validity.

2. There will be an effect of stimulus luminance on the visual acuity and contrast threshold i.e. a higher luminance will give higher visual acuity, lower contrast threshold and more viable readings than a lower luminance.

3. There will be an effect of two different electrode placements i.e. Power Diva and ISCEV on visual acuity, contrast threshold and the number of viable plots.

4. There will be an effect of stimulus temporal frequency on visual acuity, contrast threshold and the number of viable plots.

5. There will be an effect of stimulus sweep direction on visual acuity and contrast threshold. Visual acuity will be better for spatial frequency sweeps from seeing to non-seeing and contrast threshold will be better for contrast sweeps from non-seeing to seeing. There will also be an effect of sweep direction on the number of viable plots.

6. There will be an effect of the presence of a central fixation target on the visual acuity and contrast threshold. With a fixation target, there will be better visual acuity and lower contrast threshold than without a fixation target. There will be more viable plots with a fixation target than without a fixation target.

7. There will be an effect of different stimulus area on the visual acuity and contrast threshold i.e. a larger stimulus area will give better visual acuity and lower contrast threshold than a smaller stimulus area. A larger stimulus area will give more viable plots.

The following experiments have been performed to test these hypotheses; validity of sVEP using different criterion against psychophysical measures and repeatability by using the same parameters for 10 repeated measures to determine the best criterion for regression line fitting, the effect of luminance, electrode placement, temporal frequency, sweep direction, fixation target, stimulus area on visual acuity, contrast thresholds and the number of viable plots will be studied.

Chapter 3: Methods

3.1 Hardware

In this study, two OS 9.2 Macintosh computers were used to measure sVEP. One Macintosh computer, connected to an Apple monitor, was called the Power Diva host and the second, connected to a Philips FIMI MGD403 CRT monitor, was called the Power Diva video. The Power Diva host controlled and generated the grating stimulus on the Philips monitor. The Power Diva video was a slave computer, controlled by the Power Diva host computer. The Philips monitor was used to present the grating stimulus. This Philips monitor can produce a high luminance and high contrast image. It was connected with the Power Diva Video via a VGA video cable, an attenuator and a 3-BNC adapter as shown in Figure 3.1. The Philips CRT display was a standard 19 inch, monochromatic display. The resolution of the Philips monitor was 1600x1200, 8 bits and the refresh rate was 60 Hz. An attenuator was used to reduce the contrast of the monitor. Without the attenuator it was not possible to get a sufficiently low contrast grating on the monitor for contrast threshold measurement. Image "ghosting" was also diminished with the attenuator. The 75 Ω button of the monitor was turned off to get the lowest contrast and brightness of the monitor.

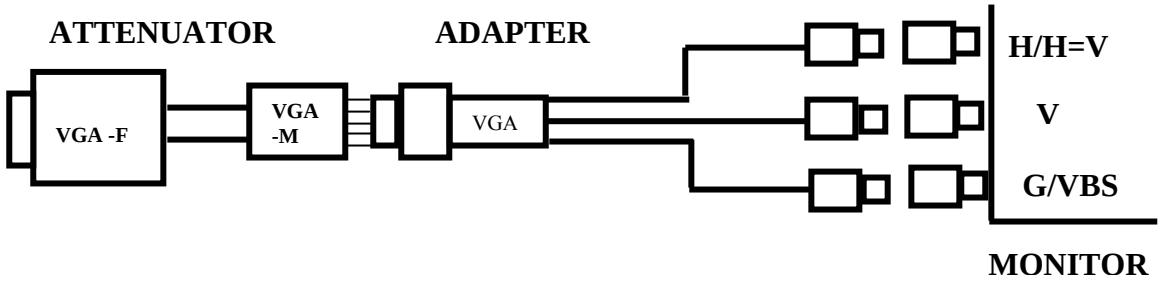


Figure 3.1: Power Diva video connected with 3-BNC adapter

3.1.1 Experimental set-up

The Power Diva Host was connected with a Grass Telefactor Neurodata Acquisition (DAQ) System Model 12, used to capture the EEG signal at an amplification of 50k. For recording the sVEP, seven electrodes (five active channel electrode, one reference electrode and one ground electrode) were connected to a Grass Bio-Potential Amplifier Model CP511, followed by the DAQ system. The EEG signals were displayed on the Power Diva Host monitor. An artifact detector cuts out artifacts in the EEG signals, caused by eye or body movements. For adults, the artifact detector was kept at 100 µv. The DAQ rate used to capture EEG signals was 601.08 Hz. A low pass filter of 100 Hz and also a high pass filter of 0.1 Hz were used to filter the noise above and below the frequency of the measured VEP signals, respectively. The experimental set-up is shown in Figure 3.2.

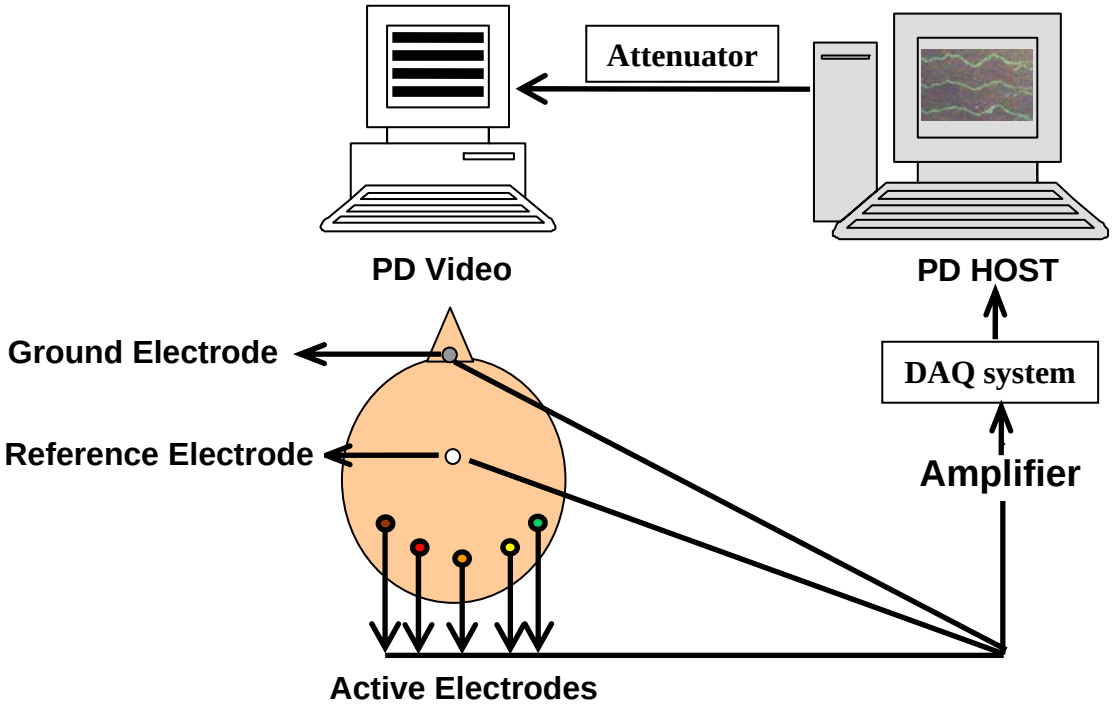


Figure 3.2: sVEP experimental set-up

3.2 General settings for visual acuity and contrast threshold measurement.

3.2.1 Visual acuity measurement

Sinusoidal horizontal black-and-white gratings of 90% contrast were used for measuring visual acuity. The spatial frequency of the reversing stimulus was increased or decreased in steps while the rate of the reversal or temporal frequency remained unchanged. Spatial frequency was swept in linear steps between 1-40 cpd, alternating at temporal frequencies of 6 Hz, 7.5 Hz or 10 Hz.

3.2.2 Contrast Threshold Measurement

Sinusoidal horizontal black-and-white gratings were used for measuring contrast threshold. The contrast of the reversing grating pattern was increased or decreased while the spatial and temporal frequencies remained unchanged. The percentage contrast was swept in logarithmic steps. using a sweep range from 0.23 to 23% contrast (or from 1.6 to 50 % contrast for 8 cpd, when no threshold was obtained with the lower sweep range). Spatial frequencies of 1 cpd, 4 cpd or 8 cpd were used. Temporal frequencies of 6 Hz, 7.5 Hz or 10 Hz were used.

3.3 Number of Steps/Bins

Ten steps and 10 bins were used for both visual acuity and contrast threshold measurement. The number of steps controls how many levels of contrast or spatial frequency were presented from the beginning to the end of a sweep and the number of bins defines the number of data points calculated for the trial i.e. the number of sections of VEP recording over which the VEP is averaged. As 10 steps and 10 bins were used, there were 10 stimulus

values (spatial frequencies or contrasts) presented and 10 data points for a particular trial. For each trial, a test duration of 10.7 seconds was used and the number of steps/bins was 10, so a data point would be acquired approximately every second.

3.4 Electrodes and electrode placements

The sVEPs were recorded from the occipital cortex using five Grass gold active channel electrodes, one reference and one ground electrode. The size of each gold electrode cup was 1 cm in diameter. Electrodes were placed according to the International 10/20 system (American Encephalographic Society, 1994). All the five active channel electrodes were placed on the scalp at positions of PO7, O1, Oz, O2, and PO8, either placed based on the Power Diva (Vladimir Y. Vildavski, personal communication) or the ISCEV standard (Odom. et al. 2004) system. Details about Power Diva and ISCEV standard electrode placements are described later in the description of Experiment 3.

3.4.1 Preparation for electrode placement

For sVEP measurements, electrodes were placed at specific locations (described later), at the top and at the back of the head as well as one on the forehead. Before placing the electrodes, the skin area was cleaned with alcohol swabs, then further cleaned with NUPREP skin abrasive gel and then the electrodes were placed with the help of TEN 20 conductive gel as shown in Figure 3.3. VETRAP (Figure 3.4) was used to keep the electrodes on the scalp. The Power Diva electrode placement was used for all the experiments except for one experiment in which the ISCEV standard electrode placement was used. Good contact of electrodes was necessary for getting noise free EEG signals and better threshold values. Subjects were

seated during the whole procedure. After electrode placement, subjects were asked to look at the small fixation target, which was placed in the center of the monitor except for one experiment in which no fixation target was used. Subjects were seated at 250 cm from the CRT monitor for visual acuity measurement and at 100 cm for contrast threshold measurement. The visual acuity and contrast threshold were measured binocularly. Refractive correction was worn during the experiment. All of the experiments were performed in a darkened room. In each session, a maximum of 5-6 conditions were measured. Each condition consisted of 10 trials, each trial was of 10.7 seconds, and the 10 trials were averaged together for that particular condition. Subjects were given breaks in between different conditions. Each session took approximately an hour to complete.

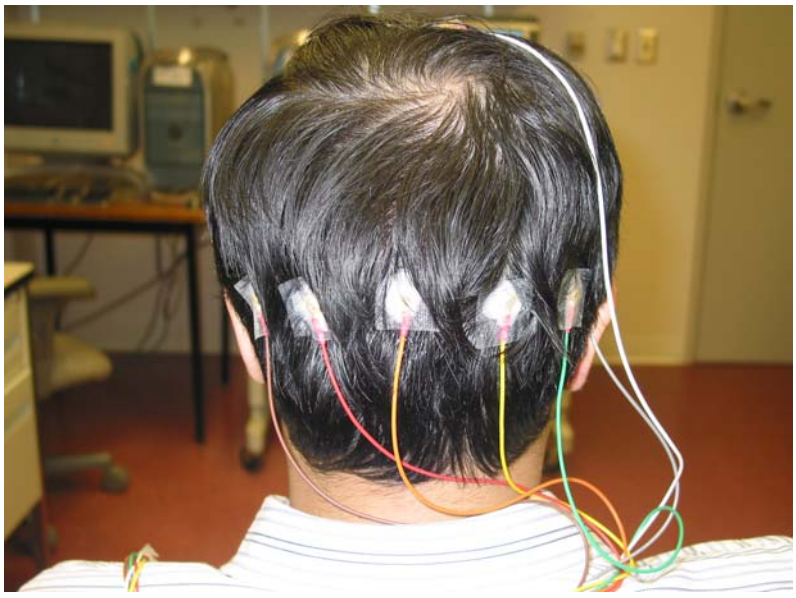


Figure 3.3: Electrode placement

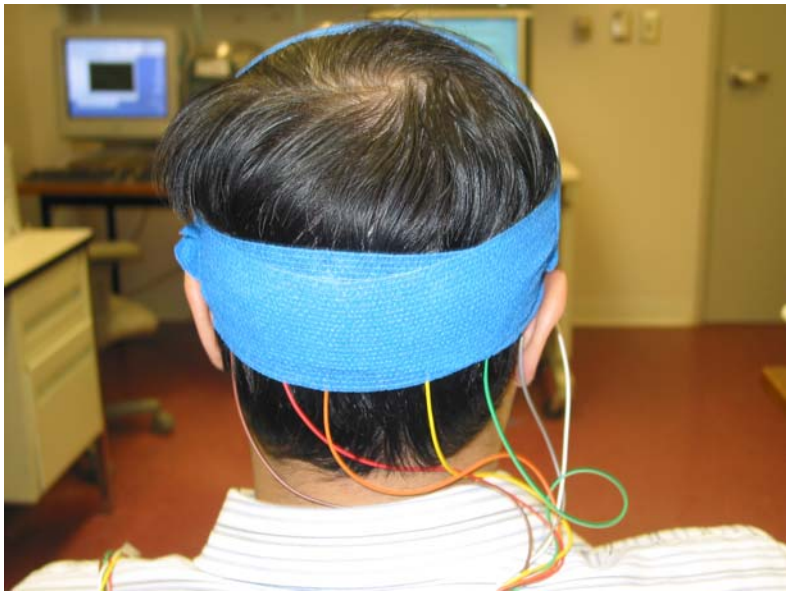


Figure 3.4: Electrode placement with VETRAP

3.5 Description of sVEP data plots

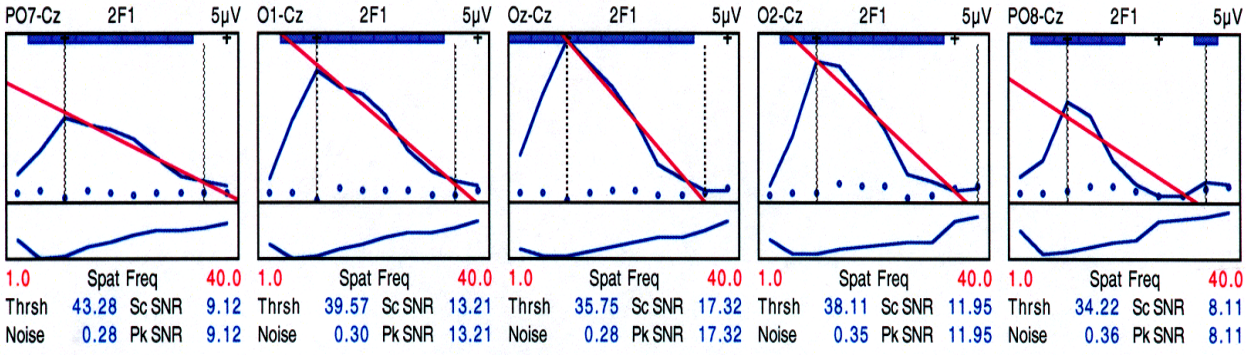


Figure 3.5: Visual acuity threshold plots

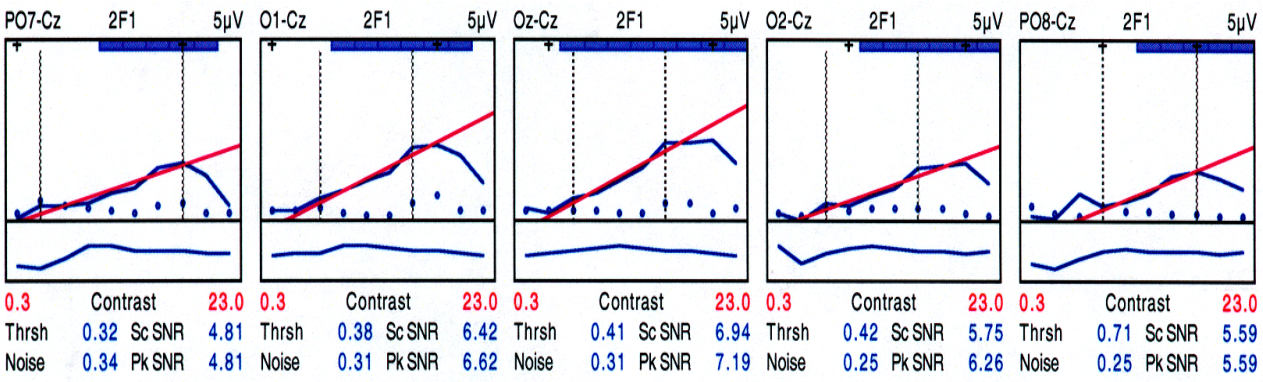


Figure 3.6: Contrast threshold plots

In Figure 3.5 and Figure 3.6, PO7-Cz, O1-Cz, Oz-Cz, O2-Cz and PO8-Cz represent the plots of each of the five active electrodes with reference to the Cz electrode. 2F1 represents the plot at the second harmonic and the Y-axis is the value of the signal amplitude (µV). The plots of the linearly scaled VEP signal (shown as blue solid lines) and noise (shown as dots) amplitudes against spatial frequency or contrast are provided in the upper panels and the phase values of the signal (between $-\pi$ at the bottom and $+\pi$ at the top) are shown in the lower panels either as a continuous line or a broken line. The blue horizontal bars in the upper panels show if there is a significant difference between signal and noise at each particular data point. This was determined by the software and the experimenter could change the significance level. In this, study, a significance level of 0.05 was used. The vertical dotted lines determine the data points used to fit the regression line. The best fit regression line includes all data points between these vertical lines by the software. The experimenter could move these vertical lines. Sc SNR represents the maximum signal-to-noise within the vertical lines and Pk SNR represents the maximum SNR in that sVEP plot.

3.6 General criteria used for accepting a sVEP plot and determining a threshold

Threshold was determined by extrapolation of the regression line from the signal peak to zero amplitude against spatial frequency for visual acuity threshold and against percentage contrast for contrast threshold as shown in Figure 3.5 and Figure 3.6. The threshold is determined by where the regression line crosses zero amplitude.

Two general criteria for accepting a plot were obtained from the literature as described below. These are:

(1.) The peak signal-to-noise ratio (SNR) should be ≥ 3 (Norcia and Tyler, 1985; Norcia and Tyler, 1985; Norcia et. al., 1985; Tyler et. al., 1985; Allen et. al., 1986; Norcia et. al., 1989; Gottlob et. al., 1990; Lopes de Faria et. al., 1998; Lauritzen et. al,. 2004) .The signal is the sVEP amplitude in microvolts whereas noise is the signal amplitude at frequencies on either side which are different (either less or more) from the stimulation frequency. In this study, to measure the noise, the mean amplitude at two frequencies about 1 Hz on either side of the detection frequency were used. For example if the detection frequency was 15 Hz, the noise was measured at 14.06 Hz and 15.94 Hz, which was 0.94 Hz above and below the detection frequency. This noise value was used to estimate the noise level for each data point.

(2.) Phase should be constant or gradually changing.

In this study, the Power Diva software also uses one more criterion, that the extrapolated thresholds should be close to the last data point used to calculate threshold. If not, then the sVEP plot becomes grey, which indicates it is not a reliable plot, as shown in Figure 3.10 for the PO8Cz channel. Only plots which met these criteria were utilized.

Apart from these three general criteria for accepting a sVEP plot (peak SNR, phase and threshold being close to the last data point), four other criteria were used for threshold determination.

3.7 Determination of signal peak for all criteria

Four criteria (0, 1, 2, 3) were used to determine the position of the vertical lines between which the regression line is drawn. For all criteria one vertical line is positioned at the signal peak which must therefore be defined. The signal peak for criterion 0 was determined by the Power Diva software. For criteria, 1, 2 & 3, the signal peak was defined by placing one dotted vertical line at the obvious peak amplitude. If there were multiple peaks, then the peak closest to the highest spatial frequency or lowest percentage contrast having a SNR ≥ 3 was considered as the signal peak as shown in Figure 3.7.

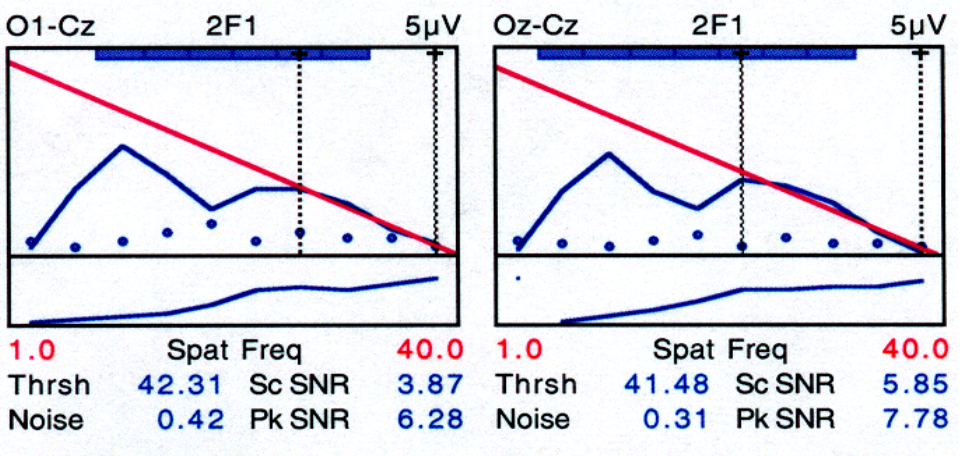


Figure 3.7: Determination of signal peak

3.8 Different criteria for fitting regression line to determine threshold.

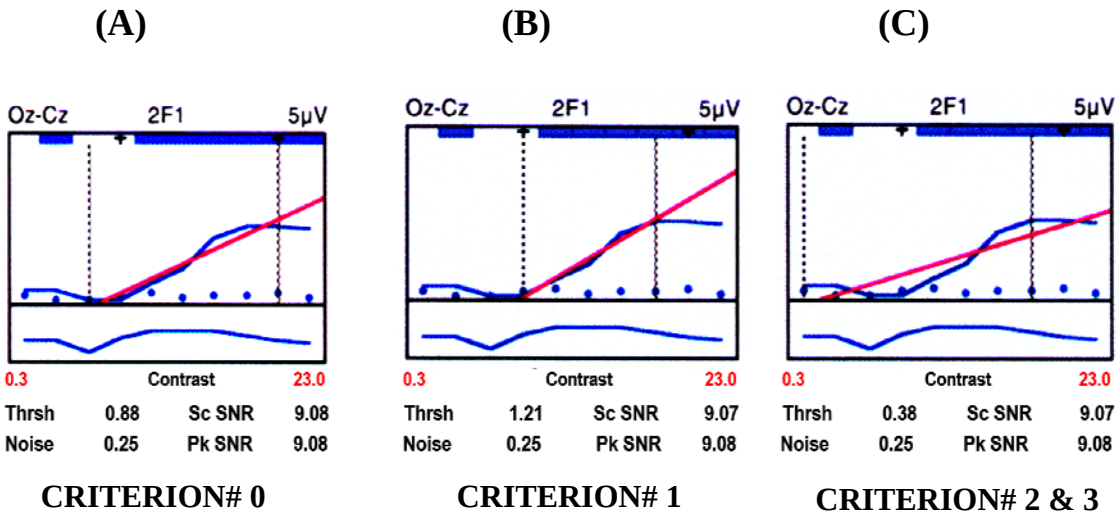


Figure 3.8: Example showing contrast threshold using different criteria (A) Criterion # 0, (B) Criterion # 1, (C) Criterion # 2 & 3.

CRITERION 0 – Power Diva output i.e. threshold given by the software. In this criterion the regression line fitting was determined by the software as shown in Figure 3.8 (A). It is not defined clearly in the Power Diva software manual, how Power Diva positions the vertical lines between which the regression line is calculated.

CRITERION 1 – Fitting the regression line by eye. In this criterion to draw the regression line, one vertical line was placed at the peak amplitude. The second vertical line was placed so as to give the best fit of the straight line portion of the graph by eye as shown in Figure 3.8 (B).

CRITERION 2 – Fitting the regression line between the signal peak and the last data point with a SNR **>** 1 as shown in Figure 3.8 (C). Criterion 2 is a more objective method than criterion 1 to fit the regression line to determine the threshold.

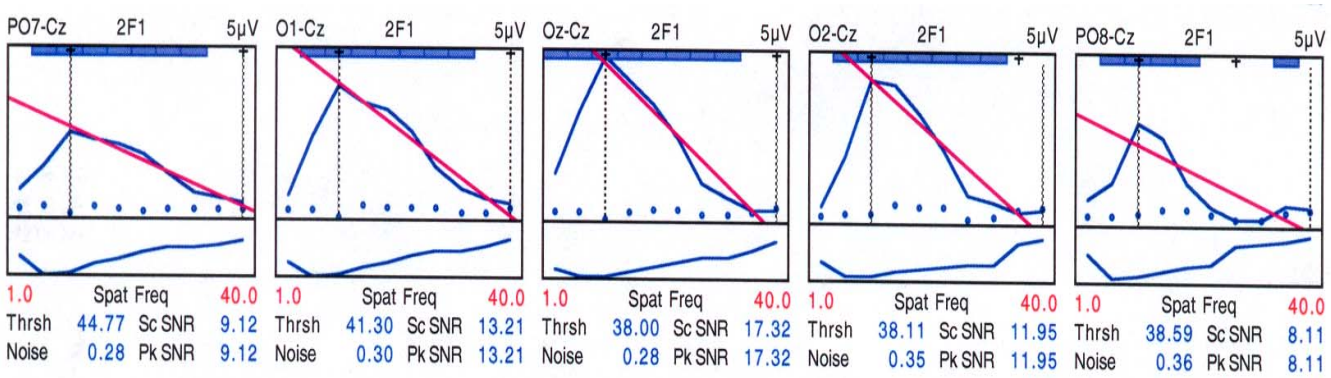


Figure 3.9: Visual acuity threshold using criterion 2

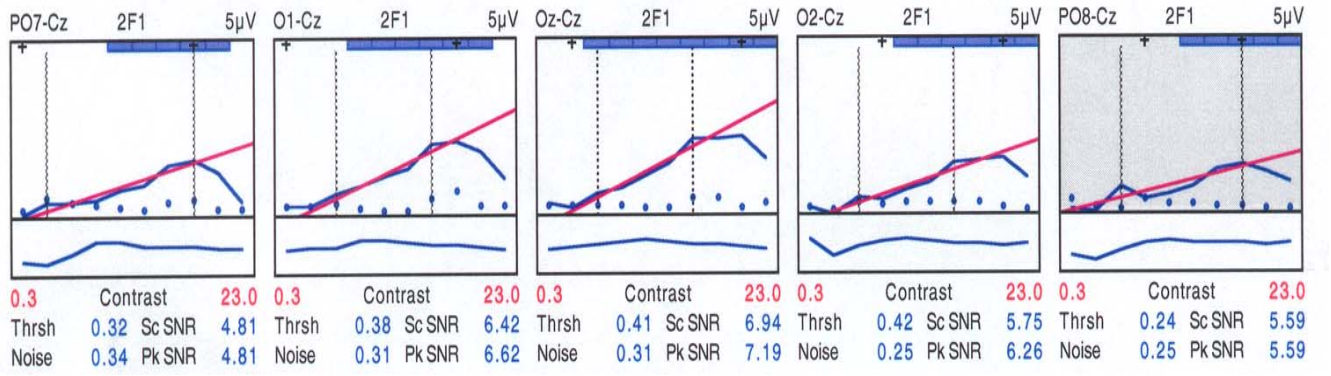


Figure 3.10: Contrast threshold using criterion 2

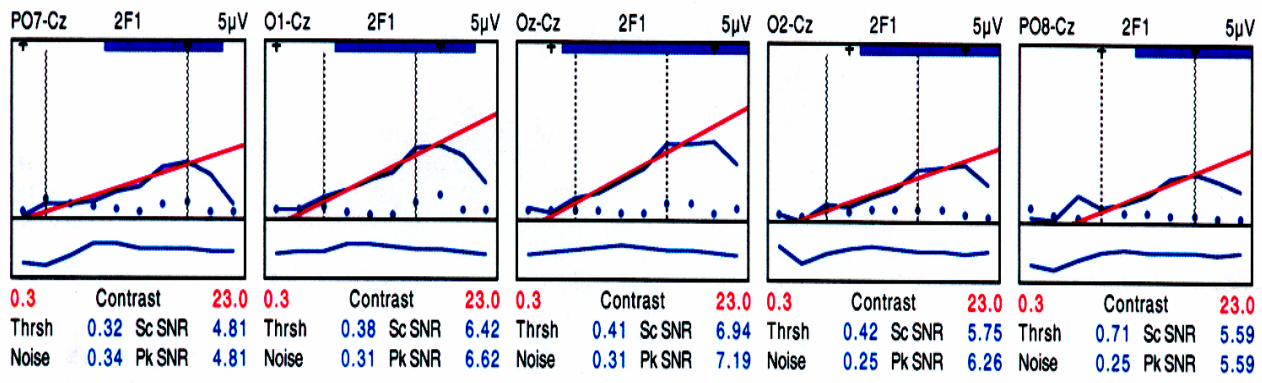
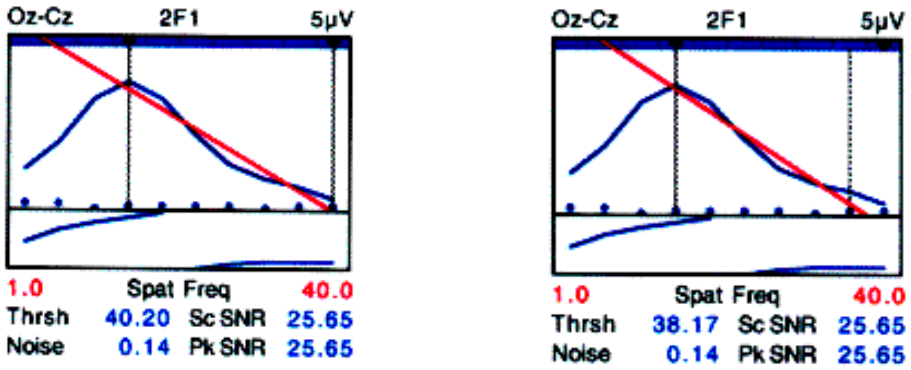


Figure 3.11: Contrast threshold using criterion 2

Choosing the endpoint for the zero amplitude regression in criterion 2 - In criterion 2, for determining the thresholds, the regression line fitting was done between the signal peak and last data point having SNR > 1, as shown in Figures 3.9, 3.10 and 3.11 for the visual acuity and contrast threshold. On occasions, when the vertical lines were moved to the last data point with a SNR > 1, the plot turned grey. This indicates that it is not a reliable plot according to the software criterion. In that case the vertical line was moved to the next data point having SNR > 1 to get a reliable plot. This is shown for the PO8Cz channel in Figures 3.10 and 3.11. Also, criterion 2 sometimes resulted in a threshold beyond the sweep range, as shown in Figure 3.9, for channels PO7 and O1. To measure visual acuity threshold, a sweep range was used from 1 – 40 cpd, but the threshold in these cases was 44.77 cpd and 41.30 cpd at channels PO7 and O1, respectively. Therefore, criterion 3 was developed to give a threshold within the range used.

CRITERION 3 – Similar to Criterion 2, but threshold should be within sweep range used to measure the visual acuity and contrast threshold.



CRITERION# 2 **CRITERION# 3**

Figure 3.12: (a.) Showing Criterion # 2; (b.) Showing Criterion # 3, threshold within sweep range (1 to 40 cpd) used.

As shown in the example in Figure 3.12 (a.), with criterion 2, visual acuity was 40.20 cpd., which was above the sweep range used. Therefore, to get a threshold within the range used, the second vertical line was moved to the next data point having a SNR > 1 as shown in Figure 3.12 (b.), until a threshold was given which was within the range used.

3.9 Experiments

The following parameters of sVEP were investigated in adults.

3.9.1 Experiment 1. Repeatability and validity using different criteria for regression line fitting.

(a.) Repeatability. Ten repeated measurements were done on three participants using the same parameters but on different days. All three participants were males (mean age = 26.6 years, SD ± 1.52). The standard deviation was the measure used to compare repeatability.

Table 3.1: Parameters for visual acuity measurement.

Luminance	**Sweep Range**	**Contrast %**	**Temporal Frequency**	**Viewing Distance**
50 cd/m^2	1 to 40 cpd.	90	7.5 Hz	250 cm

Table 3.2: Parameters for contrast threshold measurement.

Luminance	**Sweep Range**	**Spatial Frequency**	**Temporal Frequency**	**Viewing Distance**
50 cd/m^2	0.3 to 23%	1 cpd	7.5 Hz	100 cm

(b.) Validity. sVEP thresholds were compared with psychophysical visual acuity and contrast thresholds. This experiment had six participants, four males and two females (mean

age = 25.6 years, SD ± 1.50). The Psychophysical Power Diva software was used for psychophysical visual acuity and contrast threshold measurement on six subjects. The sinusoidal horizontal gratings were used as stimuli. A temporal two alternative forced-choice staircase (2 AFC) procedure was used. In the temporal 2AFC method, the sinusoidal horizontal grating stimulus was presented randomly with a blank and the subject had to detect the presence of the grating in one of the two periods by responding either "first" or "second". For the staircase, the "Step down" was 0.1 and the Control was "2D1U 1-2 82%" . "2D1U" means that the stimulus intensity is based on a two down and one up method, that is, two correct responses are required for the staircase to go down towards a less visible stimulus and one incorrect response is required for the staircase to move upwards to a more visible stimulus. "1-2 82%" means that the staircase decreases the stimulus visibility (goes down) a step of 0.1 psychophysical unit and increases visibility (goes up) by 0.2 psychophysical units. The ratio 0.1/0.2=1/2 and converges to the stimulus value corresponding to an 82% correct response.

Table 3.3: Parameters for psychophysical visual acuity measurement

Luminance	**Sweep Range**	**Contrast %**	**Temporal Frequency**	**Viewing Distance**
25, 50 and 100 cd/m^2	35 to 60 cpd	90	7.5 Hz	400 cm

Table 3.4: Parameters for psychophysical contrast threshold measurement.

Luminance	**Sweep Range**	**Spatial Frequency**	**Temporal Frequency**	**Viewing Distance**
25, 50 and 100 cd/m^2	0.1 to 3 %	1 and 8 cpd	7.5 Hz	100cm.

3.9.2 Experiment 2. The effect of luminance.

Visual acuity and contrast threshold were measured at three different luminance conditions, 25, 50 and 100 cd/m^2. This experiment had same six participants as for the validity study. The luminances were randomized during the trials. The parameters used are shown in Table 3.5 and 3.6.

Table 3.5: Parameters used for visual acuity measurement

Luminance	**Sweep Range**	**Contrast %**	**Temporal Frequency**	**Viewing Distance**
25, 50 and 100 cd/m^2	1 to 40 cpd.	90	7.5 Hz	250 cm

Table 3.6: Parameters used for contrast threshold measurement

Luminance	**Sweep Range**	**Spatial Frequency**	**Temporal Frequency**	**Viewing Distance**
25, 50 and 100 cd/m^2	0.23 to 23% for 1 cpd or 1.6 to 50% for 8 cpd.	1 and 8 cpd	7.5 Hz	100cm

3.9.3 Experiment 3. The effect of electrode placement and temporal frequency

In this experiment, visual acuity and contrast threshold were measured with Power Diva or ISCEV standard electrode placement at three different temporal frequencies, 6, 7.5 and 10 Hz. This experiment had six participants, 4 males and 2 females (mean age = 24 years, SD - ± 3.74). The temporal frequencies were randomized during the trials.

Power Diva (PD) electrode placement: In PD electrode placement, the central active Oz electrode was placed 1.5 cm above the inion. The inion is the most prominent projection of the occipital bone which is located at the lower rear part of the skull. The other four active electrodes starting from left, PO7, O1, O2 and PO8, were placed laterally 2.5 cm from each other. All the five active channels were referenced to the Cz, which was mid-way between the nasion and the inion. The nasion is defined as the intersection of the frontal and two nasal bones of the human skull i.e. the dip at the top of the nose. The ground electrode was placed on the forehead. The Power Diva electrode placement is shown in Figure 3.13.

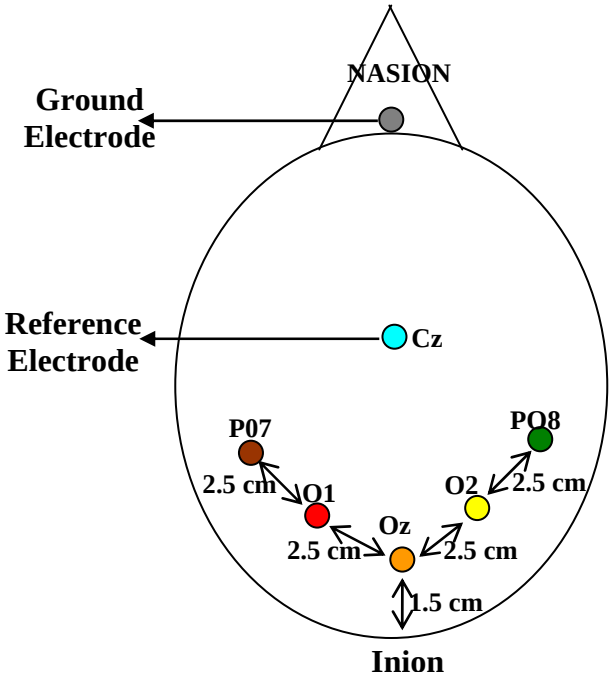


Figure 3.13: The Power Diva electrode placement

ISCEV electrode placement (Odom et. al., 2004)**:** For the ISCEV electrode placement, the vertical measurement of the skull was taken from the inion to nasion and the central active Oz electrode was placed at 10% of that vertical distance above the inion. The circumferential measurement of half of the skull was taken from Oz to nasion. The O2 active electrode was placed at 10% of that circumferential distance from Oz to nasion. Similarly, the other three active electrodes, PO7, O1 and PO8, were placed 10% from each other. They were all referenced to the Fz electrode, which was placed at 30% of the vertical distance between the nasion and inion from the nasion and 20% from the ground electrode. The ground electrode was placed on the forehead at 10% of the vertical distance between nasion and inion from the nasion. The ISCEV electrode placement is shown in Figure 3.14.

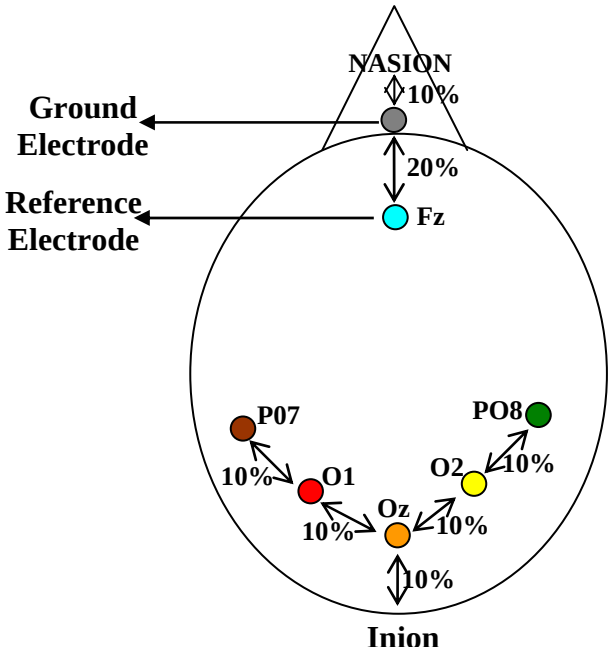


Figure 3.14: The ISCEV electrode placement

3.9.4 Experiment 4. The effect of direction of sweep and fixation target.

In this experiment, visual acuity and contrast threshold were measured by using two sweep directions i.e. from seeing to non-seeing and vice versa and also with and without a central fixation target. This experiment had six participants, 5 males and 1 female (mean age – 27.5, SD - ± 2.25).

Table 3.7: Parameters used for visual acuity measurement

Luminance	Sweep Range	Contrast %	Temporal Frequency	Viewing Distance
50 cd/m^2	1 to 40 cpd. and 40-1 cpd	90	7.5 Hz	250 cm

Table 3.8: Parameters used for contrast threshold measurement

Luminance	Sweep Range	Spatial Frequency	Temporal Frequency	Viewing Distance
50 cd/m^2	0.30 to 23% and 23 to 0.30%	1 and 8 cpd	7.5 Hz	100cm

3.9.5 Experiment 5. The effect of stimulus area

In this experiment, visual acuity and contrast threshold were measured using five different stimulus areas. This experiment had six participants, all were males (mean age = 26.3 years, SD ± 1.36). The stimulus areas were chosen to be in a logarithmic scale of 0.1 log units. The stimulus areas are shown in Table 3.9. The stimulus areas were randomized during the trial. The parameters used are shown in Tables 3.10 and 3.11.

Table 3.9: Stimulus areas for visual acuity and contrast threshold measurement.

For visual acuity measurement	For contrast threshold measurement
6.39x6.05 degrees	15.64x14.84 degrees
5.07x4.80 degrees	12.52x11.87 degrees
4.03x3.81 degrees	10.00x9.46 degrees
3.20x3.02 degrees	7.96x7.53 degrees
2.54x2.40 degrees	6.33x5.99 degrees

Table 3.10: Parameters used for visual acuity measurement

Luminance	Sweep Range	Contrast %	Temporal Frequency	Viewing Distance
50 cd/m^2	1 to 40 cpd.	90	7.5 Hz	250 cm.

Table 3.11: Parameters used for contrast threshold measurement

Luminance	Sweep Range	Spatial Frequency	Temporal Frequency	Viewing Distance
50 cd/m^2	0.30 to 23%	1 cpd	7.5 Hz	100cm.

3.10 Inclusion and exclusion criteria

In this study, visual acuity was measured with a Bailey-Lovie log MAR chart. Absence of strabismus was checked with the unilateral cover test. The Office of Human Research at the University of Waterloo approved this study.

Inclusion criteria

Participants should have corrected to normal visual acuity.

Exclusion criteria

Participants should not have any ocular health anomalies or disorders.

Participants should not have strabismus.

3.11 Data Analysis

Sweep VEP data were analyzed with the Power Diva software. The amplitude and phase of the evoked response were determined at the second harmonic (2F) frequency using the Recursive Least Square (RLS) method (explained in Appendix 1). Ten trials were averaged for each condition and then the average thresholds of five active channels which gave viable plots were used for data analysis. Apart from thresholds, numbers of viable or acceptable plots were also used for the analysis in this study. Statistical Analysis System (SAS) software was used to analyze the sVEP data. The results of all the five experiments, except for the repeatability experiment, were analyzed using repeated measure ANOVA. The repeatability results were analyzed with the F-test of variance.

Chapter 4: Results

4.1 Experiment 1: Repeatability and validity using different criteria for regression line fitting.

4.1.1 Repeatability

Visual acuity – Figure 4.1 shows that criterion 2 and 3 gave more repeatable results as shown by a lower standard deviation for all three subjects for visual acuity measurement. The F-test of variance was applied for each subject, comparing each criterion. Table 4.1 shows that with the F-test of variance there was a significant difference ($F(9,9)_{0.05} = 3.18$, so that $p < 0.05$) between criterion 0 and 3 and criterion 1 and 3 for two subjects out of three. There was also a significant difference between criterion 1 and 2 for one subject. However, criterion 2 and 3 were not significantly different for all three subjects.

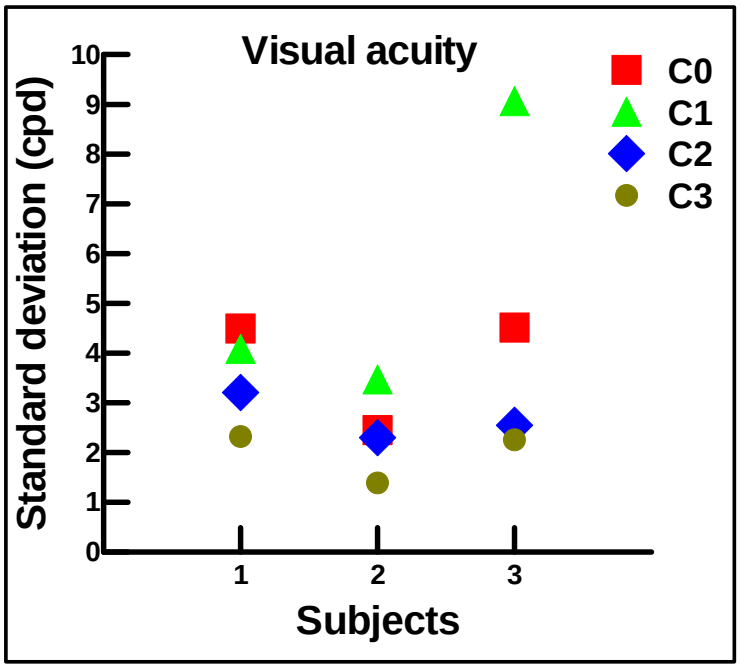


Figure 4.1: Standard deviation of visual acuity threshold (cycles per degree) for three subjects for ten repeated measures for the four criteria used for regression line fitting.

Table 4.1: F test for variance used to compare repeatability of different criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Subject 1	Subject 2	Subject 3
C0-C1			***
C0-C2			
C0-C3	***		***
C1-C2			***
C1-C3		***	***
C2-C3			

Contrast threshold – Spatial frequency – 1 cpd. Figure 4.2 shows that criterion 2 and 3 gave more repeatable results as shown by a lower standard deviation for all three subjects for contrast thresholds measurement at a spatial frequency of 1 cpd. The F-test of variance was applied for each subject, comparing each criterion. Table 4.2 shows that with the F-test of variance there was a significant difference ($F(9,9)_{0.05} = 3.18$, so that $p < 0.05$) between the criteria C1 and C2, and between C1 and C3 in all three subjects. There was also a significant difference between criterion 0 and 1 for two subjects, and criterion 0 and 2, and criterion 0 and 3 for one subject. However, criterion 2 and 3 were not significantly different for any subject.

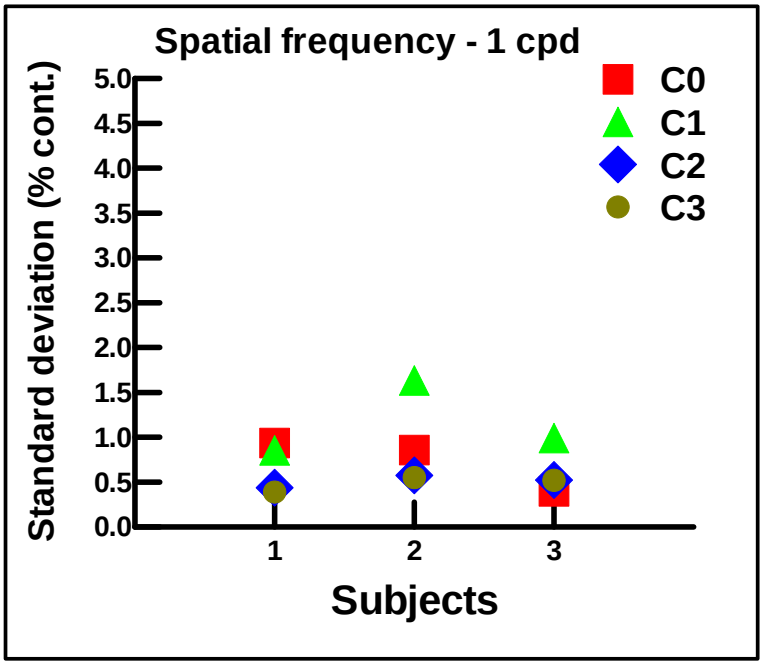


Figure 4.2: Standard deviation of contrast threshold (% contrast) at a spatial frequency of 1 cpd for three subjects for ten repeated measures for the four criteria used for regression line fitting.

Table 4.2: F test of variance used to compare repeatability of different criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Subject 1	Subject 2	Subject 3
C0-C1		***	***
C0-C2	***		
C0-C3	***		
C1-C2	***	***	***
C1-C3	***	***	***
C2-C3			

Contrast threshold – Spatial frequency – 8 cpd. Figure 4.3 shows that criterion 2 and 3 gave more repeatable results as shown by a lower standard deviation for two subjects out of three for contrast thresholds measurement at a spatial frequency of 8 cpd. The F-test of variance was applied for each subject, comparing each criterion. Table 4.3 shows that with the F-test of variance there was a significant difference ($F(9,9)_{0.05} = 3.18$, so that $p < 0.05$) between the criteria C0 and C2; C0 and C3; C1 and C2; C1 and C3 in two subjects. However, criterion 2 and 3 were not significantly different.

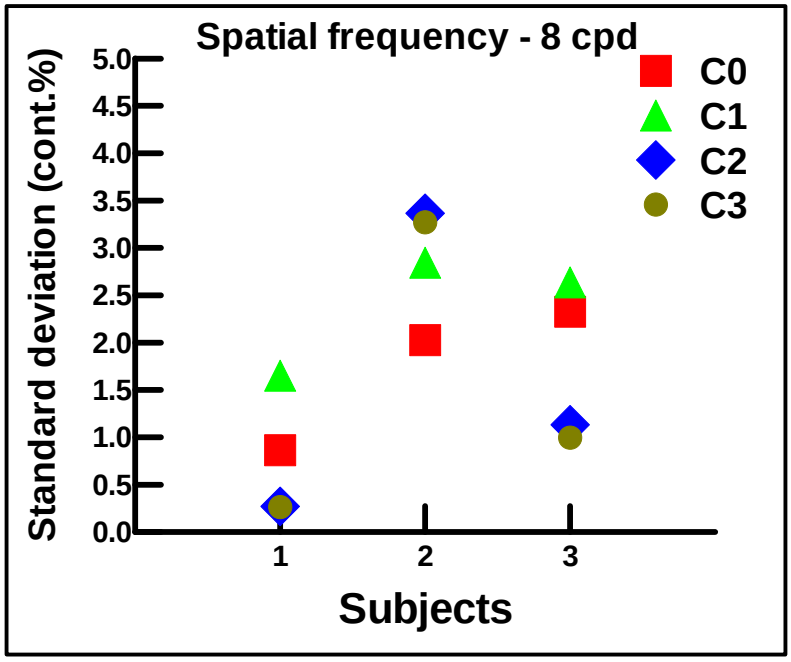


Figure 4.3: Standard deviation of contrast threshold (% contrast) at a spatial frequency of 8 cpd for three subjects for ten repeated measures for the four criteria used for regression line fitting.

Table 4.3: F test of variance used to compare repeatability of different criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Subject 1	Subject 2	Subject 3
C0-C1	***		
C0-C2	***		***
C0-C3	***		***
C1-C2	***		***
C1-C3	***		***
C2-C3			

4.1.2 Validity

Visual acuity – Figure 4.4 shows that criterion 2 values were closer to the psychophysical values than criteria CO, C1 and C3 at all three luminances. Repeated measures ANOVA (3 luminances x 5 threshold measures) showed a main effect of criterion/psychophysical acuity ($F = 15.83$, $df = 4$, $p < 0.0001$) and no main effect of luminance ($F = 1.68$, $df = 2$, $p = 0.2344$). There was no interaction of luminance with criterion/psychophysical threshold ($F = 1.27$, $df = 8$, $p = 0.2856$). The post hoc Dunnett's t test (Table 4.4) showed that criteria CO, C1 and C3 values were significantly different from the psychophysical acuity at all three luminances. However, there was no significant difference between criterion C2 and psychophysical acuity.

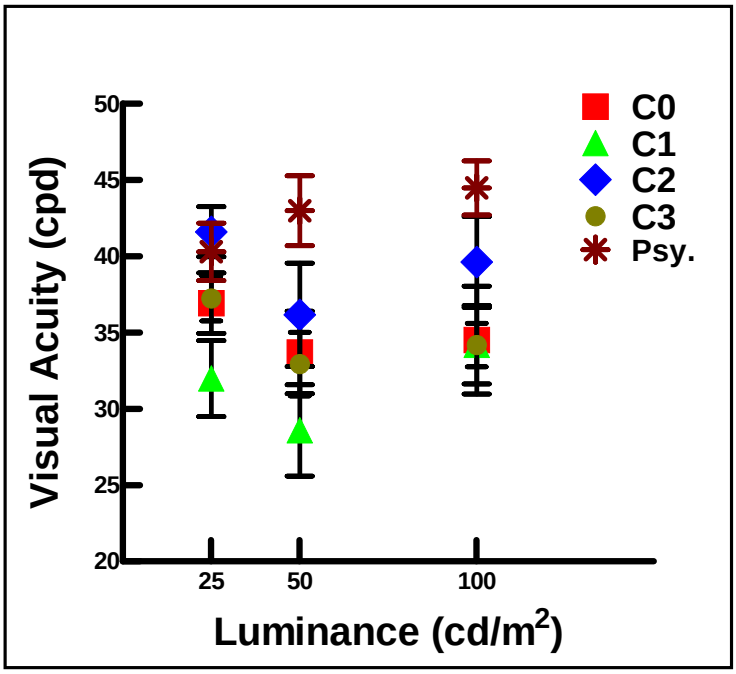


Figure 4.4: Mean sVEP and psychophysical visual acuity threshold for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3 and Psy is the psychophysical threshold.

Table 4.4: Post hoc Dunnett's t test for differences between criteria and psychophysical acuity. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-Psy	***
C1-Psy	***
C2-Psy	
C3-Psy	***

Contrast threshold – Spatial frequency 1 cpd. Figure 4.5 shows that criterion 2 values were closer to the psychophysical threshold than criteria CO, C1 and C3 at all three luminances. Repeated measures ANOVA (3 luminances x 5 threshold measures) showed a main effect of criterion/psychophysical threshold ($F = 10.37$, $df = 4$, $p = 0.0001$) and luminance ($F = 4.15$, $df = 2$, $p = 0.0488$). There was no interaction of luminance with criterion/psychophysical threshold ($F = 1.76$, $df = 8$, $p = 0.1187$). The post hoc t test (LSD) for means (Table 4.5) showed that the luminance of 25 and 50 cd/m^2 were significantly different. The post hoc Dunnett's t test (Table 4.6) showed that criteria CO, C1 and C3 were significantly different from the psychophysical threshold at all three luminances. There was, ; however, no significant difference between criterion C2 and the psychophysical threshold.

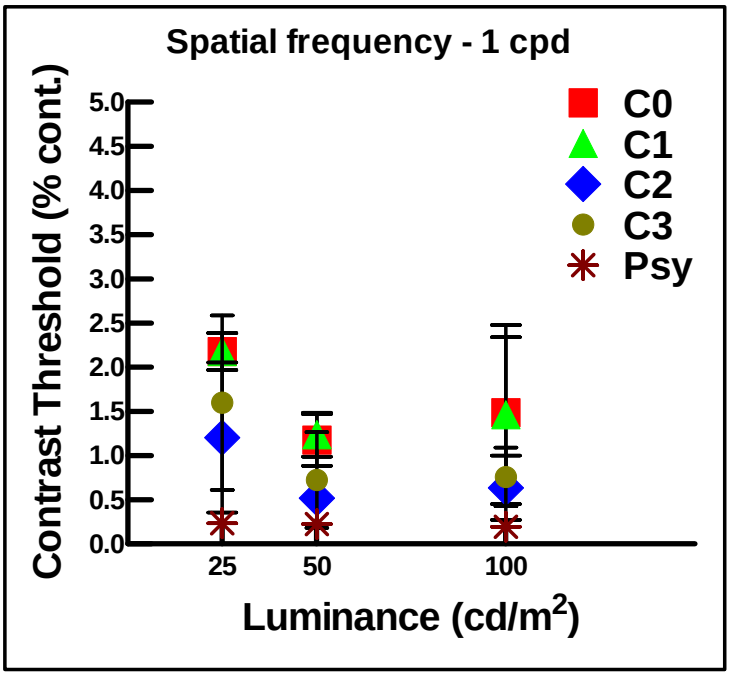


Figure 4.5: Mean sVEP and psychophysical contrast threshold for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3 and Psy is the psychophysical threshold.

Table 4.5: Post hoc t test (LSD) for means for differences between luminances. Comparisons significant at 0.05 level are indicated by ***.

Luminance	Significant effect
25-100	
25-50	***
100-50	

Table 4.6: Post hoc Dunnett's t test for differences between criteria and psychophysical threshold. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-Psy	***
C1-Psy	***
C2-Psy	
C3-Psy	***

Contrast threshold – Spatial frequency 8 cpd. Figure 4.6 shows that criterion 2 and 3 were closer to the psychophysical threshold than criterion CO and C1 at all three luminances. Repeated measures ANOVA (3 luminances x 5 threshold measures) showed a main effect of criterion/psychophysical threshold ($F = 15.40$, $df = 4$, $p < 0.0001$) and no main effect of luminance ($F = 2.31$, $df = 2$, $p = 0.1500$). There was no interaction of luminance with criterion/psychophysical threshold ($F = 1.66$, $df = 8$, $p = 0.1381$). The post hoc Dunnett's t test (Table 4.7) showed that criterion CO and C1 gave values which were significantly different from the psychophysical threshold at all three luminances. However,

there was no significant difference between criterion C2 and the psychophysical threshold or C3 and the psychophysical threshold.

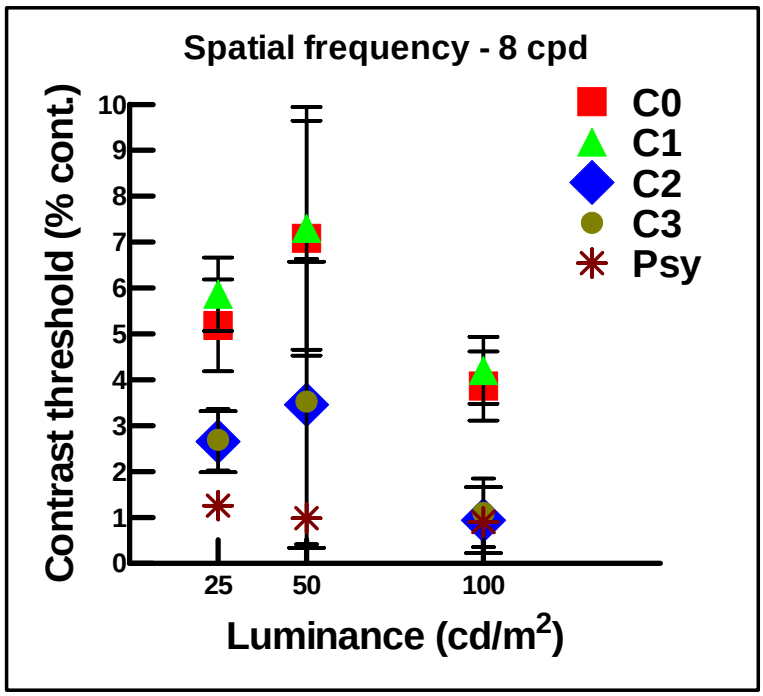


Figure 4.6: Mean sVEP and psychophysical contrast threshold for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3 and Psy is the psychophysical threshold

Table 4.7: Post hoc Dunnett's t test for differences between criteria and psychophysical threshold. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-Psy	***
C1-Psy	***
C2-Psy	
C3-Psy	

4.2 Experiment 2: The effect of luminance (25, 50 and 100 cd/m^2).

4.2.1 Visual acuity and number of viable plots.

Visual acuity - Figure 4.7 shows that criterion 2 gave higher visual acuity at each luminance than criteria 0, 1 and 3. Repeated measures ANOVA (3 luminances x 4 criteria) showed a main effect of criterion (F = 9.41, df = 3, p = 0.0010) and no main effect of luminance (F= 2.15, df = 2, p = 0.1673). There was no interaction of luminance with criterion (F = 0.47, df = 6, p = 0.8267). The post hoc t test (LSD) for mean (Table 4.8) showed that criterion 2 was significantly different from criterion 0, 1 and 3 and criterion 1 was also significantly different from criterion 0.

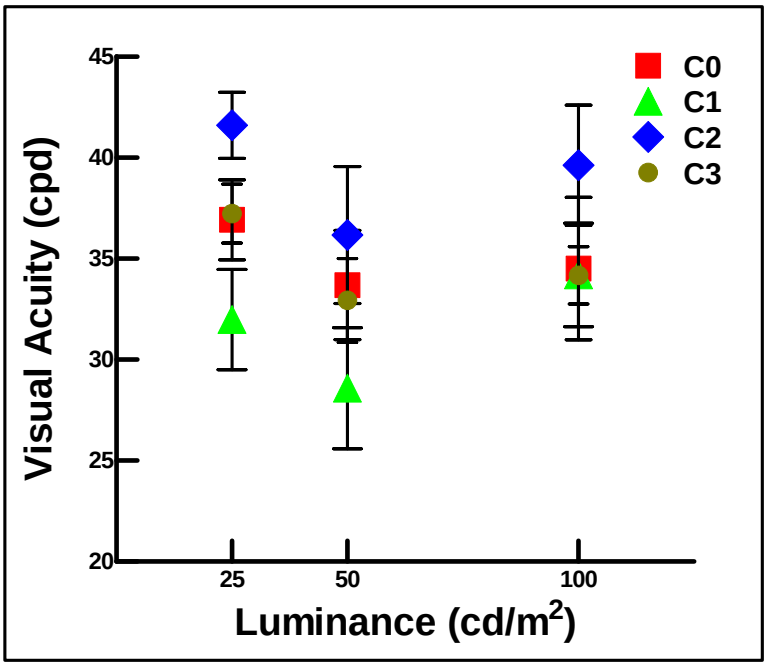


Figure 4.7: Mean visual acuity threshold for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.8: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	***
C0-C2	***
C0-C3	
C1-C2	***
C1-C3	
C2-C3	***

Number of viable plots - Figure 4.8 shows that the luminance of 50 and 100 cd/m^2 gave more viable readings than the luminance of 25 cd/m^2. Repeated measures ANOVA (3 luminances x 4 criteria) showed a main effect of criterion ($F = 6.16$, $df = 3$, $p = 0.0061$) and luminance ($F = 5.11$, $df = 2$, $p = 0.0295$) on the number of readings. There was no interaction of luminance with criterion ($F = 2.35$, $df = 6$, $p = 0.0560$). The post hoc t test (LSD) for mean (Table 4.9) showed that criterion 1 and 2 were significantly different from the criterion 0 and 3. Post hoc testing (Table 4.10) also showed that the luminance of 25 and 50 cd/m^2 were significantly different, but the luminance of 100 cd/m^2 was not significantly different from 25 and 50 cd/m^2.

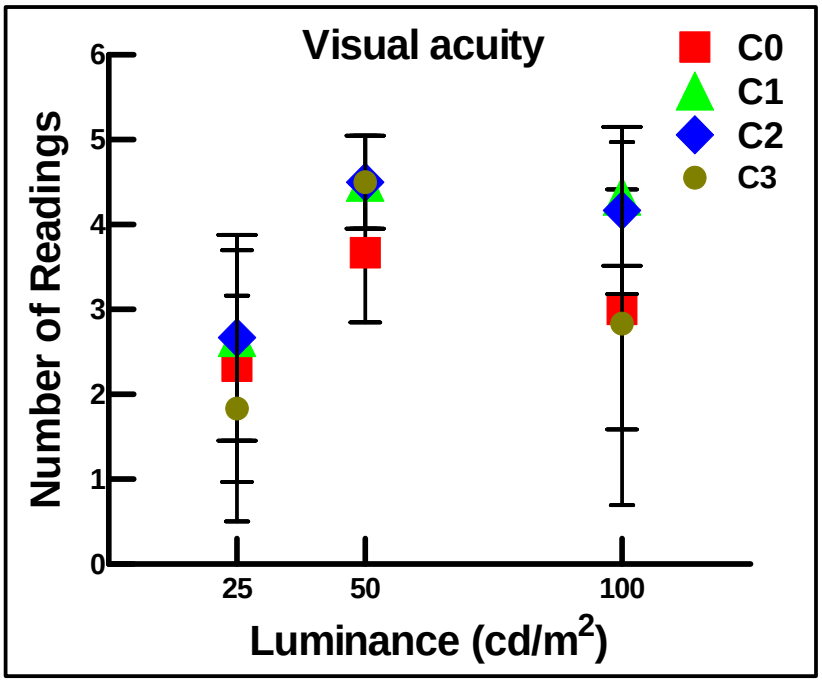


Figure 4.8: Mean number of readings for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP number of viable plots or number of readings determined with criterion 0 to 3.

Table 4.9: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	***
C0-C2	***
C0-C3	
C1-C2	
C1-C3	***
C2-C3	***

Table 4.10**:** Post hoc t test (LSD) for means for differences between luminances. Comparisons significant at 0.05 level are indicated by ***.

Luminance	**Significant effect**
25-50	***
25-100	
50-100	

4.2.2 Contrast threshold and number of viable plots - Spatial frequency 1 cpd.

Contrast threshold - Figure 4.9 shows that criterion 2 and 3 gave lower contrast thresholds than criterion 0 and 1. Repeated measures ANOVA (3 luminances x 4 criteria) showed a main effect of criterion ($F = 8.46$, $df = 3$, $p = 0.0016$) and no main effect of luminance ($F = 4.15$, $df = 2$, $p = 0.530$) on contrast threshold. There was no interaction of luminance with criterion ($F = 0.59$, $df = 6$, $p = 0.7331$). The post hoc t tests (LSD) for mean (Table 4.11) showed that criterion 0 and 1 were significantly different from criterion 2 and 3.

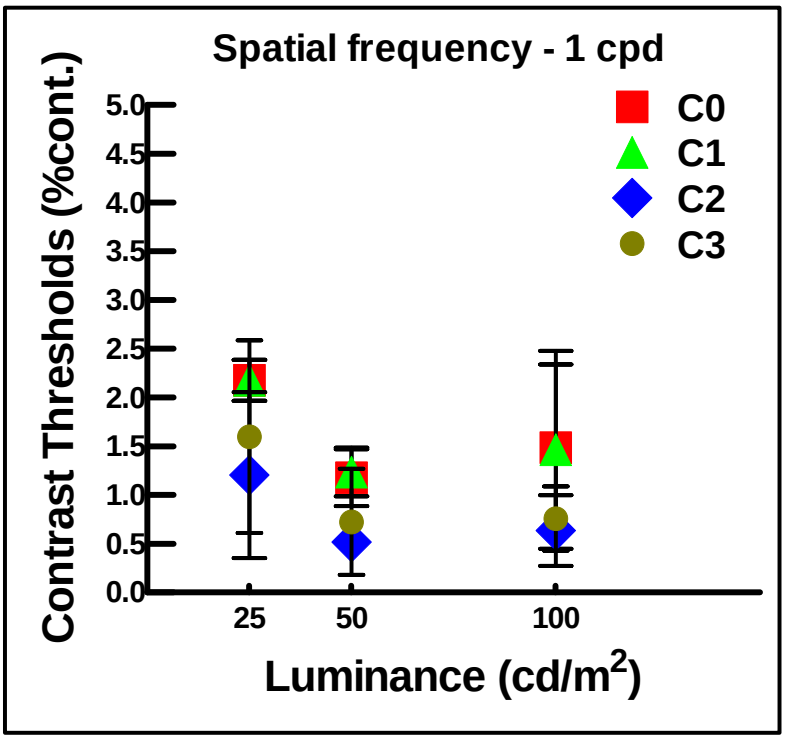


Figure 4.9: Mean contrast threshold for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.11: Post hoc t test (LSD) for means for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	***
C0-C3	***
C1-C2	***
C1-C3	***
C2-C3	

Number of viable plots - Figure 4.10 shows the number of viable plots against luminance. Repeated measures ANOVA (3 luminances x 4 criteria) showed no main effect of criterion ($F = 0.43$, $df = 3$, $p = 0.7338$) and luminance ($F = 3.03$, $df = 2$, $p = 0.0938$). There was no interaction of luminance with criterion ($F = 1.92$, $df = 6$, $p = 0.1094$).

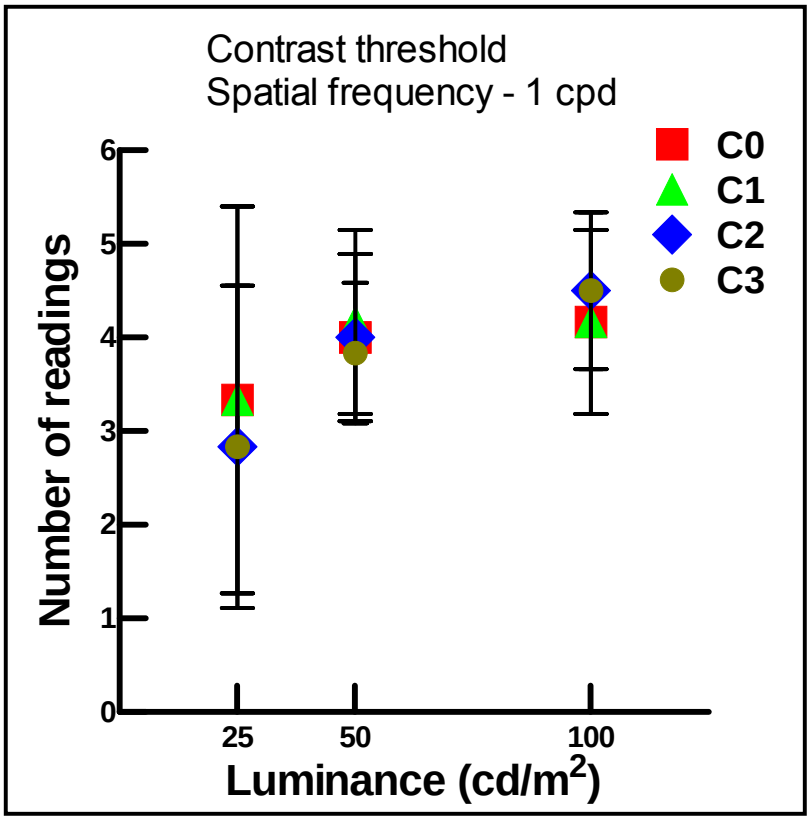


Figure 4.10: Mean number of readings for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP number of viable plots or number of readings determined with criterion 0 to 3.

4.2.3 Contrast threshold and number of viable plots - Spatial frequency 8 cpd.

Contrast threshold - Figure 4.11 shows that criterion 2 and 3 gave lower contrast thresholds than criterion 0 and 1. Repeated measures ANOVA (3 luminances x 4 criteria) showed a main effect of criterion ($F = 18.65$, $df = 3$, $p < 0.0001$) and no main effect of luminance ($F = 2.29$, $df = 2$, $p = 0.1522$). There was no interaction of luminance with criterion ($F = 0.63$, $df = 6$, $p = 0.7074$). The post hoc t tests (LSD) for mean (Table 4.12) showed that criterion 0 and 1 are significantly different from criterion 2 and 3.

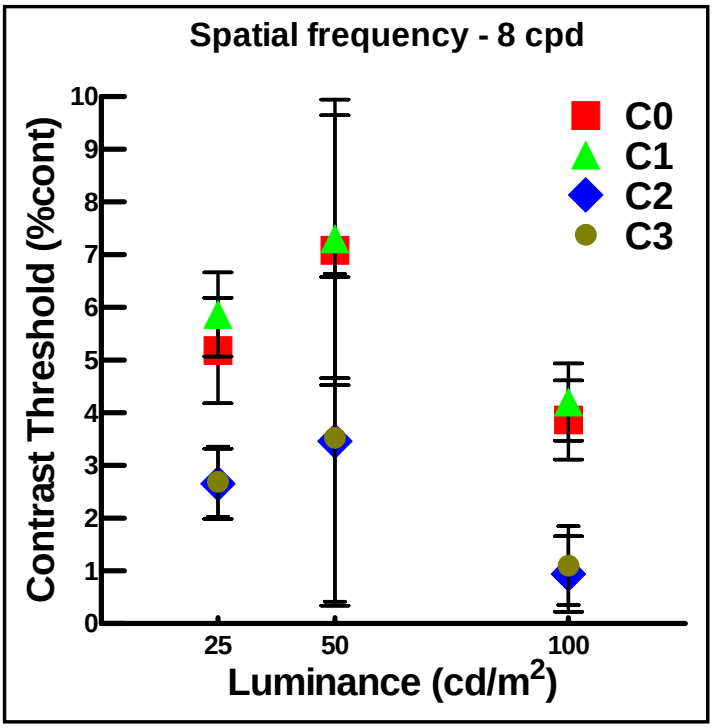


Figure 4.11: Mean contrast threshold for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.12**:** Post hoc t test (LSD) for means for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	**Significant effect**
C0-C1	
C0-C2	***
C0-C3	***
C1-C2	***
C1-C3	***
C2-C3	

Number of viable plots - Figure 4.12 shows the number of viable readings plotted against luminance. Repeated measures ANOVA (3 luminances x 4 criteria) showed no main effect of criterion ($F = 1.29$, $df = 3$, $p = 0.3139$) and luminance ($F = 2.97$, $df = 2$, $p = 0.0970$). There was no interaction of luminance with criterion ($F = 0.12$, $df = 6$, $p = 0.9929$).

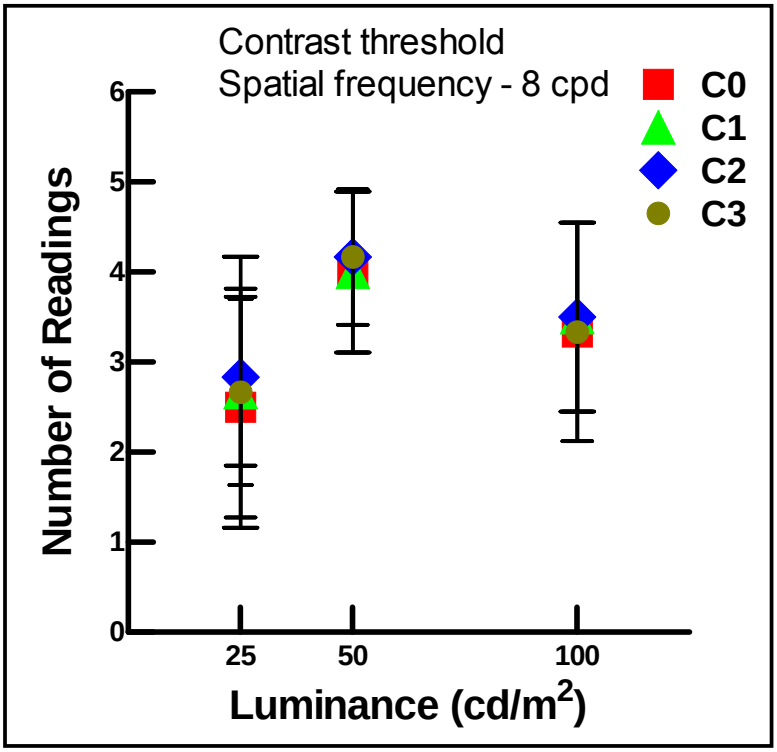


Figure 4.12: Mean number of readings for 6 subjects against luminance. Error bars are ± 1 SD. C0 to C3 are sVEP number of viable plots or number of readings determined with criterion 0 to 3.

4.3 Experiment 3: The effect of two electrode placements i.e. Power Diva (PD) and ISCEV and three temporal frequencies (6, 7.5 and 10 Hz).

4.3.1 Visual acuity and number of viable plots.

Visual acuity - Figure 4.13 shows that criterion 2 gave higher visual acuity than criterion 0, 1 and 3 with both the PD and ISCEV electrode placement at all three temporal frequencies. Repeated measures ANOVA (2 electrode placements x 3 temporal frequencies x 4 criteria) showed a main effect of criterion ($F = 12.50$, $df = 3$, $p = 0.0002$) but no main effect of electrode placement ($F = 0.20$, $df = 1$, $p = 0.6747$) or temporal frequency ($F = 0.02$, $df = 2$, $p = 0.9775$). There were no interactions of electrode placement with criterion ($F = 0.39$, $df = 3$, $p = 0.7615$) or temporal frequency ($F = 0.11$, $df = 2$, $p = 0.7723$). The post hoc t tests (LSD) for mean (Table 4.13) showed that the criterion 1, 2 and 3 were significantly different from each other. However, criterion 0 and 1 were not significantly different. Criterion 2 and 3 were significantly different from criterion 0.

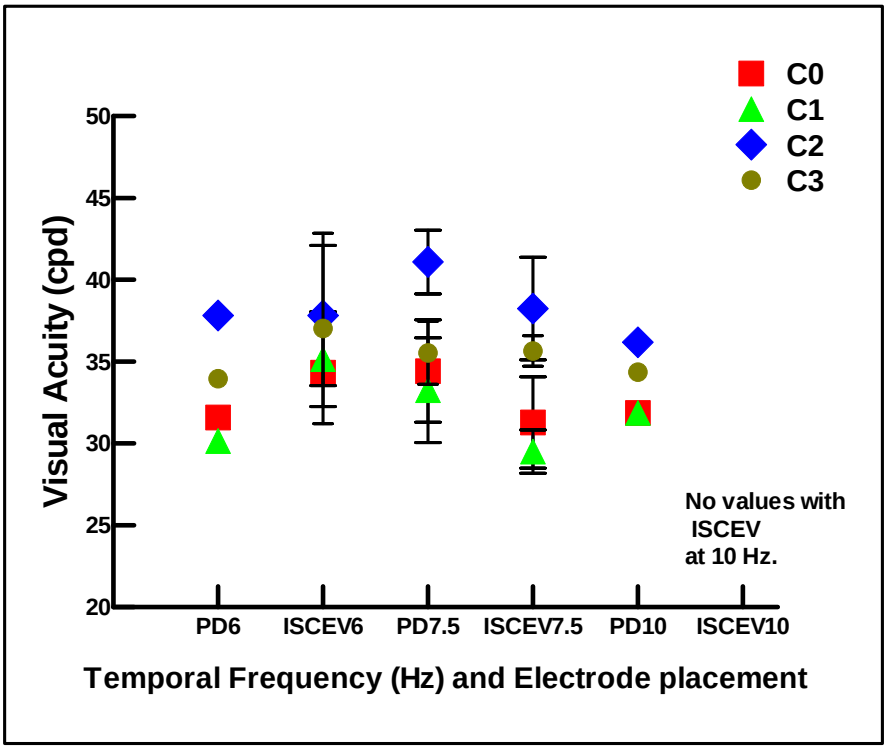


Figure 4.13: Mean visual acuity threshold for 6 subjects against temporal frequency and electrode placement. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.13: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	***
C0-C3	***
C1-C2	***
C1-C3	***
C2-C3	***

Number of viable plots - Figure 4.14 shows that the temporal frequency of 7.5 Hz gave more viable readings than 6 and 10 Hz, with both the PD and ISCEV electrode placement. Repeated measures ANOVA (2 electrode placements x 3 temporal frequencies x 4 criteria) showed a main effect of criterion ($F = 3.63$, $df = 3$, $p = 0.0376$) and temporal frequency ($F = 50.53$, $df = 2$, $p < 0.0001$) but no main effect of electrode placement ($F = 0.07$, $df = 1$, $p = 0.8070$) on the number of readings. There were no interactions of electrode placements with criterion ($F = 2.63$, $df = 3$, $p = 0.0882$) or temporal frequency ($F = 0.50$, $df = 2$, $p = 0.6223$). The post hoc t tests (LSD) for mean (Table 4.14) showed that criterion 2 was significantly different from the criterion 0 and 3. However, criterion 3 was significantly different from criterion 1 and 2 and criterion 1 was significantly different from criterion 3. The post hoc t test (Table 4.15) also showed that the temporal frequency of 6, 7.5 and 10 Hz were significantly different from each other.

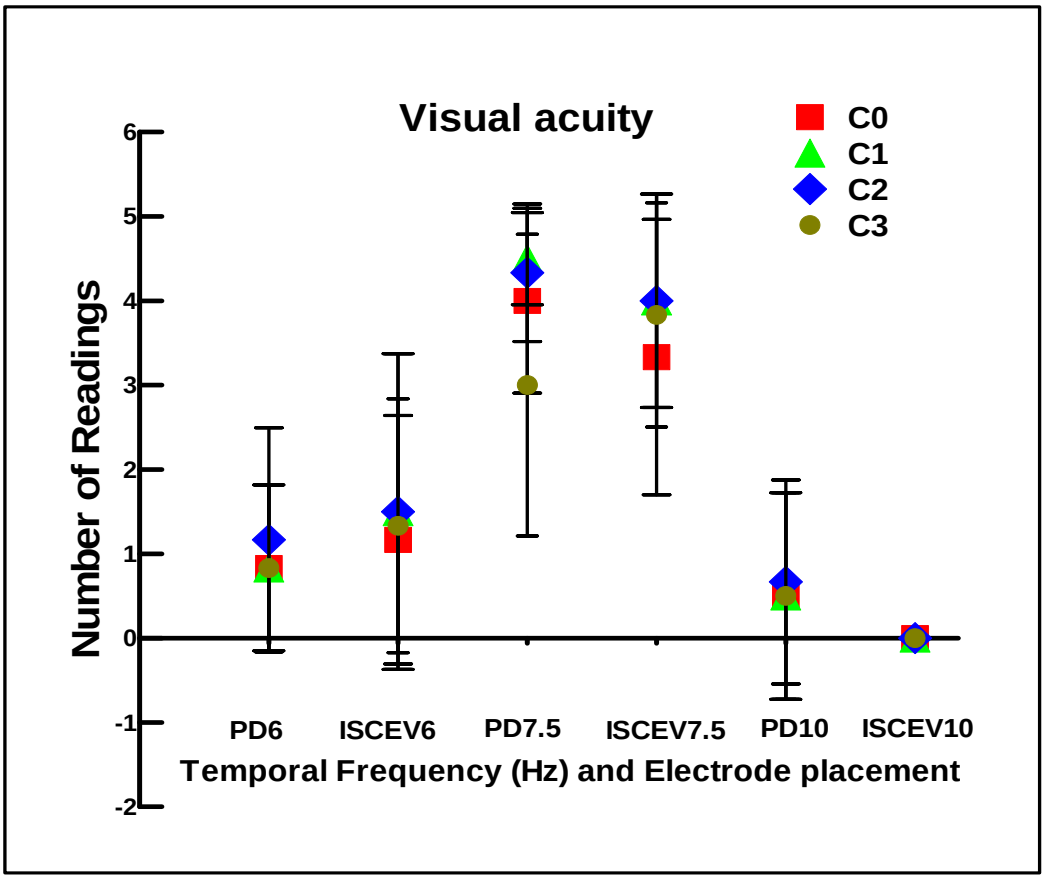


Figure 4.14: Mean number of readings for 6 subjects against temporal frequency and electrode placement. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.14: Post hoc t test (LSD) for means for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	***
C0-C3	
C1-C2	
C1-C3	***
C2-C3	***

Table 4.15: Post hoc t test (LSD) for means for differences between temporal frequencies. Comparisons significant at 0.05 level are indicated by ***.

Temporal frequency	Significant effect
6-7.5	***
6-10	***
7.5-10	***

4.3.2 Contrast threshold and number of viable plots – Spatial frequency 4 cpd.

Contrast threshold - Figure 4.15 shows that criterion 2 and 3 gave lower contrast thresholds than criterion 0 and 1 with both the PD and ISCEV electrode placement at three temporal frequencies. Repeated measures ANOVA (2 electrode placements x 3 temporal frequencies x 4 criteria) showed a main effect of criterion ($F = 4.00$, $df = 3$, $p = 0.0281$) but no main effect of electrode placement ($F = 0.41$, $df = 1$, $p = 0.5656$) or temporal frequency ($F = 0.19$, $df = 2$, $p = 0.8500$) on the contrast thresholds. The post hoc t tests (LSD) for mean (Table 4.16) showed that the criterion 0 and 1 are significantly different from the criterion 2 and 3. There was no interaction of electrode placement with criterion ($F = 0.29$, $df = 3$, $p = 0.8298$), but there was highly significant interaction of criterion with temporal frequency ($F = 1536.98$, $df = 6$, $p < 0.0001$). Figure 4.16 shows the interaction between different criterion and temporal frequency. Since there was no main effect of electrode placement, the electrode placements data at all three temporal frequencies were averaged to show the interaction

between criterion and temporal frequency. No statistical analysis was possible because of missing data at the temporal frequency of 6 and 10 Hz. There were only two subjects at 6 Hz and three subjects at 10 Hz out of six subjects, who gave a threshold. Figure 4.16 shows that except criterion 1, all other criteria follow the same trend at all three temporal frequencies. Criterion 1 gave lower threshold at 10 Hz compared to 6 and 7.5 Hz. However, criterion 0, 2 and 3 gave lower threshold at 7.5 Hz compared to 6 and 10 Hz.

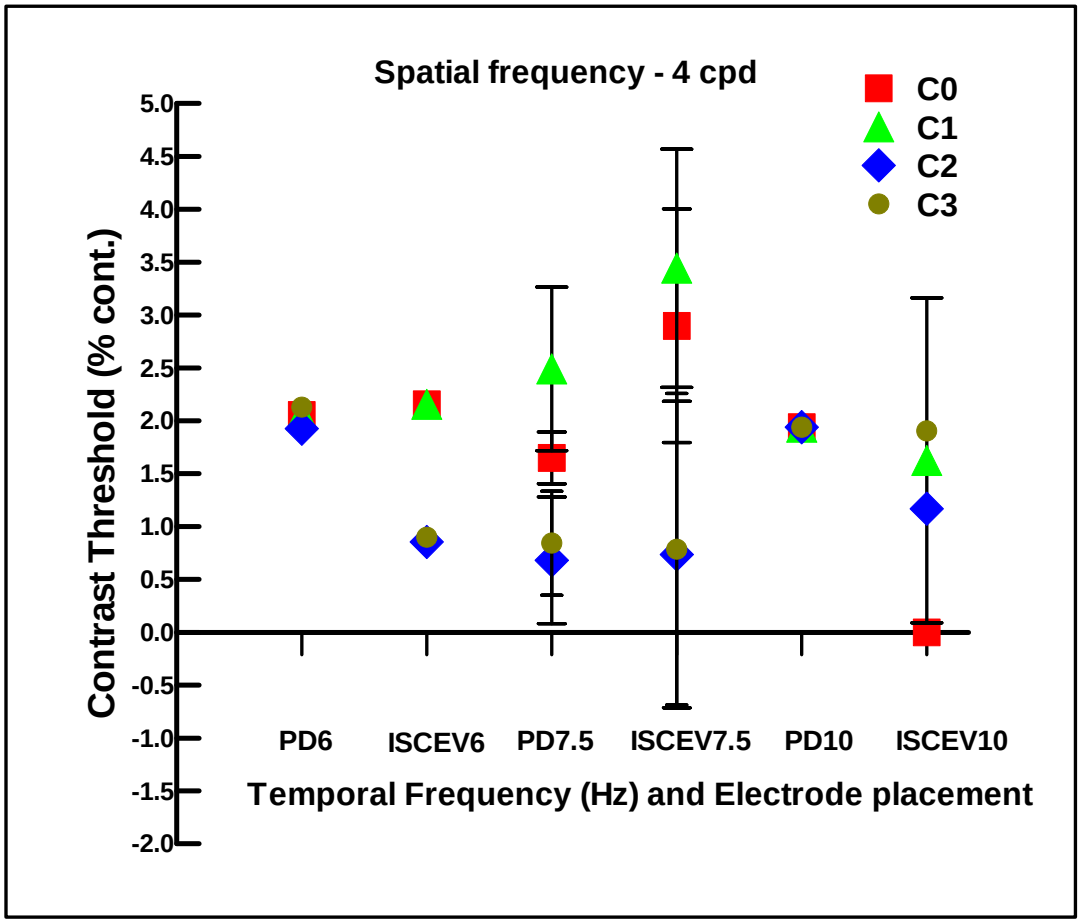


Figure 4.15: Mean contrast threshold for 6 subjects against temporal frequency and electrode placement. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.16: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	***
C0-C3	***
C1-C2	***
C1-C3	***
C2-C3	

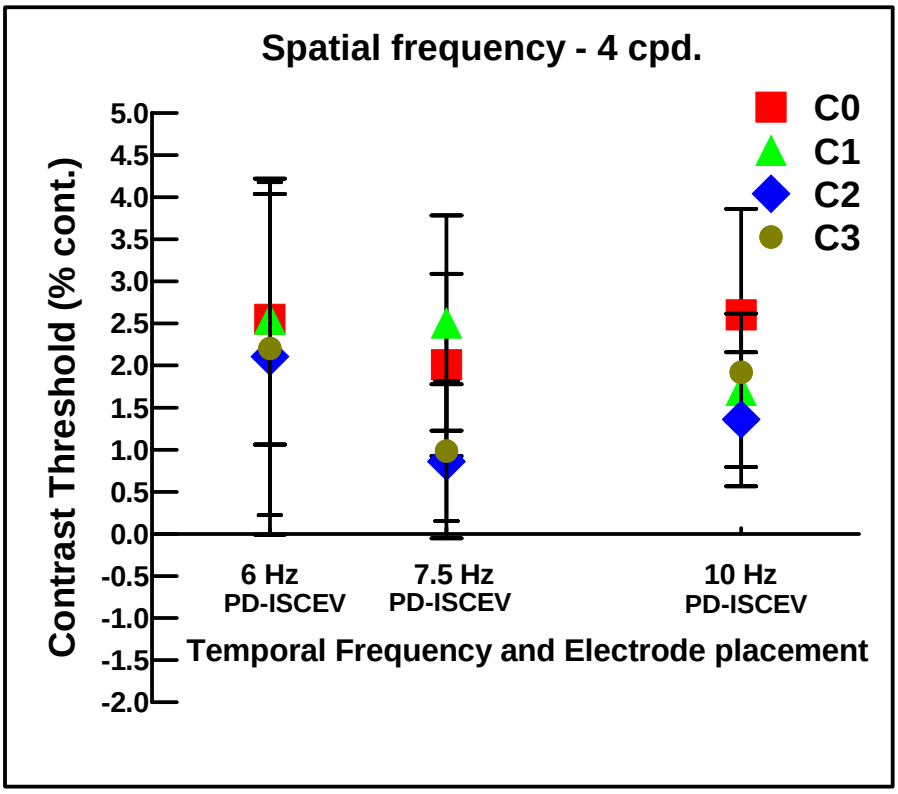


Figure 4.16: Mean contrast threshold (average of both electrode placements) showing the interaction between criterion and temporal frequency. Error bars are ± 1 SD.

Number of viable plots - Figure 4.17 shows that the temporal frequency of 7.5 Hz gave more viable readings than 6 and 10 Hz with both the PD and ISCEV electrode placement. Repeated measures ANOVA (2 electrode placements x 3 temporal frequencies x 4 criteria) showed a main effect of criterion ($F = 3.07$, $df = 3$, $p = 0.0600$) and temporal frequency ($F = 9.87$, $df = 2$, $p = 0.0043$) but no main effect of electrode placement ($F = 1.02$, $df = 1$, $p = 0.3595$) on the number of readings. There was no interaction of electrode placements with criterion ($F = 0.19$, $df = 3$, $p = 0.9023$) and temporal frequency ($F = 2.71$, $df = 2$, $p = 0.1147$). The post hot t tests (LSD) for means (Table 4.17) showed that criterion 0 was significantly different from criterion 1 and 2. However, there was no significant difference between criterion 0 and 3. The post hoc t tests (Table 4.18) also showed that the temporal frequency of 7.5 Hz was significantly different from 6 and 10 Hz.

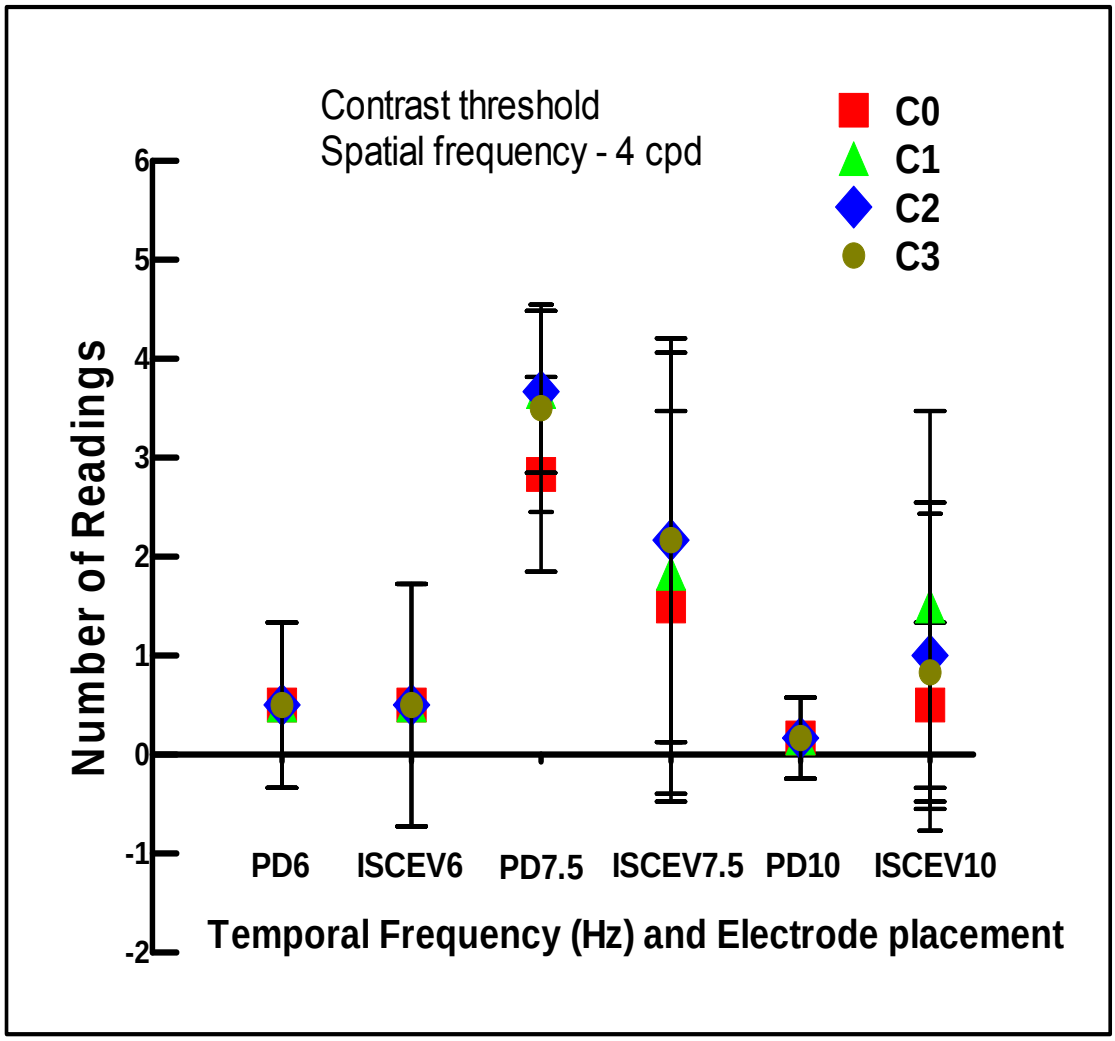


Figure 4.17: Mean number of readings for 6 subjects against temporal frequency and electrode placement. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.17: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	***
C0-C2	***
C0-C3	
C1-C2	
C1-C3	
C2-C3	

Table 4.18: Post hoc t test (LSD) for means for differences between temporal frequencies. Comparisons significant at 0.05 level are indicated by ***.

Temporal frequency	Significant effect
6-7.5	***
6-10	
7.5-10	***

4.4 Experiment 4: The effect of sweep direction and fixation target.

4.4.1 Visual acuity and number of viable plots.

Visual acuity - Figure 4.18 shows that criterion 2 gave higher visual acuities than criterion 0, 1 and 3, for both the sweep directions, with and without a fixation target. Repeated measures ANOVA (2 fixations x 2 directions x 4 criteria) showed a main effect of criterion ($F = 7.53$, $df = 2$, $p = 0.0026$) but no main effect of sweep direction ($F = 2.69$, $df = 1$, $p = 0.1619$) or fixation target ($F = 0.14$, $df = 1$, $p = 0.7221$). The post hoc t tests (LSD) for mean (Table 4.19) showed that the criterion 2 is significantly different from the criterion 0, 1 and 3.

There was no interaction of fixation target with criterion ($F = 0.57$, $df = 3$, $p = 0.6447$) or sweep direction ($F = 0.03$, $df = 1$, $p = 0.8671$). However, there was an interaction of criterion with sweep direction ($F = 4.26$, $df = 3$, $p = 0.0231$). Figure 4.19 shows the interaction between different criterion and sweep direction, both with and without a fixation target. As there was no main effect of fixation target, the data with and without a fixation target data for both sweep directions were averaged to show the interaction between criterion and sweep direction. A paired t-test was used to compare sweep direction for each criterion and showed an effect only for criterion 1 ($p = 0.035$). There was no significant difference for criterion 0, 2 and 3 ($p > 0.05$).

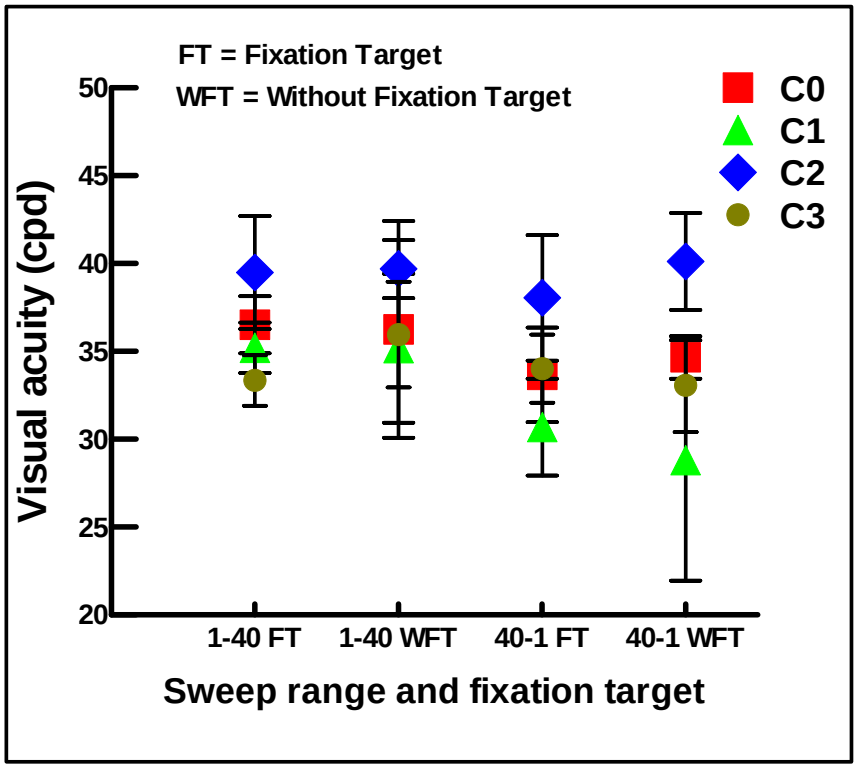


Figure 4.18: Mean visual acuity for 6 subjects against sweep direction and fixation target. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.19: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	***
C0-C3	
C1-C2	***
C1-C3	
C2-C3	***

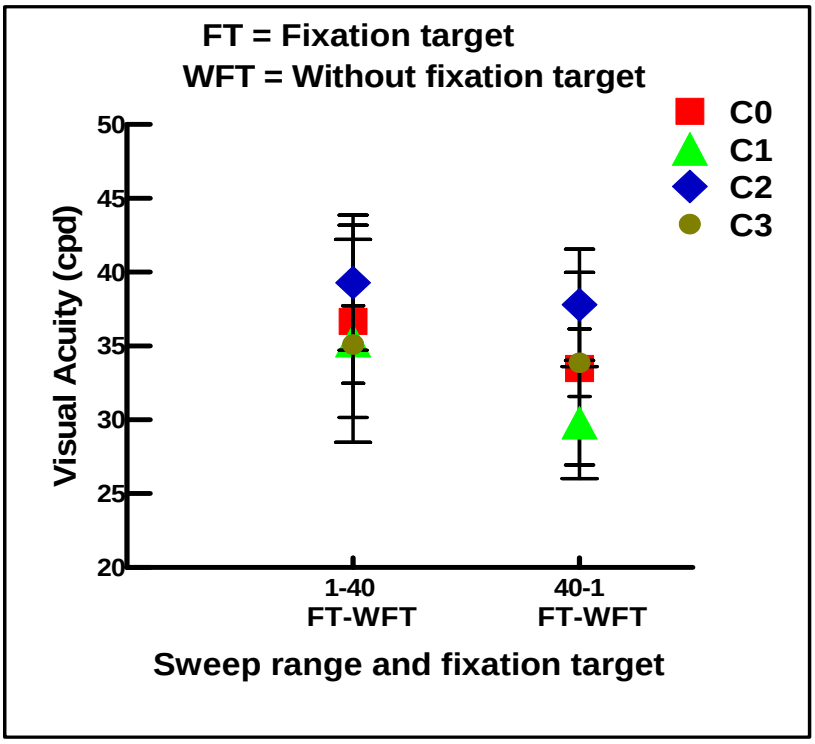


Figure 4.19: Mean visual acuity (average of both fixation targets) showing the interaction between criterion and sweep direction. Error bars are ± 1 SD.

Number of viable plots - Figure 4.20 shows that there are more viable readings with the fixation target than without a fixation target, for both the sweep directions. Repeated measures ANOVA (2 fixations x 2 directions x 4 criteria) showed a main effect of criterion ($F = 11.01$, $df = 3$, $p = 0.0004$) and fixation target ($F = 7.64$, $df = 1$, $p = 0.0396$) but no main effect of sweep direction ($F = 3.87$, $df = 1$, $p = 0.1063$) on the number of readings. There were more readings with a fixation target than without a fixation target. The post hoc t test (LSD) for mean (Table 4.20) showed that criterion 3 was significantly different from criterion 0, 1 and 2.

There was no interaction of fixation target with criterion ($F = 0.10$, $df = 3$, $p = 0.9576$) or sweep direction ($F = 1.22$, $df = 1$, $p = 0.3204$**).**, There was, however, an interaction of

criterion with sweep direction (F = 3.75, df = 3, p = 0.0343). The post hoc test was not possible. Qualitatively, Figure 4.20 shows that all criterion except criterion 3 gave more readings with sweep direction from seeing to non-seeing both with and without a fixation target, whereas for criterion 3 sweep directions has no effect.

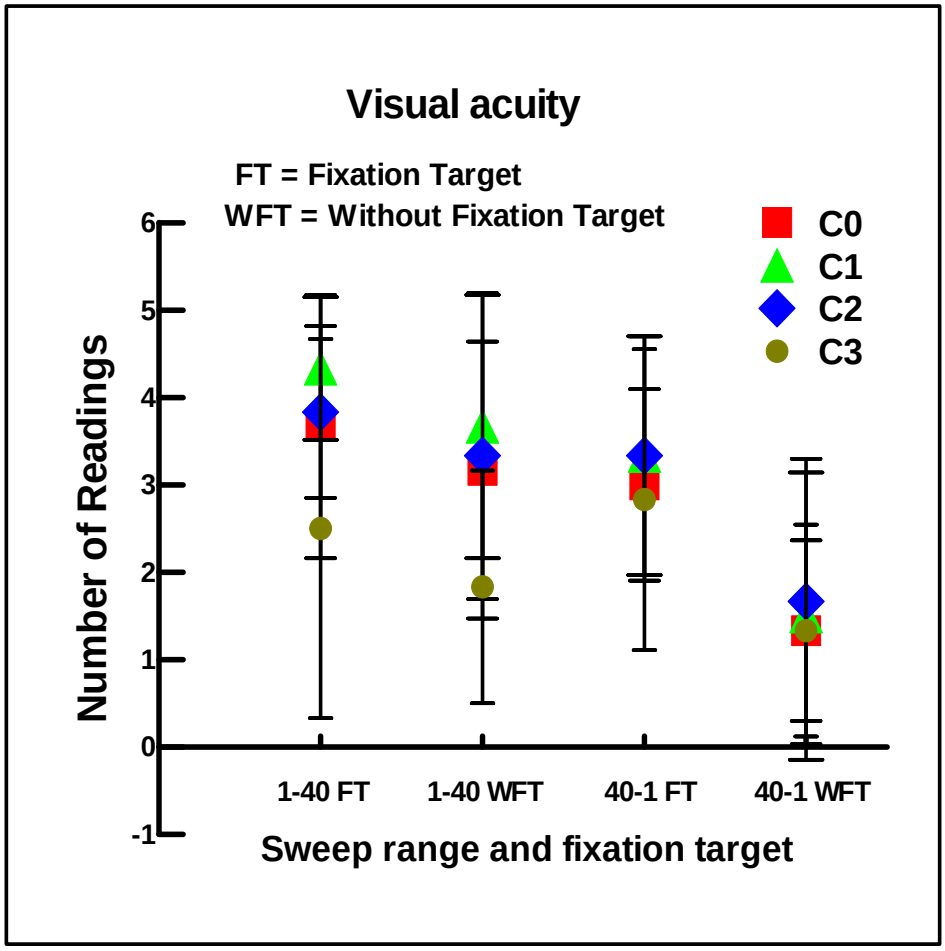


Figure 4.20: Mean number of reading for 6 subjects against sweep direction and fixation target. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.20**:** Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	
C0-C3	***
C1-C2	
C1-C3	***
C2-C3	***

4.4.2 Contrast threshold and number of viable plots – Spatial frequency 1 cpd.

Contrast threshold - Figure 4.21 shows that criterion 2 and 3 gave lower contrast thresholds than criterion 0 and 1 for both the sweep directions, with and without a fixation target. Repeated measures ANOVA (2 fixations x 2 directions x 4 criteria) showed a main effect of criterion ($F = 7.09$, $df = 3$, $p = 0.0034$) but no main effect of sweep direction ($F = 0.64$, $df = 1$, $p = 0.4610$) or fixation target ($F = 0.91$, $df = 1$, $p = 0.4103$) on contrast threshold. The post hoc t tests (LSD) for mean (Table 4.21) showed that criterion 1 is significantly different from criterion 2 and 3, whereas criterion 0 is significantly different from criterion 2.

There was no interaction of presence of fixation target with criterion ($F = 1.93$, $df = 3$,

$p = 0.1954$) or sweep direction ($F = 0.00$, $df = 1$, $p = 0.9493$). However, there was an interaction of criterion with sweep direction ($F = 4.97$, $df = 3$, $p = 0.0136$). Figure 4.22 shows the interaction between different criterion and sweep direction. As there was no main effect of fixation target, the data with and without a fixation target data for both sweep directions were averaged to show the interaction between criterion and sweep direction. A paired t-test was used to compare sweep direction for each criterion and showed no significant effect of any of the criterion ($p > 0.05$). However, in Figure 4.22, criterion 3 shows a different trend than criterion 0, 1 and 2. Criterion 3 shows lower contrast threshold while criterion 0, 1 and 2 gave higher contrast threshold with seeing to non-seeing compared to non-seeing to seeing.

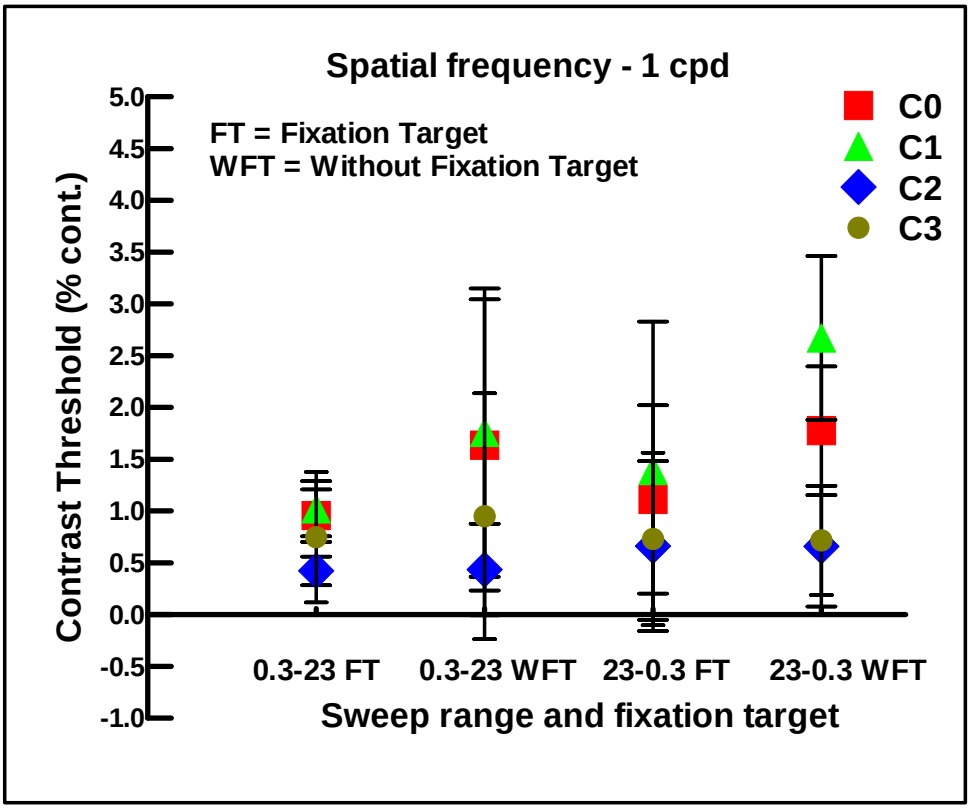


Figure 4.21: Mean contrast threshold for 6 subjects against sweep direction and fixation target. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.21: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	***
C0-C3	
C1-C2	***
C1-C3	***
C2-C3	

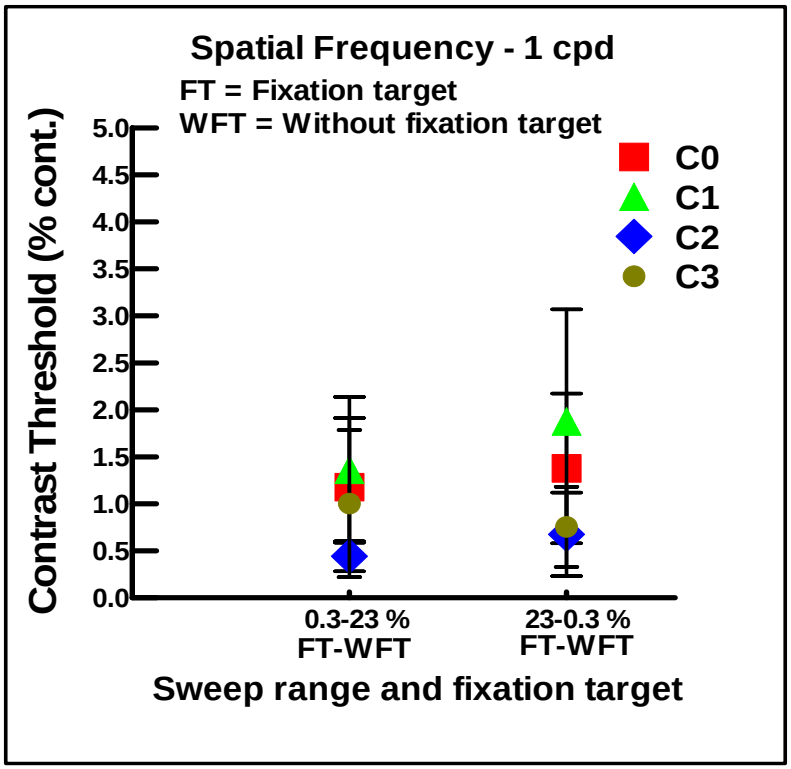


Figure 4.22: Mean contrast threshold (average of both fixation targets) showing the interaction between criterion and sweep direction. Error bars are ± 1 SD.

Number of viable plots - Figure 4.23 shows the number of readings against sweep range and fixation target for the four criterions. Repeated measures ANOVA (2 fixations x 2 directions x 4 criteria) showed a main effect of criterion ($F = 4.49$, $df = 4.49$, $p = 0.0194$) but no main effect of sweep direction ($F = 0.13$, $df = 1$, $p = 0.7351$) or fixation target ($F = = 5.42$, $df = 1$, $p = 0.0673$) on the number of readings. There were no interactions of fixation target with criterion ($F = 2.00$, $df = 3$, $p = 0.1569$) or sweep direction ($F = 0.21$, $df = 1$, $p = 0.6660$). There was also no interaction of criterion with sweep direction ($F = 1.77$, $df = 3$, $p = 0.1968$). The post hoc t tests (LSD) for mean (Table 4.22) showed that criterion 0 and 1, and criterion 0 and 2 were significantly different. The post hoc t test also showed that criterion 1 and 3 were significantly different.

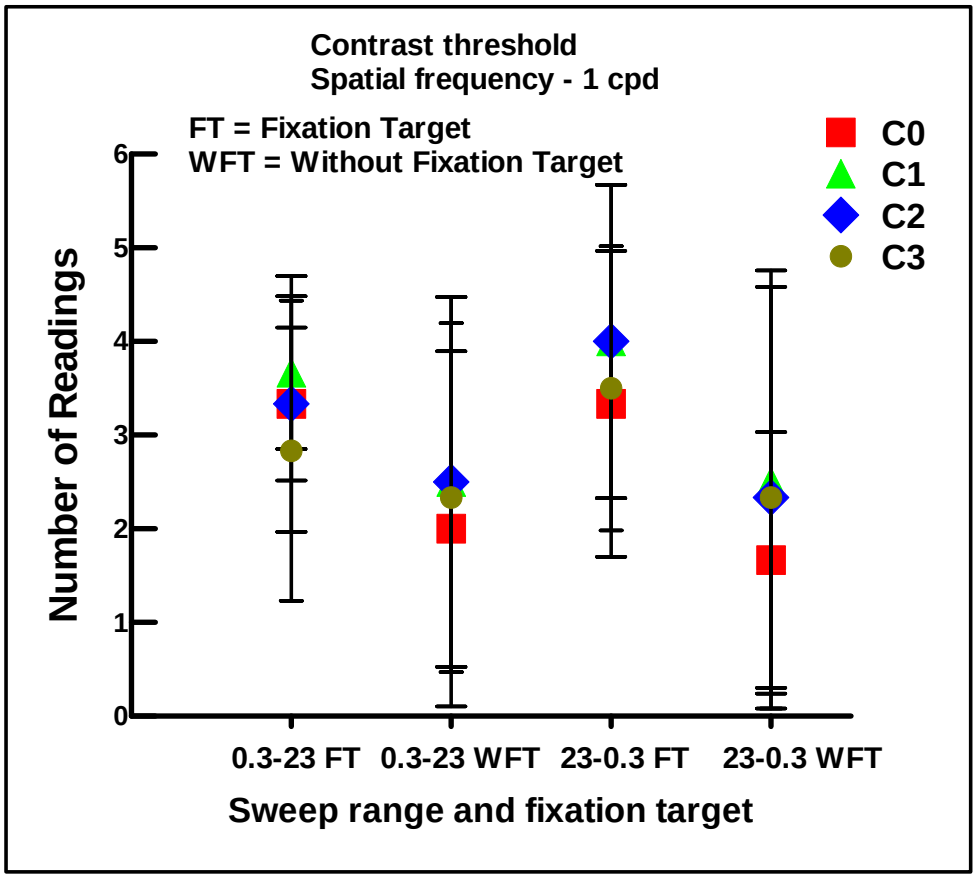


Figure 4.23: Mean number of reading for 6 subjects against sweep direction and fixation target. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.22: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	***
C0-C2	***
C0-C3	
C1-C2	
C1-C3	***
C2-C3	

4.4.3 Contrast threshold and number of viable plots – Spatial frequency 8 cpd.

Contrast threshold - Figure 4.24 shows that criterion 2 and 3 gave lower contrast thresholds than criterion 0 and 1 for both the sweep directions, with and without a fixation target. Repeated measures ANOVA (2 fixations x 2 directions x 4 criteria) showed a main effect of criterion ($F = 65.77$, $df = 3$, $p < 0.0001$) but no main effect of sweep direction ($F = 7.32$, $df = 1$, $p = 0.0734$) or fixation target ($F = 0.01$, $df = 1$, p value $= 0.9133$) on the contrast threshold. There was no interaction of fixation target with criterion ($F = 0.75$, $df = 3$, $p = 0.5412$) or sweep direction ($F = 0.38$, $df = 1$, $p = 0.6008$). There was also no interaction of criterion with sweep direction ($F = 1.54$, $df = 3$, $p = 0.2698$). The post hoc t tests (LSD) for mean (Table 4.23) showed that criterion 0 was significantly different from criterion 1, 2 and 3., There was, however, no significant difference between the criterion 2 and 3.

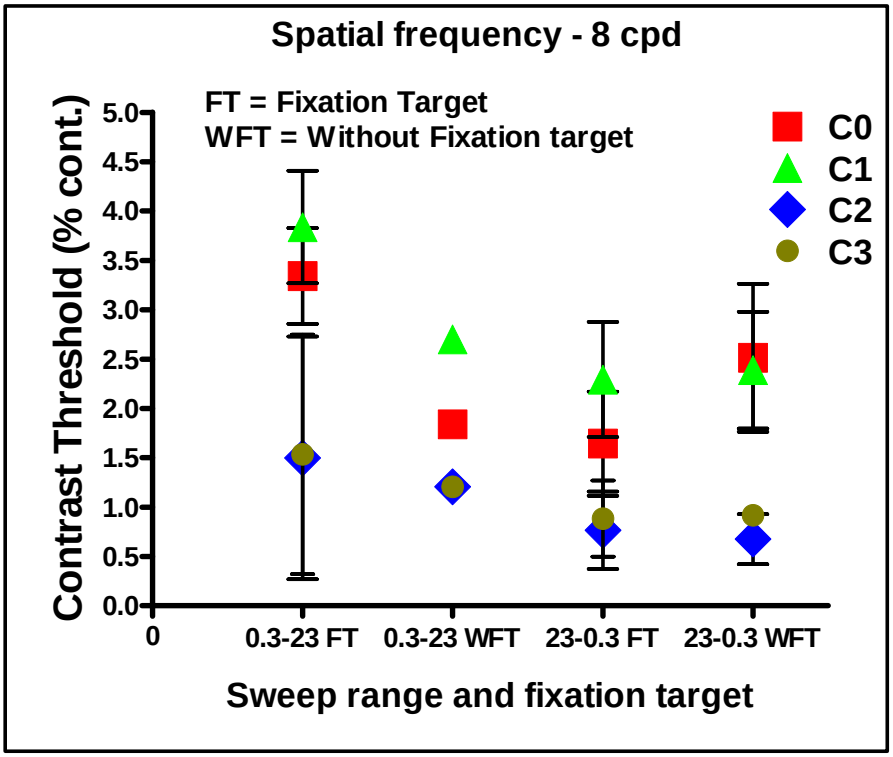


Figure 4.24: Mean contrast threshold for 6 subjects against sweep direction and fixation target. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.23: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	***
C0-C2	***
C0-C3	***
C1-C2	***
C1-C3	***
C2-C3	

Number of viable plots - Figure 4.25 shows that criterion 1, 2 and 3 gave more viable readings than criterion 0. Repeated measures ANOVA (2 fixations x 2 directions x 4 criteria) showed a main effect of criterion ($F = 5.26$, $df = 3$, $p = 0.0111$) but no main effect of sweep direction ($F = 0.92$, $df = 1$, $p = 0.3826$) or fixation target ($F = 2.52$, $df = 1$, $p = 0.1729$) on contrast threshold. There was no interaction of fixation target with criterion ($F = 0.12$, $df = 3$, $p = 0.9479$) or sweep direction ($F = 3.37$, $df = 1$, $p = 0.1260$). There was also no interaction of criterion with sweep direction ($F = 0.68$, $df = 3$, $p = 0.5803$). The post hoc t tests (LSD) for means (Table 4.24) showed that criterion 0 was significantly different from criterion 1, 2 and 3.

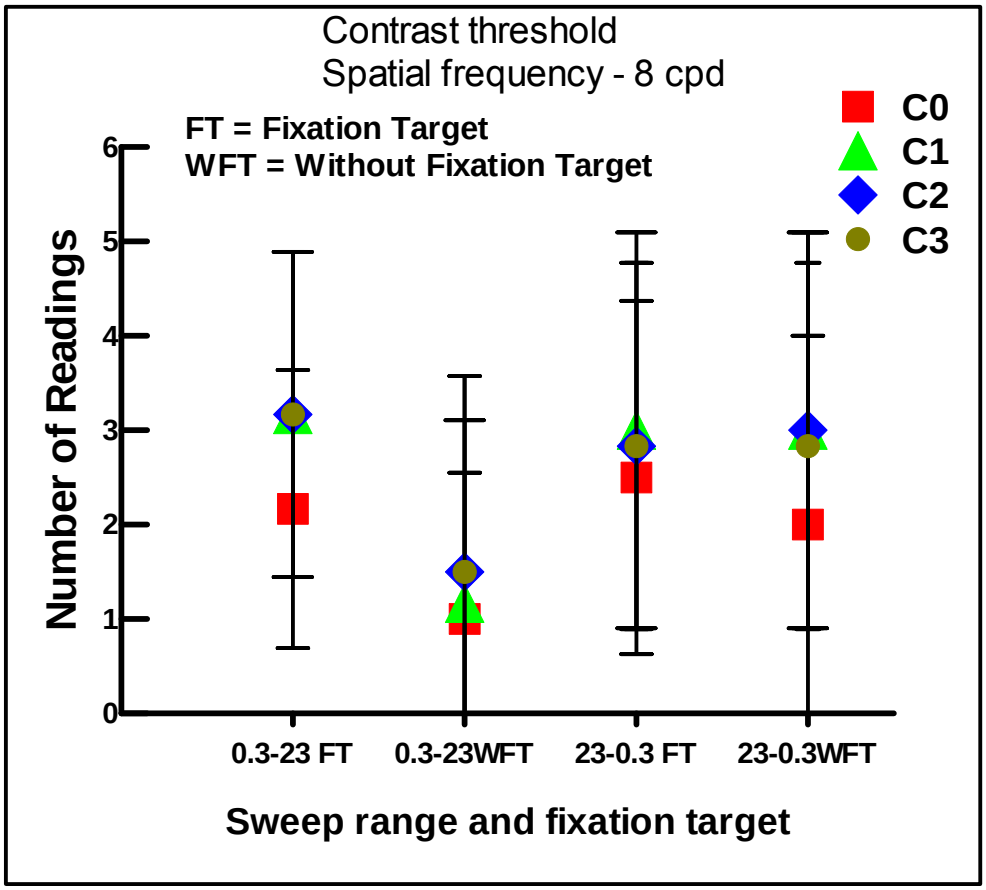


Figure 4.25: Mean number of reading for 6 subjects against sweep direction and fixation target. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.24: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	***
C0-C2	***
C0-C3	***
C1-C2	
C1-C3	
C2-C3	

4.5 Experiment 5: The effect of stimulus area.

4.5.1 Visual acuity and number of viable plots.

Visual acuity - Figure 4.26 shows that criterion 2 gave higher visual acuities with all the five-stimulus areas. Repeated measures ANOVA (5 stimulus area x 4 criteria) showed a main effect of criterion ($F = 20.42$, $df = 3$, $p < 0.0001$) but no main effect of stimulus area ($F = 1.65$, $df = 4$, $p = 0.2034$). There was no interaction of stimulus area with criterion ($F = 1.54$, $df = 12$, $p = 0.1401$). The post hoc t tests (LSD) for mean (Table 4.25) showed that criterion 3 was significantly different from criterion 1 and 2. Similarly, criterion 0 was significantly different from criterion 1 and 2.

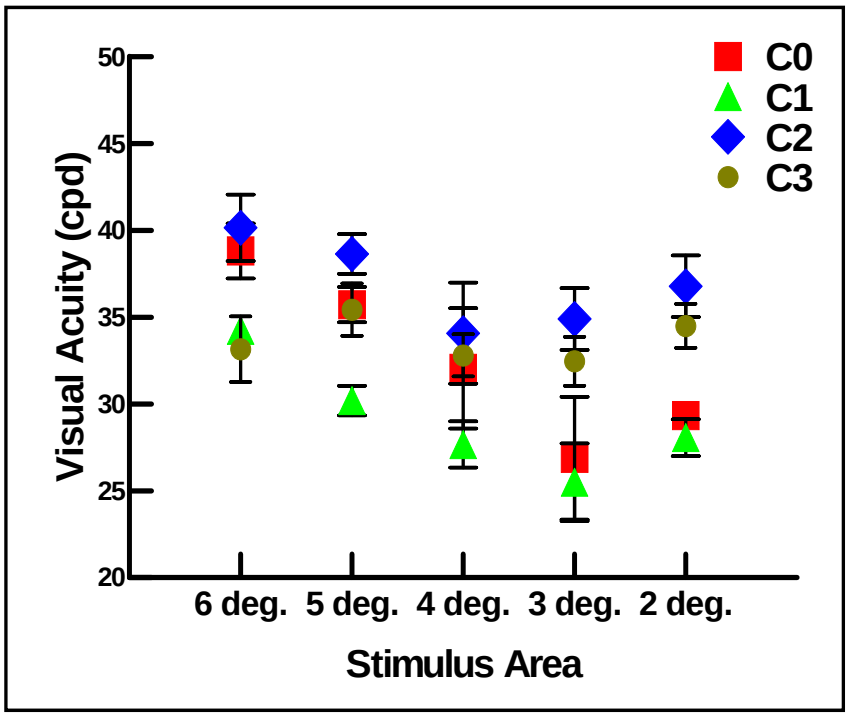


Figure 4.26: Mean visual acuity threshold for 6 subjects against stimulus area. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.25: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	**Significant effect**
C0-C1	***
C0-C2	***
C0-C3	
C1-C2	***
C1-C3	***
C2-C3	***

Number of viable plots – Figure 4.27 shows the number of readings against stimulus area for the four criteria. Repeated measures ANOVA (5 stimulus area x 4 criteria) showed no main effect of criterion ($F = 2.38$, $df = 3$, $p = 0.1109$) or stimulus area ($F = 0.75$, $df = 4$, $p = 0.5710$) on the number of readings. There was no interaction of stimulus area with criterion ($F = 1.44$, $df = 12$, $p = 0.1737$).

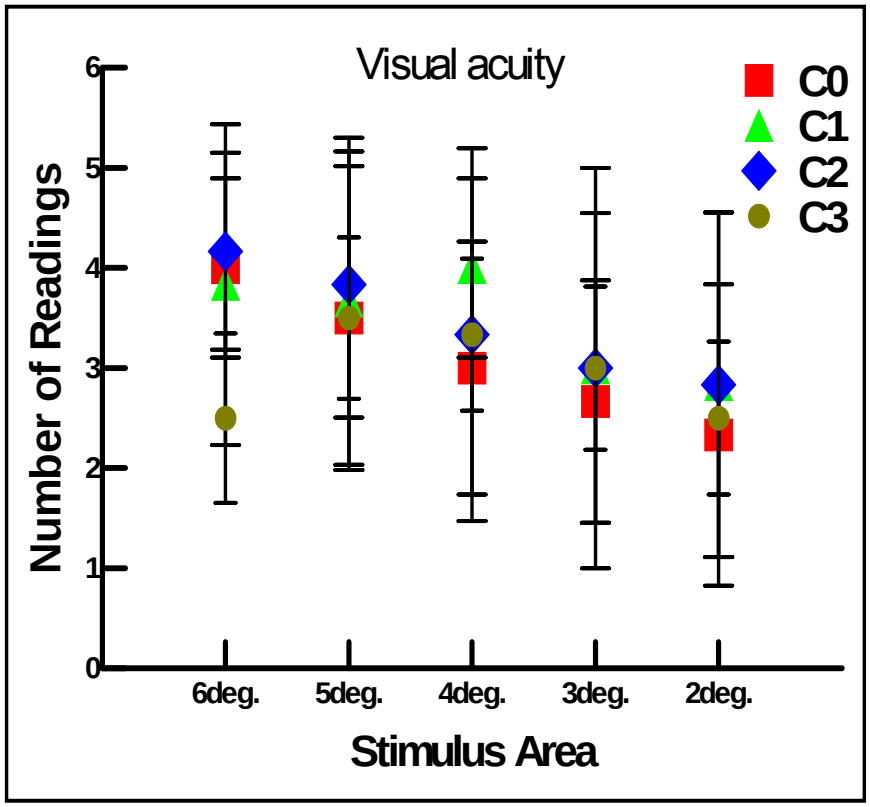


Figure 4.27: Mean number of readings for 6 subjects against stimulus area. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

4.5.2 Contrast threshold and number of viable plots – Spatial frequency 1 cpd.

Contrast threshold - Figure 4.28 shows that criterion 2 and 3 gave lower contrast thresholds than criterion 0 and 1 for all the five-stimulus areas. Repeated measures ANOVA (5 stimulus

area x 4 criteria) showed a main effect of criterion (F = 10.18, df = 3, p = 0.0007) but no main effect of stimulus area (F = 1.37, df = 4, p = 0.2919) on contrast threshold. There was no interaction of stimulus area with criterion (F = 1.12, df = 12, p = 0.367). The post hoc t test (LSD) for means (Table 4.26) showed that criterion 2 and 3 were significantly different from criterion 0 and 1.

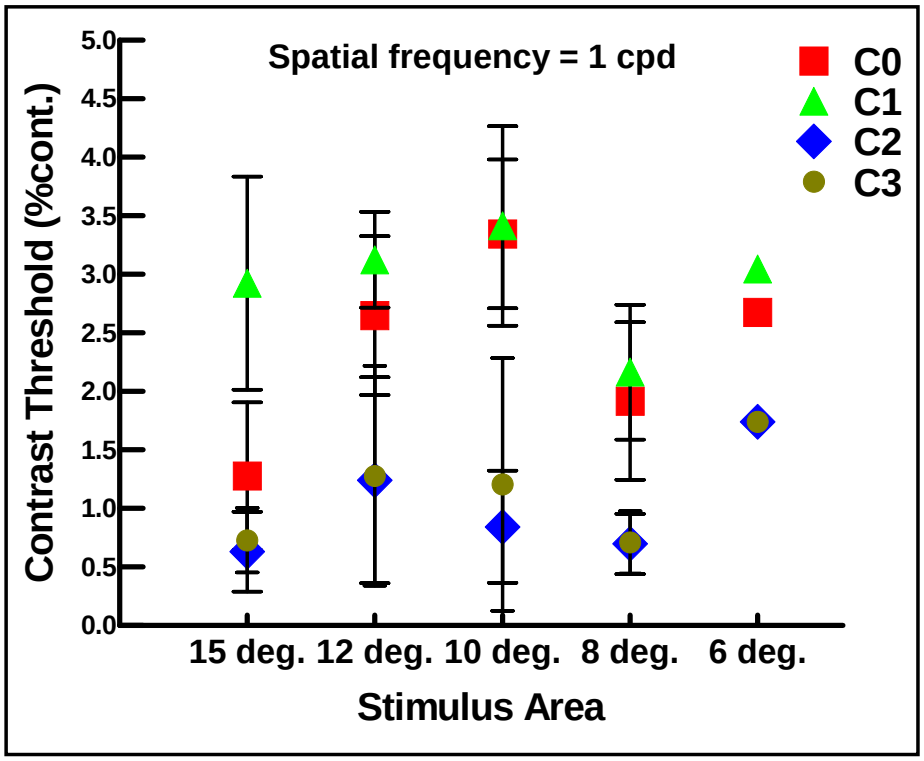


Figure 4.28: Mean contrast threshold for 6 subjects against stimulus area. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.26: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	
C0-C2	***
C0-C3	***
C1-C2	***
C1-C3	***
C2-C3	

Number of viable plots - Figure 4.29 shows that a larger stimulus area gave more viable readings than a smaller stimulus area. Repeated measures ANOVA (5 stimulus area x 4 criteria) showed a main effect of criterion ($F = 8.80$, $df = 3$, $p = 0.0013$) and stimulus area ($F = 11.78$, $df = 4$, $p < 0.0001$) on the number of readings. There was no interaction of stimulus area with criterion ($F = 0.50$, $df = 12$, $p = 0.9092$). The post hoc t test (LSD) for means (Table 4.27) showed that criterion 0 was significantly different from criterion 1, 2 and 3. The post hoc t test (Table 4.28) also showed that the number of readings recorded with an area of 7.96x7.53 and 6.33x5.99 degrees were significantly lower than with 15.64x14.84, 12.52x11.87 and 10.00x9.46 degrees.

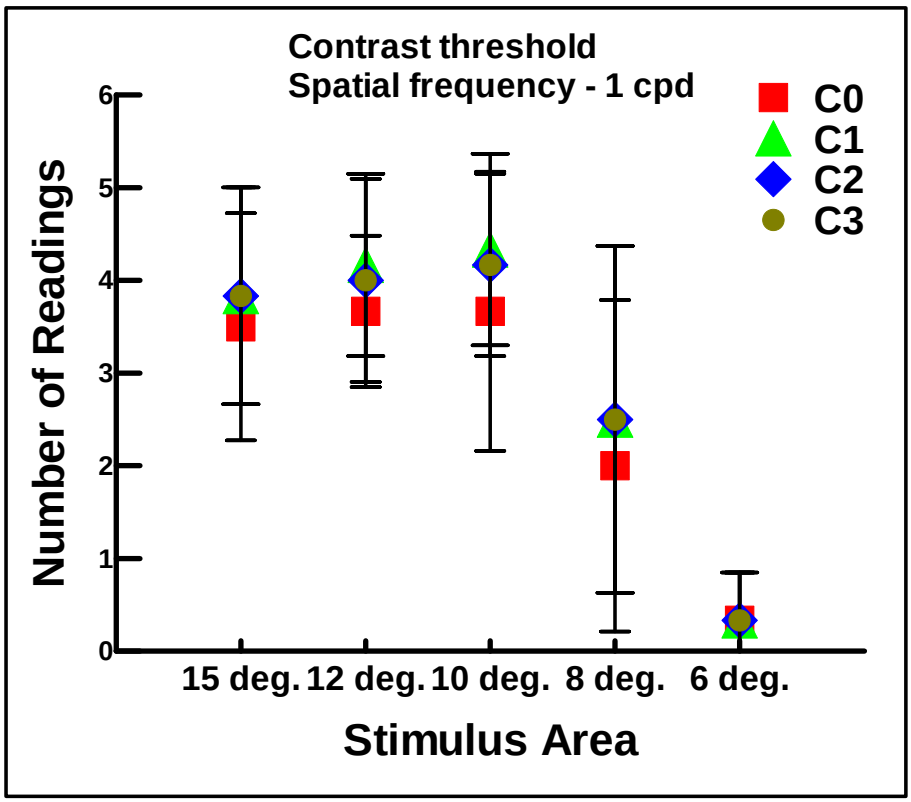


Figure 4.29: Mean number of readings for 6 subjects against stimulus area. Error bars are ± 1 SD. C0 to C3 are sVEP thresholds determined with criterion 0 to 3.

Table 4.27: Post hoc t test (LSD) for mean for differences between criteria. Comparisons significant at 0.05 level are indicated by ***.

Criteria	Significant effect
C0-C1	***
C0-C2	***
C0-C3	***
C1-C2	
C1-C3	
C2-C3	

Table 4.28: Post hoc t test (LSD) for means for differences between stimulus areas. Means with the same letter are not significantly different.

Area	**Significant effect**
15.64x14.84 degrees	A
12.52x11.87 degrees	A
10.00x9.46 degrees	A
7.96x7.53 degrees	B
6.33x5.99 degrees	C

Chapter 5

5.1 Discussion

At present, there are few previous studies, which evaluate the different parameters of sVEP in adults. In the present study, the effect of different parameters on the adult's visual acuity, contrast threshold and on the number of readings (viable sVEP plots) out of five channels were studied. The effects of the following parameters are discussed in this chapter.

5.1.1 The effect of the different criteria for assessing threshold.

The results of this study indicated that there were significant effects of criterion on visual acuity, contrast threshold and on the number of readings for all the parameters studied i.e. luminance, electrode placement, temporal frequency, sweep direction, fixation target and stimulus area. In all previous studies plus the present study, the regression line for visual acuity and contrast threshold was fitted from the signal peak and the threshold was taken where it crossed the zero amplitude. However, there are only a few studies (Norcia et al., 1989; Gottlob et al., 1990; Ridder et al. 1998), in which the regression line was fitted between the signal peak and the endpoints based on specific criteria. In the present study, criterion 2 and 3 were based on a specific choice of endpoint. The endpoint criteria in the present study are different from the endpoint point criterion used by Norcia et al. (1989) and Gottlob et al. (1990). In the present study, choice of endpoint criterion was based on the SNR of the last data point with a SNR > 1 whereas in the Norcia et al. (1989) and Gottlob et al. (1990) studies endpoint criterion was based on an SNR > 1.5:1.. In the present study repeatability and validity were considered when choosing the best criterion out of four

criterion i.e. C0, C1, C2 and C3. The results of the repeatability experiment showed that criterion 2 and 3 were more repeatable with lower standard deviation than criterion 0 and 1 as determined by the F-test of variance for visual acuity and contrast thresholds for ten repeated measures. Allen et al. (1992) showed that the adult's sVEP visual acuity threshold is lower than the psychophysical visual acuity threshold. Similar results were found in our study, as shown in Figure 4.4, in which psychophysical visual acuity was higher than the sVEP visual acuity by using criterion 2 except at 25 cd/m^2. Figure 4.4 also shows that criterion 2 gave a visual acuity value not significantly different to the psychophysical acuity while criterion 0, 1 and 3 gave thresholds that were significantly higher. Both criterion 2 and 3 at a spatial frequency of 8 cpd gave contrast threshold value closer to the psychophysical threshold than criterion 0 and 1. Similar to the present study a number of investigators compared the sVEP threshold with the psychophysical threshold, to estimate the validity of the sVEP determined threshold (Tyler et al., 1979; Siepel et al., 1984; Wiener et al., 1985; Allen et al., 1986; Chen et al, 1990; Allen et al., 1992; Riddell et al., 1997). They used psychophysical measures as a gold standard to check the validity of sVEP. The results of this study showed that there were significant effects of criterion on almost all the parameters. The parameters that showed no significant effect of criterion were the effect of luminance while measuring contrast threshold at spatial frequency 1 cpd and stimulus area while measuring visual acuity and number of readings. The present study results also showed a significant interaction of criterion with temporal frequency and sweep direction. The interaction results showed that criterion 2 gave higher visual acuity, lower contrast threshold and more viable readings with both parameters.

From the present study, criterion 2 and 3 would be the criterion of choice, giving better repeatability, better validity (compared to psychophysical measures) and being a more objective way to determine the range of values for the regression line.

5.1.2 The effect of luminance

The hypothesis of the present study was that there is an increase in visual acuity and contrast threshold with luminance. Allen et al. (1992) showed an improvement in visual acuity between luminance of 0.01 and 10 cd/m^2. Visual acuity then remained constant after a luminance of 10 cd/m^2 until 100 cd/m^2. The result of the present study indicated that there was no significant effect of luminance on visual acuity and contrast threshold in adults. For the luminances tested, these results are in agreement with the Allen et al. (1992) studies findings using sVEP method., There was, however, a significant effect of luminance on the number of viable readings, while measuring visual acuity i.e. there were more readings with the luminance of 50 and 100 cd/m^2 than with the luminance of 25 cd/m^2. There was no significant effect of luminance on the number of readings for contrast threshold. Thus, the better luminances to choose for sVEP measurement would be 50 or 100 cd/m^2. More readings would, presumably, lead to a more reliable estimate of threshold, if the readings are averaged, and also give an estimate of threshold based on recordings from a larger area of visual cortex.

5.1.3 The effect of electrode placement.

There is only one study (Allen et al., 1986) which looked at the effect of different electrode placements on the contrast threshold and they used only one active channel to measure the contrast threshold. They found no effect of electrode placement on contrast threshold. Similar results with two different electrode placements were found in this study. The results of this study indicate that there was no significant difference of PD and ISCEV electrode placement on the visual acuity, contrast threshold and on the number of readings, at three temporal frequencies i.e. 6, 7.5 and 10 Hz. The reason might be that there was not much difference in the distance at which the electrode was placed with both the PD and ISCEV method. In the PD electrode placement, the central Oz electrode was placed at 1.5 cm above the inion while in the ISCEV electrode placement, the central Oz electrode placement depends on the vertical distance between inion and nasion, which ranged in adults from 32 to 33 cms in this study. Therefore, in ISCEV placement the Oz electrode was placed at 3.2 or 3.3 cms above the inion, which is approximately twice the distance to the PD Oz active electrode placement. In some subjects, the inion was difficult to recognize, in which case the Oz electrode might have been placed nearly at the same position with both the electrode placements. In the PD electrode placement, the other four active electrodes starting from left, PO7, O1, O2 and PO8, were placed laterally 2.5 cm from each other. According to ISCEV, placement of these four electrodes is based on the circumferential distance from Oz to nasion. In adults, the circumferential half of the skull is about 28 to 30 cms in this study. Therefore, in ISCEV electrode placement, other four electrodes starting from left, PO7, O1, O2 and PO8, were placed laterally 2.8 to 3.0 cms from each other, which was close to the PD active electrode placement. Thus, for adults there may not be a great difference between the

electrode placements and both provided the same visual information. Another useful point is that the electrophysiologists need not to worry about slight differences in variability in the placement of these electrodes.

5.1.4 Effect of temporal frequency

As discussed in the Introduction, some studies showed that a lower temporal frequency gave better visual acuity and contrast threshold than a higher temporal frequency. Most researchers, as showed in Table 1.1, used a temporal frequency of 6 Hz to measure visual acuity and contrast threshold in infants, children and adults using sVEP. The result of this study showed that there was no significant effect of temporal frequency on visual acuity and contrast threshold. However, there was a significant effect of temporal frequency on the number of readings as shown in Figure 4.14 and 4.17. The result of this study showed that the temporal frequency of 7.5 Hz gave more viable readings than 6 and 10 Hz. The results also showed a significant interaction between criterion and temporal frequency while measuring contrast threshold at a spatial frequency of 4 cpd. The results showed that criterion 2 and 3 gave lower contrast threshold at a temporal frequency of 7.5 Hz compared to 6 and 10 Hz.

It is generally recommended that the stimulation frequency should not be within the alpha rhythm (8-13 Hz), to avoid loss of visual information (Fagan et al., 1985; Mast and Victor, 1991; Pigeau and Fram, 1992). This might explain why the temporal frequency of 7.5 Hz gave more readings than 6 Hz, as 6 Hz (for which the second harmonics = 12 Hz) is within the alpha rhythm. With the temporal frequency of 10 Hz, as the stimulus modulation is very fast, it is possible that the visual system does not respond so well at that temporal frequency.

Therefore, of three frequencies, a temporal frequency of 7.5 Hz is indicated, rather than 6 or 10 Hz.

5.1.5 The effect of sweep direction and fixation target.

Sweep direction - The results of this study showed that there was no significant main effect of sweep direction on the visual acuity, contrast threshold and on the number of readings. A significant interaction was found between criterion and sweep direction on visual acuity and contrast threshold at a spatial frequency of 1 cpd. For the number of readings also there was a significant interaction between criterion and the sweep direction while measuring contrast threshold at a spatial frequency of 1 cpd. However, there was no significant effect of any of the criteria on sweep direction while measuring contrast threshold. As discussed in the Introduction, different studies have found an adaptation effect of sweep direction on the visual acuity and the contrast threshold. However, in this study, there was no significant effect of sweep direction on visual acuity or contrast threshold. The reason for this difference might be that in the current study spatial frequency and contrast were swept for 10.7 seconds only compared to 20 seconds in Nelson et al. (1984) and Seipel et al. (1988) studies i.e. there is much less adaptation effect with this short duration. Therefore, future studies could investigate the effect of sweep direction with duration.

Fixation target - The result of this study showed that there was no significant effect of fixation target on visual acuity and contrast threshold. However, there was a significant effect of fixation target on the number of readings while measuring visual acuity but not for the contrast threshold measurement. There are more viable readings with a fixation target

than without a fixation target as shown in Figure 4.20. The reason for not getting a significant effect of fixation target on visual acuity and contrast threshold in adults might be that they are more attentive than children and infants, and they always fixate well on the stimulus, whether there is any fixation target or not. A fixation target may be more important in children. Allen et al. (1986) and Chen et al. (1990) used a small central fixation target to measure contrast threshold in adults using sVEP. The central fixation target was used to control the accommodation and to minimize the eye movements in adults, because excessive eye movements cause artifacts in the EEG signals and if the accommodation is not accurate, it may also cause overestimation of threshold. Therefore, it is recommended to use a fixation target for visual acuity measures, since more viable readings may be obtained.

5.1.6 The effect of stimulus area.

The results of the current study indicated that there was no effect of stimulus area on either visual acuity or contrast threshold. This is in agreement with a previous study (Tyler et al., 1979), which also showed that there was no significant effect of stimulus area on the visual acuity in adults. However, there was a significant effect of stimulus area on the number of readings while measuring the contrast threshold, although not with the visual acuity measurement. Figure 4.29 shows that there were more viable readings with the stimulus area of 15.64x14.84, 12.52x11.87, 10.00x9.46 degrees compared to 7.96x9.46 and 6.33x5.99 degrees. The reason for not getting any effect of stimulus area on visual acuity and contrast threshold in adults might be due to complete maturation of photoreceptors across retina, as photoreceptors mature completely by the age of 4 years. As a larger stimulus area gave more viable plots, it is better to use a stimulus area of at least 10.00x9.46 degrees for contrast

threshold measurement using sVEP. For visual acuity measurement, the stimulus area does not have to be so large, according to the present study results, any size of 2.54x2.40 degrees and above is adequate.

5.1.7 Statistical Power (P)

Statistical power determines the probability of a Type II error occurring (accepting the null hypothesis when it is false) in the study. To discuss the statistical power in this study, an example of one of the parameters was taken i.e. the effect of stimulus area (6 and 2 degrees) degrees) on visual acuity threshold. The average visual acuity of 6 subjects (Figure 4.26) with criterion 2 and 3 was considered. These were chosen because they are the criteria that are recommended.

The average visual acuity using criterion 2 for a stimulus area of 6 degrees was 40.14 cpd and for a stimulus area of 2 degrees was 36.77 cpd. The mean SD of both the stimulus areas was ± 1.84. These values were used to calculate the statistical power (P) and beta.

- Statistical power using criterion 2 –For an alpha of 0.05, the calculated power was 0.903, so the beta was 0.097 which was higher than alpha. To obtain 80% power, 12 subjects would have been required.

The average visual acuity using criterion 3 for a stimulus area of 6 degrees was 33.15 cpd and for a stimulus area of 2 degrees was 34.49 cpd. The mean SD of both stimulus areas was ± 1.57. These values were used to calculate the statistical power (P) and beta.

- Statistical power using criterion 3 - The alpha was 0.05, calculated power was 0.394, so the beta was 0.606 which was higher then alpha. To obtain 80% power, 14 subjects would have been required.

The above examples show that the beta is higher than alpha both for criterion 2 and 3, so the probability of a Type II error occurring is higher than a Type I error (rejecting the null hypothesis when it is true). Therefore, on the basis of the above example, there is a chance, I did not find an effect of area on visual acuity, with more subjects, an effect would be found. The positive findings of this study are valid e.g. the effects of criteria, temporal frequency etc.

Chapter 6

6.1 Conclusion

The conclusions of this study are that the following sVEP parameters give optimal results for adult's visual acuity and contrast threshold measurement.

1. Either criterion 2 or 3 is recommended for fitting the regression line to determine threshold. The criterion 2 and 3 compared to criterion 0 and 1 gave better visual acuity, lower contrast threshold, more viable readings, better repeatability and gave threshold values closer to the psychophysical measurements.

2. The study results showed no significant effect of luminance on the visual acuity and the contrast threshold; however, a luminance of 50 and 100 cd/m^2 compared to a luminance of 25 cd/m^2 gave more viable readings. Therefore, either a luminance of 50 or 100 cd/m^2 is recommended.

3. The study results showed no significant effect of either the PD or the ISCEV electrode placement on the adult's visual acuity, contrast threshold and on the number of viable readings. Therefore, in adults, either of these electrode placements can be used for measuring the visual acuity and the contrast threshold.

4. The study results showed no significant effect of temporal frequency i.e. 6, 7.5 and 10 Hz, on visual acuity and contrast threshold. However, the temporal frequency of

7.5 Hz, compared to 6 and 10 Hz, gave a higher number of viable readings. Therefore, a temporal frequency of 7.5 Hz is recommended.

5. The study results showed no significant effect of the sweep directions on visual acuity, contrast threshold and on the number of readings. Therefore, either of the sweep directions i.e. from seeing to non-seeing or vice versa can be used, with a total sweep direction of approximately 10 seconds.

6. The study results showed no significant effect of stimulus area on the visual acuity and the contrast threshold. However, a larger stimulus area compared to a smaller stimulus area gave more viable readings for contrast threshold. The following recommendations are made; a larger stimulus area of at least i.e. 4.03x3.81 degrees for visual acuity and 10.00x9.46 degrees for contrast threshold measurement.

7. The study results showed no significant effect of fixation target on the visual acuity and contrast threshold. However, measurement done with the central fixation target gave more viable readings than without the central fixation target. Therefore, a central fixation target is recommended when measuring both visual acuity and contrast threshold.

This is the only study which has looked at the effect of different parameters on the number of viable sVEP plots while measuring visual acuity and contrast threshold. Obtaining a greater number of viable sVEP plots provides more information from different positions of

visual cortex and will presumably result in a more reliable measure. These optimized sVEP parameters are recommended for future studies.

6.2 Recommendations to International Society for Clinical Electrophysiology of Vision (ISCEV)

The parameters for the sVEP that could be most strongly recommended to ISCEV based on the results of this study are:

1. The criterion 2 and 3 for fitting the regression line to determine visual acuity and contrast threshold. Criterion 2 and 3 are more repeatable, valid and objective to determine threshold than criterion 0 or 1.

2. Luminance of 50 and 100 cd/m^2, as they gave more sVEP viable plots. As discussed earlier more viable plots provides a more reliable estimate of threshold.

3. Temporal frequency of 7.5 Hz, as this gave more readings and the response frequency was not within the alpha rhythm.

Appendices

A.1 Appendix 1: Software

Most of the information given in the software section is taken from the Power Diva Manual Version 1.9. In this study, the Power Diva software version 1.9 was used. This software was developed at Smith-Kettlewell Eye Research Institute, California (USA). It was used to control and generate the grating stimulus and to analyze the sVEP output. To start the experiment, the Power Diva video must be launched first. The name of the calibrated system on the Power Diva video is selected before launching the Power Diva host. Then the Power Diva host is started and the PDH screen 1 appears (Figure1). For a new session the "new" button is clicked and the PDH screen 2 opens (Figure 2). The open button allows the operator to re-open an old session, but normally new data is not added to a previous session.

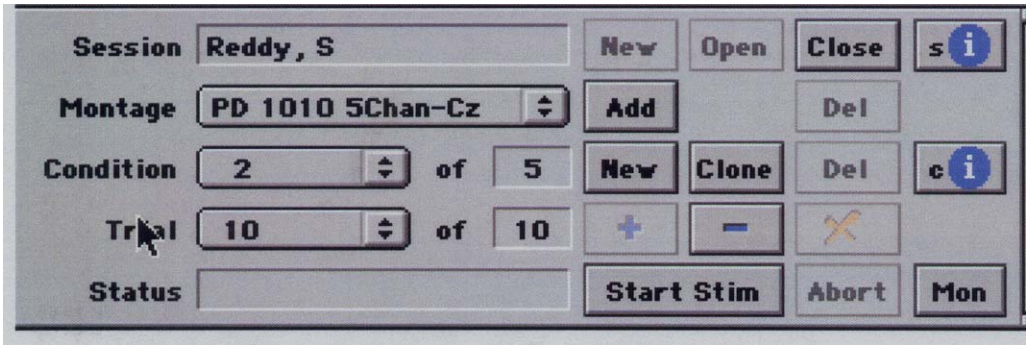


Figure 1: Power Diva Host (PDH) Screen 1.

Power Diva Host (PDH) Screen 2: For a new session the following information is entered.

Operator**:** This section is optional.

Subject**:** This section is mandatory.

Dominant Eye: This is an optional pull-down menu.

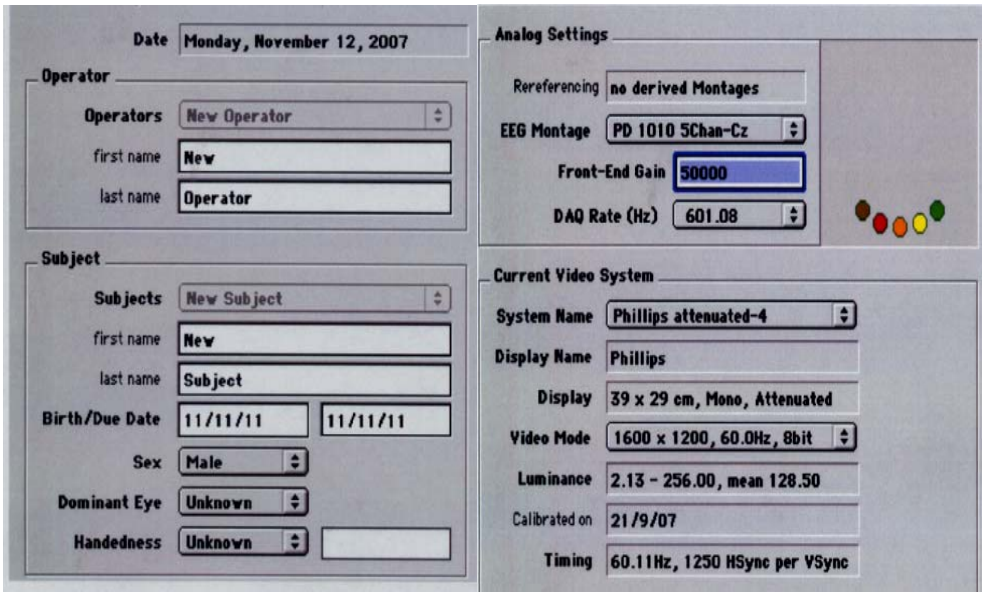


Figure 2: Power Diva Host (PDH) Screen 2

Analog Settings window (Screen 2)

EEG Montage: This pull-down menu allows the selection of between 1 and 8 EEG channels. In this study, 5 EEG channels were used.

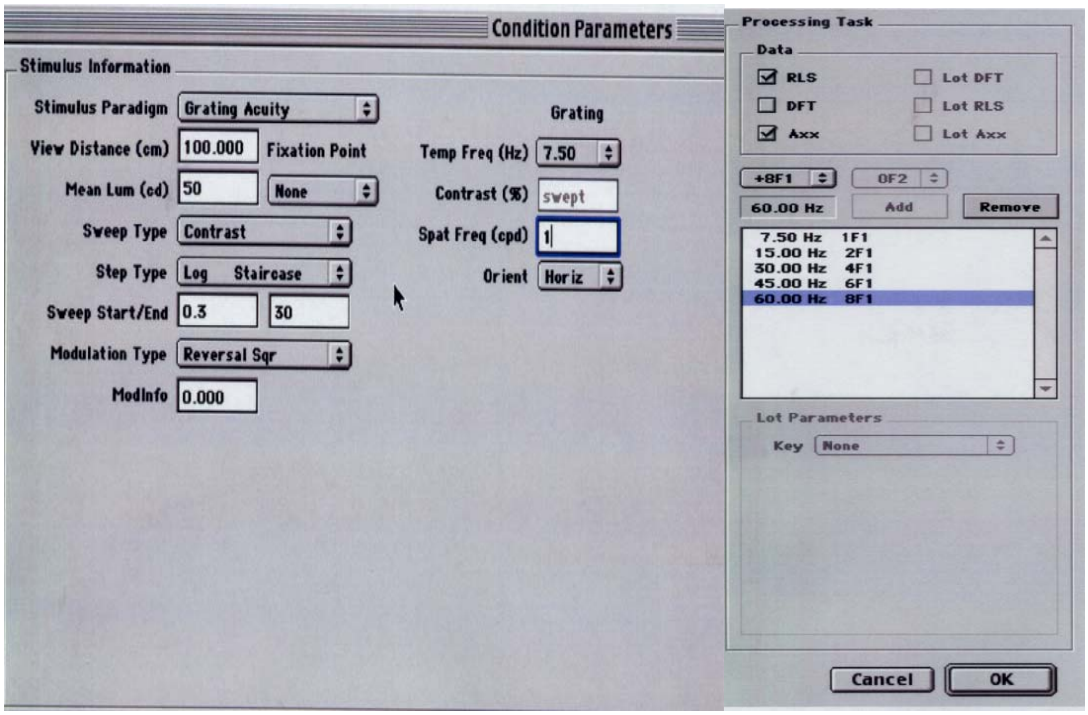
Front-end Gain**:** A front-end gain of 50,000 was used.

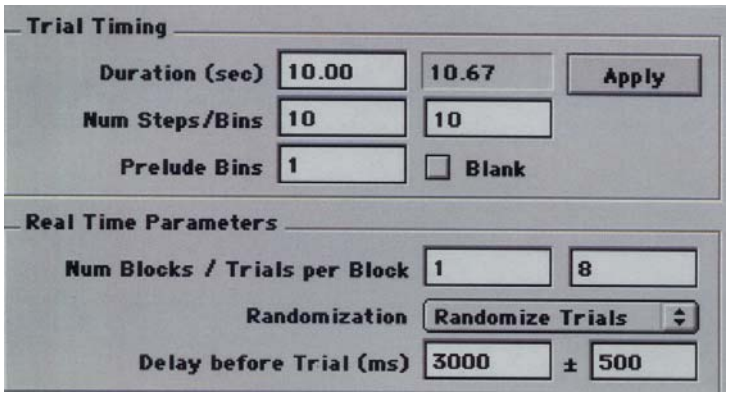
DAQ rate**: A** DAQ rate of 601.08 Hz was used.

Current Video System**:** This dialogue gives access to all the video modes that have previously been calibrated using the Power Diva video computer. The video mode that corresponds to that chosen in the PD video programme must be chosen.

After completing the new session dialogue, OK is clicked and the PDH screen 3 (Figure 3) appears.

This screen is the Condition Parameter Dialogs window.





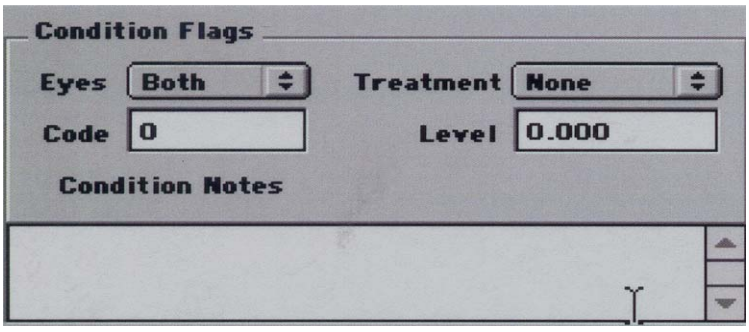


Figure 3: Power Diva Host (PDH) Screen 3

Power Diva Host (PDH) Screen 3

There are 4 parts in this dialogue box:

1.) Stimulus Information

2.) Trial Timing

3.) Condition Flags

4.) Processing Task

1.) Stimulus Information: The various parameters listed under stimulus information are.

- Stimulus Paradigm: The grating acuity paradigm was used for spatial frequency sweeps and contrast sweeps.
- Viewing Distance: Entering the viewing distant allows the software to determine the spatial frequency accurately.
- Mean Luminance: The required luminance value was entered. This can be any value less than the calibrated mean luminance of the monitor.
- Sweep Type: For the visual acuity measurement, sweep type was spatial frequency. For the contrast threshold measurement, sweep type was contrast. If sweep type was spatial frequency, then the spatial frequency box was grayed out and only the contrast % box was available. If sweep type was contrast, then the contrast % box was grayed out and only the spatial frequency box was available.
- Step Type: For the visual acuity measurement, the linear staircase was selected and for the contrast threshold measurement, the log-staircase was selected.

- Sweep Start/End: The starting and ending value of the sweep is entered here. For the visual acuity measurement, this was in cycles per degree and for the contrast threshold measurement, this was in % contrast.
- Modulation Type: The modulation type was Reversal Square Counter phase modulation.
- Temporal frequency: This is a pull-down menu. The temporal frequency is selected from the menu.
- Contrast: The contrast in percentage for the visual acuity measurement is entered.
- Spatial frequency: The spatial frequency in cycles per degree is entered for the contrast threshold measurement.
- Orientation: The horizontal orientation of the grating was selected for this study.

2.) Trial Timing: This dialogue box controls the length of the trial, the number of stimulus values presented in the sweep and their duration as well as the bin length of the spectral analysis.

- Duration: This is the total trial duration in seconds. Depending on the particular temporal frequency chosen and the bin length, the actual trial duration may be slightly different from that entered. The box on the right displays the actual stimulus presentation time.
- Number of Steps/Bins: Number of Steps/Bins (described in Number of Steps/Bins section in Methods) was entered in this box.

- Prelude bins: The prelude bin was 1 for this study. The VEP response of the visual system requires some time to come to a steady state. The number of bins entered in this setting is the duration of the stimulus value before actual recording of the sVEP commences. If the blank prelude box is checked, the screen will be blank during the prelude bin with a sudden onset of the stimulus at the beginning of the sweep.

After entering the values for Duration and Number of Steps/Bins, the "Apply" button is clicked and the actual stimulus presentation time is updated in the right box of the row labeled "Duration".

3.) Condition Flags: In the condition window box, "both" eyes were selected**.** In the Condition notes box, any notes can be typed such as name of the experiment, parameters etc.

4.) Processing Task: For the data analysis, RLS (Recursive Least Square) and Axx methods can be used. In this study, the RLS method was used. The components (harmonics) of the steady state response to be analyzed, were selected from the pull-down menu. The harmonics appeared in the list in the order they were entered.

After all the information was entered, the "OK" box was clicked and the PDH screen 1 (Figure 1) and PDH screen 4 (Figure 4) appeared. This PDH screen 4 shows the parameters entered for the visual acuity measurement. The parameters for a second condition can be changed by clicking on the clone box, shown in PDH screen 1.

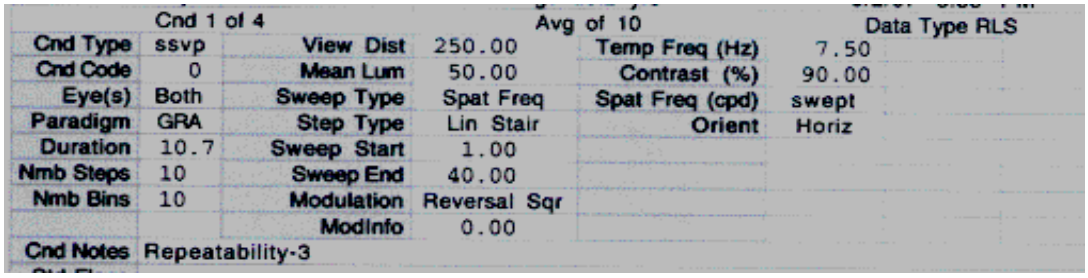


Figure 4: Power Diva host (PDH) Screen 4

Power Diva Host (PDH) Screen 1:

Running Trials:

- Start: This button starts the real-time digital EEG on the Power Diva host monitor.
- Start Stimulus: The first click on this button starts the stimulus alternating at the selected temporal frequency and at the value in the first bin. The second click starts actual data recording for the duration of the trial. During the data collection, a subsequent button press will pause the trial, although the stimulus grating continuous to alternate but not to sweep. A further button press resumes data collection and the stimulus sweep.
- Abort: This button is used to abort a trial, for example, when the subject blinks or when there is too much eye or head movement.
- Status: This box displays the current status of the trial. Monitoring indicates that the trial is active, but not recording. Running indicates that the trial is in progress and data is being recorded. Idling means that the trial was in progress, but was paused, waiting for another command to either resume or abort.

Data Display:

The data can be displayed in two forms.

1.) Raw EEG display (Figure 5)**.**

2.) RLS display (Figure 6).

.

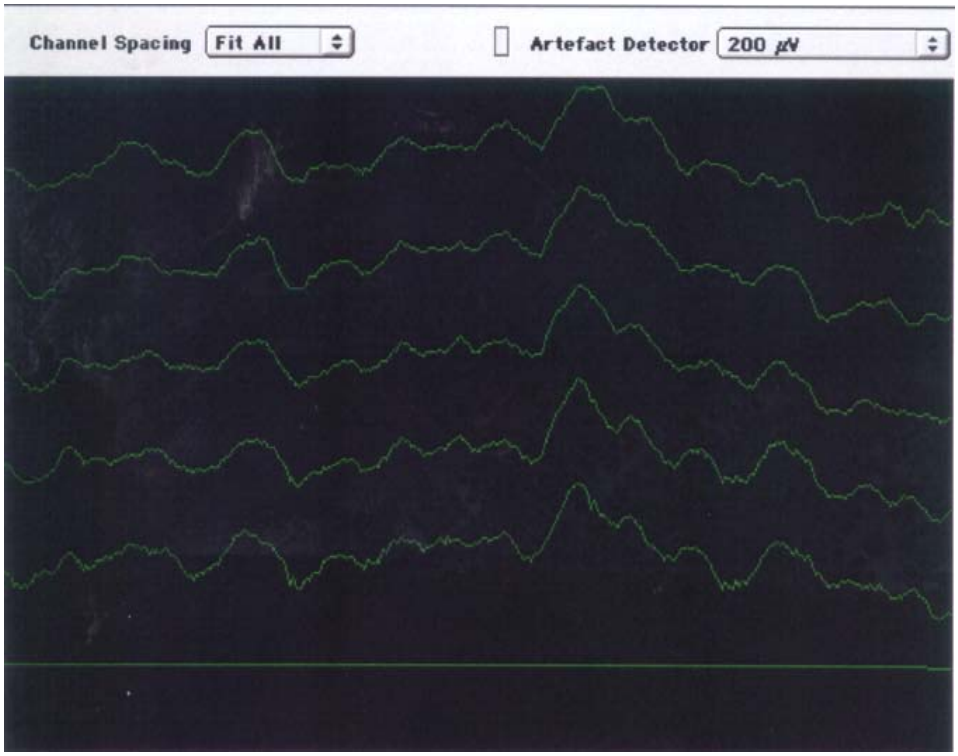


Figure 5: Raw EEG display

In this study data were analyzed with the RLS method. Figure 6 shows the whole RLS display for all channels and for the fundamental, 2F, 4F, 6F and 8F. Tang and Norcia (1995) explained that RLS method minimizes the square estimation error between the reference and recording signal at a particular response frequency. They also found in the simulations, that the RLS adaptive filter detected signals at about 3 – 4 times lower signal to noise ratios compared to the Discrete Fourier Transform (DFT).

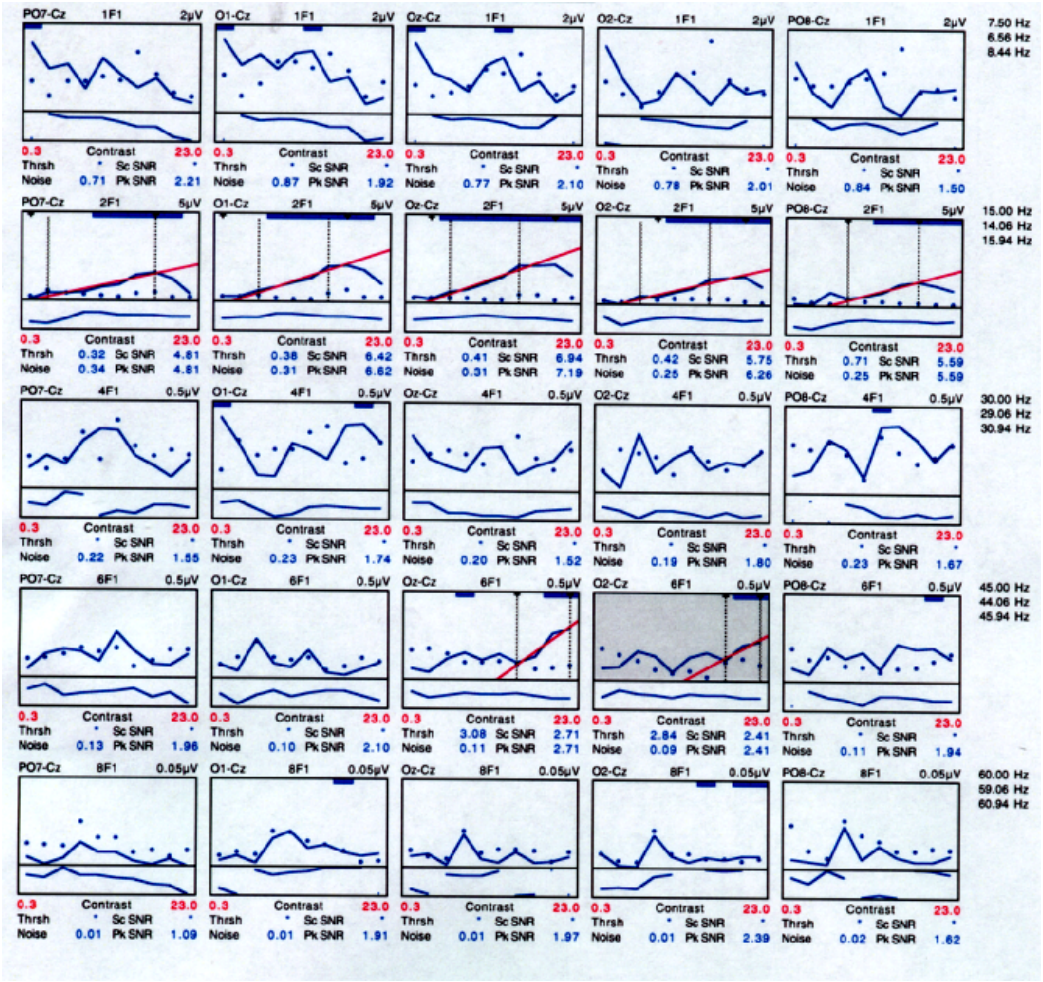


Figure 6: RLS display

A.2 Appendix 2: Power Diva video monitor settings

The CRT monitor had an easy On-Screen Display (OSD) menu to control and adjust the monitor settings by the help of four controls in front of the monitor.

The following CRT monitor settings were selected for this study:

OSD FUNCTIONS

GLOBAL MENU SETTINGS

- 3-GUNS
- DEGAUSS
- KEY LOCK OFF
- ABC OFF
- REFERENCE SETTING at 1

LOCAL MENU

- ABC MASTER OFF
- POWER SAVING - OFF
- AUTO DEGREE - OFF
- DAISY ADRESS - OFF
- DAISY CHANNEL - OFF
- INPUT 1 - BNC
- ORBITTING OFF
- LIGHT BAR - OFF
- OSD REVERSE
- OSD POSITION

    - FW- REL – 2.10
    - WORK HRS.- 1690
    - CHANNEL NUM. – 13
    - HOR. – 75.1 KHz
    - VER. – 60.1 Hz
- STORE REFERENCE SETTINGS
- HORIZONTAL SIZE – 126
- VERTICAL SIZE – 40
- HORIZONTAL SHIFT – 120
- VERTICAL SHIFT – 73
- TILT – 84
- AUTOMATIC BRIGHTNESS CONTROL (ABC) - CONTRAST.
- AUTOMATIC BRIGHTNESS CONTROL (ABC) - BRIGHTNESS

A.3 Appendix 3: Calibration of the monitor

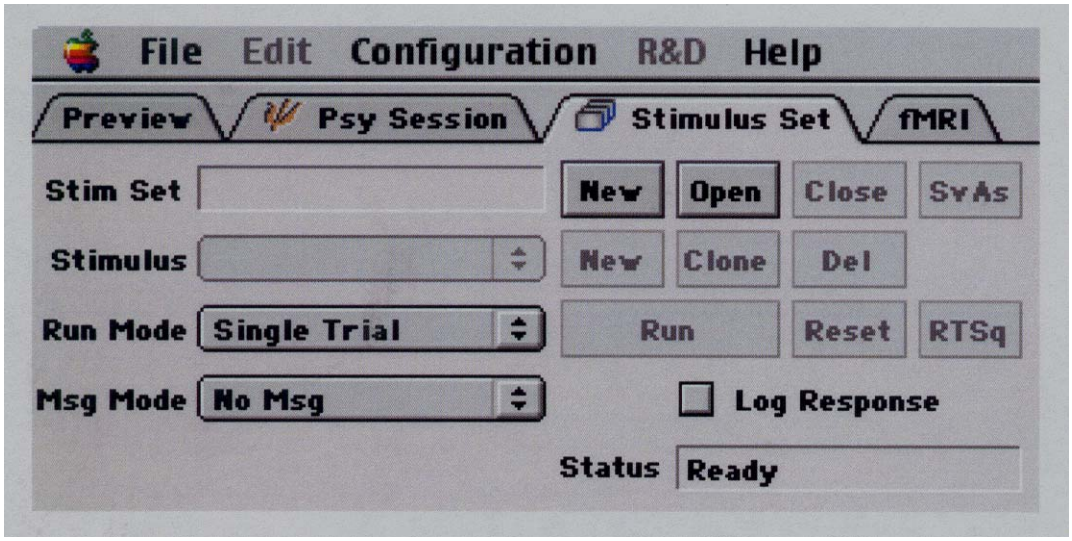


Figure 7 : Power Diva Video (PDV) Screen 1

The luminance and contrast calibration was done on the Philips FIMI MGD403 monitor using the Power Diva video software. The calibration process was started by clicking on the Configuration as shown in the Figure 7, to give the Video Manager application. After clicking on the Video Manager application, Power Diva video screen 2 (Figure 8) was opened. In PDV screen 2, the system name, the display name and display type were entered. The system name was very important, as this was the name of the calibrated system. Under Video Mode, in the mode box, the resolution of the monitor was entered. Then the calibrate luminance box was clicked to start the calibration procedure as shown in Figure 8.

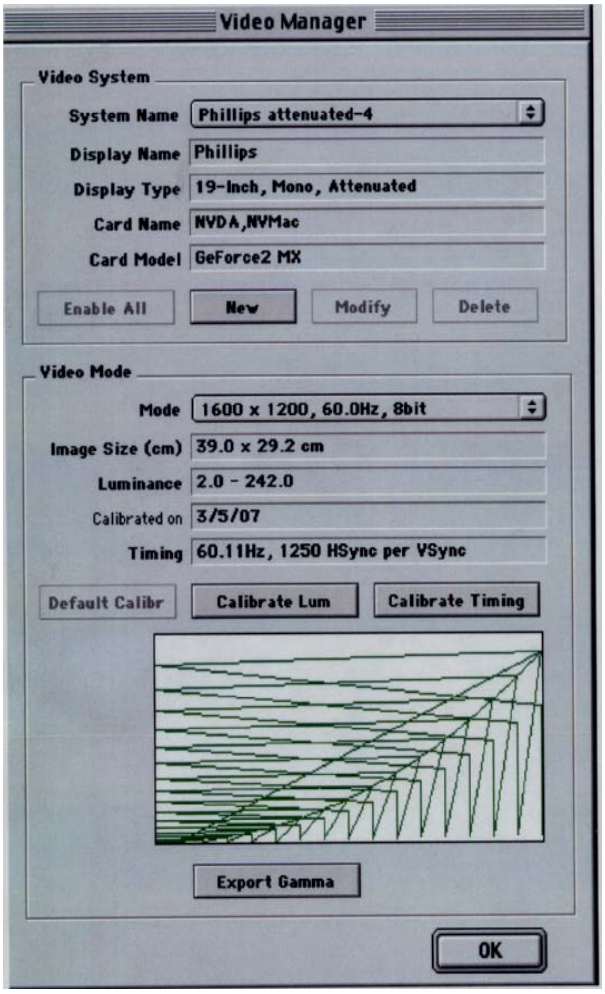


Figure 8: Power Diva Video (PDV) Screen 2

In the Power Diva Video Screen 3 (Figure 9 and 10), the size of the grating area was entered and it was 39x29.2 cms for this Philips monitor. For the luminance calibration a spacing of 4 was selected. With this spacing the software steps up the luminance of the screen in 129 steps. The luminance calibration was started with the minimum luminance as shown in Figure 9. The luminance was measured with a Minolta Chromometer CS -100 Photometer. The luminance calibration was done in a dark room at a distance of 1 m from the monitor. Each luminance reading was entered in the luminance box in candelas/m^2. The software varies the luminance on the screen. After entering the luminance value of 129th reading,

click on done. The luminance calibration was completed for the given grating size and the system named. The resultant luminance calibration graph is shown in Figure 8. After the luminance calibration was completed, the image size (cm), minimum and maximum luminance value and calibration date was shown in Video Mode window, as shown in Figure 8. The minimum and maximum luminances are shown in Figure 9 and 10.

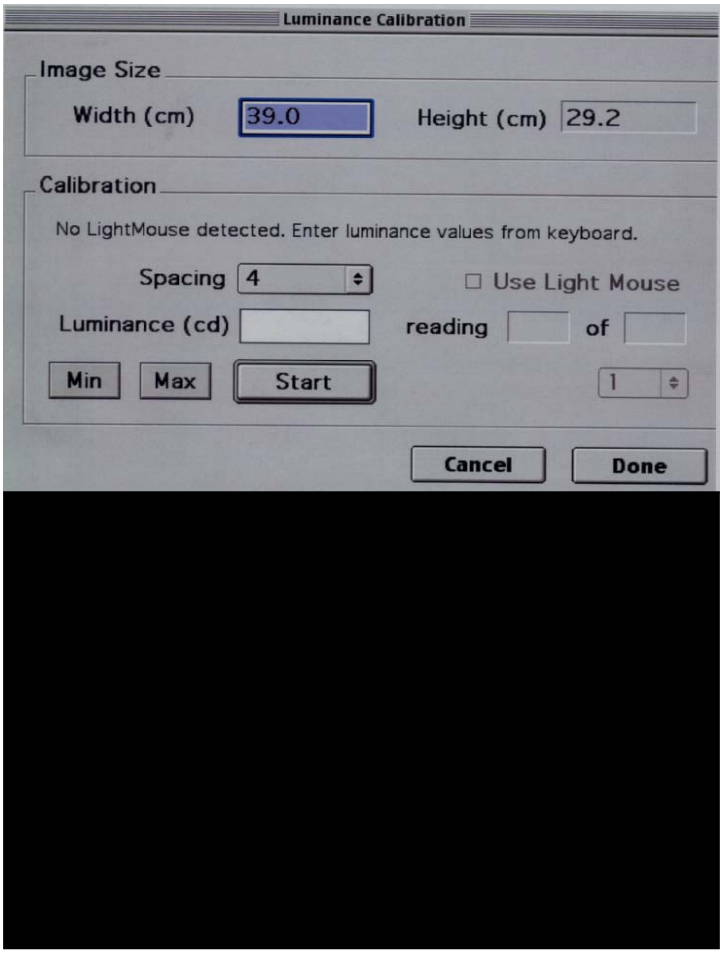


Figure 9: Power Diva Video (PDV) Screen 3 (with minimum luminance)

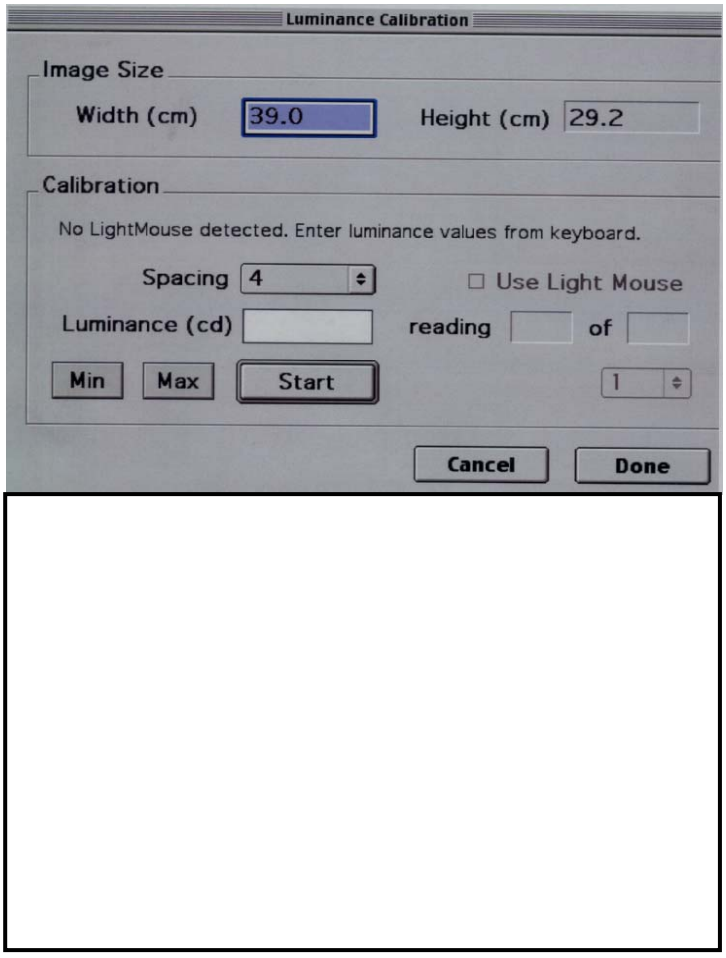


Figure10: Power Diva Video Screen 3 (with maximum luminance)

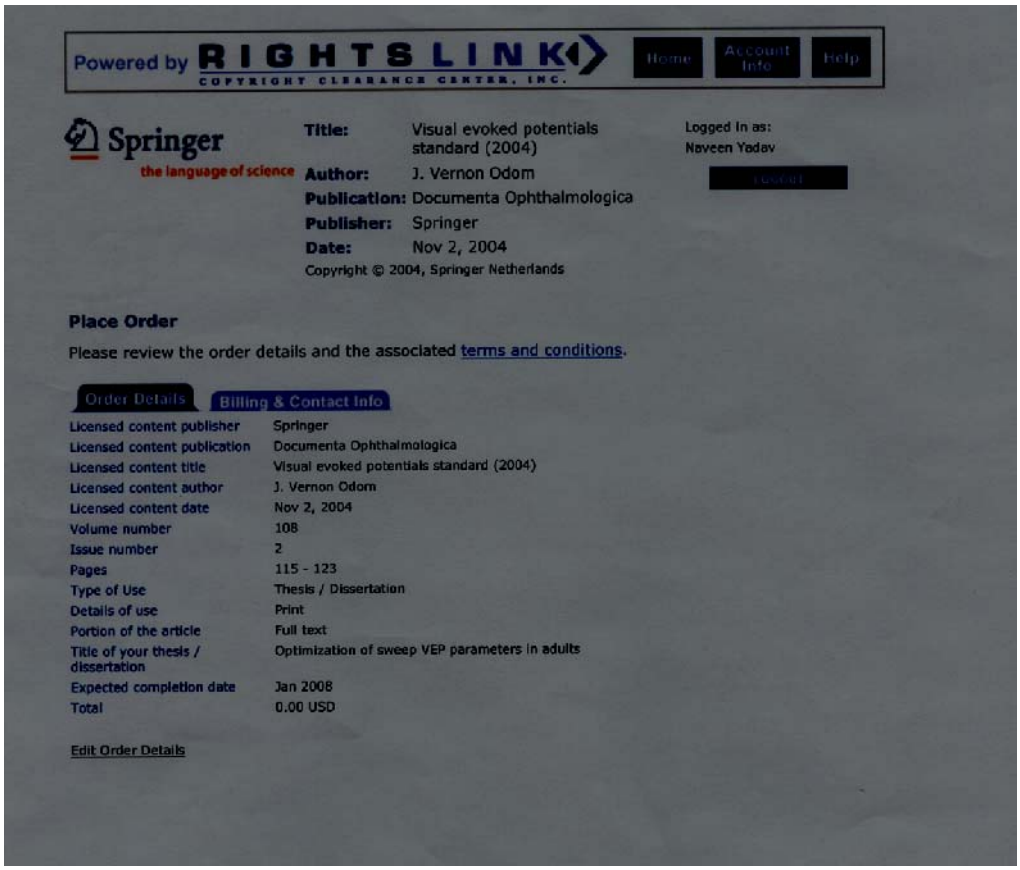
In this study, the luminance calibrations of the Philips CRT monitor were repeated every 4-5 months because the luminance and contrast of the monitor can change with time. This meant that the luminance calibration was done three times. The following parameters were used to calibrate the monitor.

A name was given to each of the calibrated system such as – Phillips Attenuated – 2 (Ist calibration), Phillips Attenuated – 3 (IInd calibration), Phillips Attenuated – 4 (IIIrd calibration). The luminance value of each calibrated system is shown in Table 1.

Table1: Mean Luminance of calibrated system.

CALIBRATED SYSTEM	**MINIMUM LUMINANCE (Lmin.) and MAXIMUM LUMINANCE (Lmax.)**	**MEAN LUMINANCE**
Phillips Attenuated – 2	Lmin. - 2 cd/m^2 Lmax - 242 cd/m^2	122 cd/m^2
Phillips Attenuated – 3	Lmin.- 1.86 cd/m^2 Lmax - 241 cd/m^2	121.43 cd/m^2
Phillips Attenuated – 4	Lmin.- 1.98 cd/m^2 Lmax – 242 cd/m^2	121.99 cd/m^2

A.4. Permission for graphs (Figure 1.1, 1.2 and 1.3)



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