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Visual Evoked Potential Measures of Blur Adaptation

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by

Andy Wei

Dr. Michael Crognale/Thesis Advisor

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Andy Wei

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Dr. Michael Crognale, Ph.D.; Faculty Mentor

Tamara Valentine, Ph.D.; Director, Honors Program

Abstract

It has been shown previously that blur adaptation occurs when subjects view a blurry image with both eyes for a significant period of time (Webster, Georgeson, & Webster, 2002). There has been no quantitative data taken on the phenomenon of blur adaptation. This study aimed to study various blur effects through the measurement of the visual evoked potential (VEP). VEP measurements were taken over time as subjects were exposed to a reversing sine-wave grating both with blur and with blur adaptation. The VEP measurement gave insight about the visual acuity, which can be used to interpret the behavior of the eyes and brain in adaption. The results reveal that there is a clear increase in the response amplitude and decrease in the latency of the VEP in response to blurred images after prior adaptation to the blur but not without prior adaptation to the blur.

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Introduction

Blur is an important attribute when it comes to the quality of vision. In the context of vision, blur refers to a lack of ability to see fine detail. Images formed on the retina are always blurred to some degree; the amount of blur is variable, and can be affected by both the environment that is being viewed and the observer (Watt & Morgan, 1983). Inaccuracy in focusing light to the eye, known as refractive error, can cause differing amounts of blur, which is the case in both near and farsightedness as well as astigmatism.

It has been shown that exposure to a blurry image has a negative impact on both acuity and contrast sensitivity (Watson & Ahumada, 2011). Visual acuity refers to the sharpness of one’s vision, commonly tested through the Snellen eye chart. Measurements of acuity are given in fractions such as 20/30; this fraction, for example, indicates that an individual must be 20 feet away from an image to see what a person with normal vision can see at 30 feet. Visual acuity is a measure of the smallest detail that can be perceived, not the overall quality of vision.

Spatial contrast is generally the difference in luminance between parts of a scene usually with reference to luminance (Owsley, 2003). Thus, luminance contrast is the comparison of the amounts of lights reflected from two different surfaces or from different sources of light. There are many different formal formulas for quantifying this comparison. Contrast can be defined from 0% to 100%. When contrast is at 0%, there is no difference between the two areas, and thus it is impossible to distinguish one area from the other. At a higher contrast level, an edge between the two areas will appear, and the areas will be differentiable. The amount of contrast that a person must have to perceive a difference in the two areas is known as the contrast threshold. Contrast sensitivity is expressed as the reciprocal of the threshold value. Blur in an image causes a decrease in contrast sensitivity, which is also an increase in threshold value. However, viewing a blurred image for a prolonged period of time can cause the perception of image focus to change (Sawides et al., 2010). After being exposed to an unfocused image and adapting to it, the image is perceived as more clear and focused.

My experiment aimed to answer the question of whether or not the effects of blur adaptation can be seen in electrophysiological measures of contrast sensitivity. Electrophysiology refers to the branch of physiology that is focused on the electrical activity in cells and tissues. Since the discovery 200 years ago by Galvani of the importance of electrical activity in the nervous system, electrical activity has been an often researched topic. Electrophysiology is a useful tool for observing the nervous system because electrical activity can be recorded directly, eliminating a large amount of variability and subjectivity inherent in behavioral (psychophysical) methods.

To better understand the neural mechanisms of blur adaptation, the study quantified the magnitude and time course of blur adaptation using visual evoked potentials (VEPs). VEPs are electrical potentials that are obtained by measuring the visual system’s response to a stimulus recorded by sensors at the occipital lobe. The occipital lobe contains the visual cortex, the area of the brain responsible for processing visual information. The evoked potential records responses from neurons in the visual cortex, and yields information on how long it takes for nerves to respond to stimulation, as well as the size of the electrical response. The VEP has been used as a sensitive and objective method of measuring visual function in both normal subjects and those with visual anomalies (Millodot & Newton, 1981).

Previous research has yet to use the VEP to quantify the effects of blur adaptation (Watson & Ahumada, 2011). Obtaining quantitative data is important because quantitative data are specific, generalizable, objective, and replicable. Qualitative data, though useful, are subjective and are more likely to vary due to outside factors and differences between studies, while quantitative, numerical data is a more unbiased form of information. Blur adaptation is a continual process that all people undergo; therefore, studying the phenomenon is useful. Because images on the retina are always blurred to some degree, people are constantly adapting to blur in their vision, and completely understanding this adaptation is important for understanding human visual processing.

In my study, participants were shown images with increasing amounts of contrast as VEP recordings were taken. Three different trials were performed for the experiment. In the first, participants viewed images of black and white checkerboards, shown in Appendix B, which were used for adaptation, and a sine-wave grating, shown in Appendix C, which was used for as a stimulus for recording the VEP. For the second trial, participants were then shown the same checkerboard and sine-wave grating images, and wore defocusing lenses to blur their vision only when recordings were taken. For the third trial, the participants viewed the same checkerboard and sine-wave grating images, but wore defocusing lenses for the entire duration of the image set, in order to induce blur adaptation.

It was reasoned that if the VEP mirrors blur adaptation mechanisms, then the unblurred trial would yield a waveform with greater amplitude and faster response times (latency) than both other trials, and that the adaptation condition would yield a waveform that had less amplitude or longer latencies than the unblurred condition, but larger amplitude or shorter latencies than the blur without adaptation condition. Blur by itself has a negative effect on both the response and temporal aspects of the electrophysiological activity of vision, but blur adaptation decreases the negative effect expressed.

To better understand blur adaptation, more background info must be provided on both the process of vision and blur. In the following chapter, the details of the visual pathway are examined, as well as information on relevant studies done on blur and blur adaptation.

Literature Review

The human visual system is a very complex process that has been studied for centuries. The retina of each eye is the layer at the back of the eyeball. On each retina, there are photoreceptor cells. When light enters the eye, a biochemical cascade occurs in the retina, and the release of neurotransmitter molecule (glutamate) from the photoreceptors is slowed as a result. Photoreceptor cells are connected to horizontal and bipolar cells, which integrate and regulate the inputs from multiple photoreceptors. These cells transmit information to the retinal ganglion cells. Retinal ganglion cells receive information and transmit the information to the brain in the form of action potentials. As nerve cells, retinal ganglion cells rest at an electrical potential of -70 mV. When the input received from bipolar cells breaks a threshold level, sodium channels in the cell open, causing sodium to rush into the cell. This sudden increase in charge, known as an action potential, is a signal that moves down the length of the cell to the lateral geniculate nucleus (LGN). The lateral geniculate nucleus acts as a relay station between the retina and the visual cortex. A retinotopic map of the visual field exists in the visual cortex, which shows the pattern of light that the retina observes.

Blurred vision is the lack of sharpness in image formation, and causes an inability to see fine detail (Hamerly & Dvorak, 1981). Blurred vision is a symptom of multiple conditions and can have many different causes. Conditions such as myopia and hyperopia, known as shortsightedness and farsightedness, respectively, are two of the most common causes of blurred vision. Both of these conditions are caused by aberrations of the optics of the eye and generally occur naturally. Myopia occurs when eyes focus images in front of the retina instead of on the retina, leading to blurred vision.

This abnormality can also be caused by elongation of the eyeball, which prevents incoming light from focusing correctly on the retina. Conversely, hyperopia is the condition wherein eyes focus images behind the retina instead of on the retina, and occurs when the eyeball length is too short for the accommodative power of the eye's optics. Treatment of these conditions is accomplished through special eye wear (lenses) or refractive surgery. Special lenses, worn over the eyes, can shift the focus of the light image directly on the retina, cancelling out the negative effect of having an abnormally shaped eyeball.

Because of its common occurrence in the general population, myriad studies have been conducted on the effects of blur on perception and visual capacities such as detection and recognition (Hamerly & Dvorak 1981; Hess, Pointer, & Watt, 1989; Westheimer, Brincat, & Wehrhahn, 1999; Watt & Morgan,1983). Studies show that blur has an important role in accommodation of the eye. Accommodation is the process that the eye undergoes to change its optical power to keep a clear image of an object as its distance from the eye changes (Kruger & Pola, 1986). Accommodation is a physical process that occurs in the eye. When looking at close objects, muscles in the eye contract to cause the lens to become more round. When looking at far objects, the muscles relax, causing the lens to be more flat. Blur is minimized when the accommodation is at the correct depth, but increases when the accommodation is either larger or smaller. In this way, blur acts as a cue for accommodation. The accuracy of the degree of accommodation can be tested, as the best accommodation will yield the least blur.

As accommodation is a vital component of visual processing, additional studies have been done on sensitivity to blur (Campbell & Westheimer, 1958; Walsh & Charman, 1988; Wang & Ciuffreda, 2005). One of the most common approaches to studying perception is to collect behavioral data by asking observers to make judgments on images that have been altered to appear blurry or sharp. However, this method may not be ideal, as estimating blur can be affected by context (De Ridder, 2001). An objective and quantitative study would yield data that could be better compared across different participants.

This subjective approach can also be compromised due to adaptation to either blurriness or sharpness (Webster, Georgeson, & Webster, 2002). The main question Webster, Georgeson, and Webster study addressed was whether adaption to a blurred or sharpened image would change the perception of the original image. The results of the study strongly supported the hypothesis that the adaptation would make a difference, as the participants in the experiment gave different answers for how focused they perceived the original image to be, depending on the degree of blur that they had adapted to.

Another study attempted to further explain the mechanisms occurring in blur adaptation (Elliott, 2011). The study examined whether renormalization of focus or a repulsion effect occurred during blur adaptation. Renormalization is the process of neglecting blur in the retinal image, changing the perception of "normal" in the perceived focus to make a blurry stimulus seem clearer. A repulsion effect, on the other hand, would involve a loss of sensitivity to the blur, which would cause an exaggeration in the perceived amount of blur of a new stimulus.

Blakemore & Sutton (1969) determined that renormalization occurred during blur adaptation, which suggests that when a person is adapted to a particular amount of blur, that degree of focus becomes a neutral level of stimulation, which is distinct from other degrees of focus. If a repulsion effect had been observed, it could be concluded that adaptation causes a loss of sensitivity at a particular point, which is the case in visual adaptation to both size and spatial frequency. As in previous studies, however, there is no explanation for the mechanism behind blur adaptation. As of yet, there has been very little research done on the electrophysiological effects that blur induces. The present study aims to shed light on this issue by using visual evoked potentials.

Visual evoked potentials have been used in the past to study visual processing (Odom et al., 2010). Waveforms yielded by VEP recordings are consistent across normal populations, which make them useful for data analysis. VEPs run under different conditions can be compared to VEPs run under normal conditions in order to determine what effect certain conditions have on neurons in the visual cortex. The analysis can then be generalized for all people – this is what makes VEP waveforms very useful as an experimental tool.

Though there have already been studies done on blur and blur adaptation, they have focused on qualitative results. The technology for collecting quantitative results is not yet common, and no research labs with the equipment necessary have been interested in studying vision. To remedy this in my research, I utilized VEP recordings in order to generate quantitative data for blur, blur adaptation, and unblurred conditions.

Methodology

IRB approval was provided by Dr. Michael Crognale's current protocol. Three participants were recruited during the spring semester of 2012 from acquaintances of the researcher. Tests were conducted in the last week of April in Dr. Crognale’s vision lab on UNR campus. There were two male participants, and one female. All participants were nineteen to twenty-two years of age. The participants were required to complete informed consent procedures, which described the methodology of the experiment and obtained the participants’ permission for the entire procedure.

After completing the informed consent forms, three sensors were placed on the scalp of each participant with skin cleanser and conductive gel using the international 10-20 system. A tape measure was used to measure the distance from the inion, the projection of the occipital bone on the back of the head, to the nasion, where the frontal and nasal bones connect on the face. This measurement of the head length was taken for each participant for the placement of sensors. Two sensors were placed on the back of the head near the visual cortex. One sensor was placed on Oz and used as an active recording site. The Oz sensor was placed 1/10 of the head length up from the inion. The other back sensor was placed on Pz, which served as a reference. The Pz sensor was placed 3/10 of the head length up from the inion. The Pz sensor was placed on an area that produced differential responses to that produced at Oz. The last sensor was also placed on an area that was relatively unresponsive to visual stimuli, the forehead, and acted as a ground.

Sensor impedances were kept below 10 kOhm measured at 30 Hz. An impedance meter was used to ensure that the amount of resistance between each pair of sensors was kept low. Increased resistance values cause diminished electrical activity, which, in turn, causes lower recorded values. Scalp signals were stored on a PC using a USB data acquisition board (NI-USB-6009). The total amplification used was 50,000. A 100 Hz low pass, 1 Hz high pass, and 60 Hz notch (mains) filter were used to filter the data. The high pass filtered out any data that had a lower frequency than 1 Hz, while the low pass attenuated data that had a higher frequency than 100 Hz. These are standard filter levels, used to remove unneeded data as recommended.

Each participant viewed stimuli on a computer monitor as the VEP signal was recorded. Two stimuli were used - an adapting pattern comprising a black and white checkerboard that reversed at 2 Hz and a test pattern comprising sine-wave grating patterns with 15.68 cycles per degree that was on for 100 ms and off for 400 ms. The checkerboard is illustrated in Appendix B, and was chosen because it has a broad spectrum. The checkerboard yields both high and low contrast responses, and its sharp edges are ideal for adaptation. The sine-wave grating pattern is illustrated in Appendix C, and was chosen because it is a standard and there is an established waveform in literature. The patterns were displayed on a gray background, with the same averaged chromaticity and mean luminance (37 cd/m^2). Each participant viewed patterns from 300 cm away from the monitor.

Three different trials were run for each participant. The condition for the first trial was no blur. The condition for the second trial was blur without adaptation, and the condition for the third trial was blur with adaptation. Each trial was also run at five different contrast levels. Contrast levels were taken in log step intervals of 0.3, starting at 0.6. At the 0.3 mark, the contrast was 10^0.3 = 3.98%. These contrast levels were chosen so that there would be a significant difference between changing levels and so that the final contrast level would be at 63.10%. This high contrast level was tested to ensure that even with blur, the stimuli would be visible enough to induce a response. Multiple contrast levels were used in order to construct a contrast response function for each condition of the experiment.

For the first condition, each participant was shown the checkerboard stimulus for five minutes. Then VEPs were recorded to four presentations of the sine-wave pattern. Following the recordings, each participant was shown the checkerboard pattern for 15 seconds. The recording and readapt procedure was repeated eighteen times, resulting in 72 total recordings. The large number of recordings ensured that at least 60 artifact-free recordings were available for the final averaged VEP waveform. The checkerboard pattern was used in order to prevent the participants from adapting to the sine-wave grating pattern.

In the second trial, the above procedure was repeated, except the participants wore a defocusing lens with a +1.5 diopter power over both eyes during VEP recording of the sine-wave stimuli. The +1.5 diopter lens was used to simulate a natural blur, one that could occur in a nearsighted person. The blur was used only during the recording so that the participants would not have time to adapt to the blur. In case there was some adaptation during the recording, the unblurred checkerboard pattern was viewed between the recording sessions.

In the final trial, the above procedure was repeated except the participants wore the defocusing lens over their eyes for both the recording and adapting periods. The initial five minute checkerboard stimuli was tested beforehand to ensure that there was enough time for blur adaptation. Because the blur condition was not removed for the entire trial, participants experienced blur adaptation for all recording sessions.

Because each test took nearly three hours to complete, participants were run on two separate days. On the first day, the unblurred data were obtained, and on the second day, the rest of the data was obtained. When taking the test, all lights were turned out other than that of the monitor, and the participant was told not to move or speak throughout. Before each condition, each participant ran a trial with no blur at the highest contrast level of 63.10% in order to obtain a baseline measurement. The baseline measurement yielded responses to be compared with those from the test conditions.

Results

In order to summarize the results, the VEP data were run through a program for filtering. The program was written specifically for this experiment. It filtered out artifacts in the data and generated a VEP waveform for each contrast level for each condition. Appendix D shows an example of a VEP waveform from a blurred trial of the experiment. There is a trough just before the 100 ms mark, followed by a large peak. These areas of the waveform are the N75 and P100, respectively. To assess the waveform, the points of two characteristic components of a pattern reversal VEP were examined. The N75 is the first negative peak, or trough, in the standard waveform, and the P100 is the following positive peak; the peaks normally occur around 75 and 100 ms, respectively. One point was taken at each peak, and the latency and amplitude was recorded. Latencies were calculated as the time from stimulus reversal to the peak of the P100 response. To obtain an amplitude value for analysis, the difference between the amplitudes, recorded in microvolts, for the P100 and N75 was calculated. Because the pattern reversal waveform has low variability both in multiple tests of a single subject and across the general population, any change in the amplitude and latency from the norm can be significant.

To obtain the change in latency for analysis, the latency obtained from the participants' response without blur at the highest contrast level acted as the baseline. This baseline value was subtracted from the latency of each run. This procedure was performed to remove the noise associated with differences in response latency between individuals. The values used for analysis were recorded in Tables 1, 2, and 3 for the respective participants.

The numerical data obtained from the VEP waveform are shown in Tables 1, 2, and 3. In the first vertical column, the series designated Series 1 refers to the unblurred condition. Series 2 refers to the blurred without adaptation condition, and series 3 refers to the blurred with adaptation condition. The very first point of each VEP waveform was recorded because the N75 is sometimes difficult to pinpoint if the waveform is very flat. If the waveform is flat, the first point in the VEP can be used for analysis in its place. However, the first point was never used in analysis as the N75 was always visible. The N75 column is the amplitude value at the lowest point of the N75 trough. The P100 columns contain the amplitude and latency values of the highest point of the P100 peak. The AMPs column shows the amplitude values obtained from subtracting either the first or N75 value from the P100 value. The normed lats (latency) column shows the difference in latency between the P100 value of each trial and the baseline.

Figure 1 shows a plot of the averaged data across all three tables. The values for the amplitude (P100-N75) are plotted against the log contrast levels. The unblurred data yield the highest amplitude at each contrast level, followed by the blur-with-adaptation data. The blur-without-adaptation data never shows a significant increase in amplitude and remains at roughly the same value throughout all contrast levels.

In Figure 2, the change in latency, averaged across all three tables, is plotted against all five contrast levels. All three sets of data show a decrease in the change in latency as the contrast levels increase. The unblurred data initially have the smallest change in latency; however, at the highest level of contrast the blur-with-adaptation data overtakes it, yielding a negative change in latency. The blur-without-adaptation data consistently show the greatest change in latency across all contrast levels. To summarize, the unblurred condition produced the fastest responses, followed by the adapted-to-blur condition. The unadapted blur condition showed the slowest responses.

The plots in Figures 1 and 2 show that blur causes a decrease in the amplitude values and an increase in the latency values, but blur adaptation lessens the effect. At all contrast levels, the blur adaptation condition data is significantly closer to the unblurred data than the blur without adaptation data. As shown in Figure 2, blur adaptation even yields a faster response than the unblurred condition at the highest contrast level.

Blur_sub1		**1st point**	**N75**	**P100**		**AMPs**		**Normed Lats**
		amp	*amp*	*lat*	*amp*	*P100-1st*	*P100-N75*	*P100 lat*
Series 1	*C1*	0.2447	0.2381	116	0.2966	0.0519	0.0585	-3
	C2	0.2701	0.2125	119	0.2685	-0.0016	0.056	0
	C3	0.2417	0.2292	126	0.3746	0.1329	0.1454	7
	C4	0.281	0.2275	111	0.3573	0.0763	0.1298	-8
	C5	0.2193	0.2436	119	0.3873	0.168	0.1437	0
	baseline	0.2193	0.2436	119	0.3873	0.168	0.1437	0
Series 2	*C1*	0.245	0.2506	154	0.302	0.057	0.0514	34
	C2	0.2655	0.2282	141	0.2702	0.0047	0.042	21
	C3	0.2611	0.2563	154	0.2923	0.0312	0.036	34
	C4	0.2846	0.219	161	0.2549	-0.0297	0.0359	41
	C5	0.286	0.2329	136	0.2592	-0.0268	0.0263	16
	baseline	0.2143	0.2178	120	0.363	0.1487	0.1452	
Series 3	*C1*	0.3119	0.2793	125	0.3096	-0.0023	0.0303	7
	C2	0.3044	0.2489	132	0.2925	-0.0119	0.0436	14
	C3	0.3236	0.2842	112	0.3036	-0.02	0.0194	-6
	C4	0.2982	0.2026	116	0.233	-0.0652	0.0304	-2
	C5	0.235	0.2613	100	0.2994	0.0644	0.0381	-18
	baseline	0.2736	0.2154	118	0.3575	0.0839	0.1421	0

Table 1. Raw data obtained from the averaged VEP waveform for the first participant including data from all 3 conditions, where series 1 was the unblurred data, series 2 was the blur without adaptation data, and series 3 was the blur with adaptation data.

Blur_sub2		**1st point**	**N75**	**P100**		**AMPs**		**Normed Lats**
		amp	*amp*	*lat*	*amp*	*P100-1st*	*P100-N75*	*P100 lat*
Series 1	*C1*	0.2069	0.2621	156	0.354	0.1471	0.0919	33
	C2	0.2591	0.2192	133	0.3139	0.0548	0.0947	10
	C3	0.3495	0.1451	119	0.3043	-0.0452	0.1592	-4
	C4	0.2749	0.2104	133	0.3847	0.1098	0.1743	10
	C5	0.2874	0.1824	123	0.396	0.1086	0.2136	0
	baseline	0.2874	0.1824	123	0.396	0.1086	0.2136	
Series 2	*C1*	0.3054	0.224	138	0.293	-0.0124	0.069	18
	C2	0.3054	0.1636	138	0.2386	-0.0668	0.075	18
	C3	0.3554	0.1918	120	0.2651	-0.0903	0.0733	0
	C4	0.2966	0.2061	116	0.301	0.0044	0.0949	-4
	C5	0.2623	0.2393	116	0.3429	0.0806	0.1036	-4
	baseline	0.3217	0.2045	120	0.3346	0.0129	0.1301	
Series 3	*C1*	0.2632	0.1994	108	0.3231	0.0599	0.1237	-5
	C2	0.2196	0.2469	116	0.2905	0.0709	0.0436	3
	C3	0.3141	0.2484	137	0.3145	0.0004	0.0661	24
	C4	0.2295	0.1994	101	0.3356	0.1061	0.1362	-12
	C5	0.2594	0.08558	118	0.4448	0.1854	0.35922	5
	Baseline	0.3094	0.2914	113	0.4382	0.1288	0.1468	0

Table 2. Raw data obtained from the averaged VEP waveform for the second participant including data from all 3 conditions, where series 1 was the unblurred data, series 2 was the blur without adaptation data, and series 3 was the blur with adaptation data.

Blur_sub3		**1st point**	**N75**	**P100**		**AMPs**		**Normed Lats**
		amp	*amp*	*lat*	*amp*	*P100-1st*	*P100-N75*	*P100 lat*
Series 1	*C1*	0.3036	0.3331	118	0.3472	0.0436	0.0141	-12
	C2	0.3318	0.1883	125	0.3343	0.0025	0.146	-5
	C3	0.3149	0.2338	126	0.3113	-0.0036	0.0775	-4
	C4	0.2847	0.2487	124	0.3339	0.0492	0.0852	-6
	C5	0.3034	0.1486	130	0.3977	0.0943	0.2491	0
	baseline	0.201	0.2735	127	0.3996	0.1986	0.1261	
Series 2	*C1*	0.2481	0.2241	114	0.3365	0.0884	0.1124	-9
	C2	0.2547	0.2403	129	0.2654	0.0107	0.0251	6
	C3	0.2629	0.2756	118	0.3329	0.07	0.0573	-5
	C4	0.3174	0.2955	95	0.326	0.0086	0.0305	-28
	C5	0.2491	0.2859	117	0.3166	0.0675	0.0307	-6
	baseline	0.2489	0.1691	123	0.423	0.1741	0.2539	0
Series 3	*C1*	0.2728	0.2792	107	0.3422	0.0694	0.063	-14
	C2	0.2722	0.278	122	0.31	0.0378	0.032	1
	C3	0.2434	0.2549	117	0.3621	0.1187	0.1072	-4
	C4	0.3183	0.2309	141	0.3899	0.0716	0.159	20
	C5	0.2489	0.2951	123	0.41	0.1611	0.1149	2
	baseline	0.201	0.2735	121	0.3996	0.1986	0.1261	0

Table 3. Raw data obtained from the averaged VEP waveform for the third participant including data from all 3 conditions, where series 1 was the unblurred data, series 2 was the blur without adaptation data, and series 3 was the blur with adaptation data.

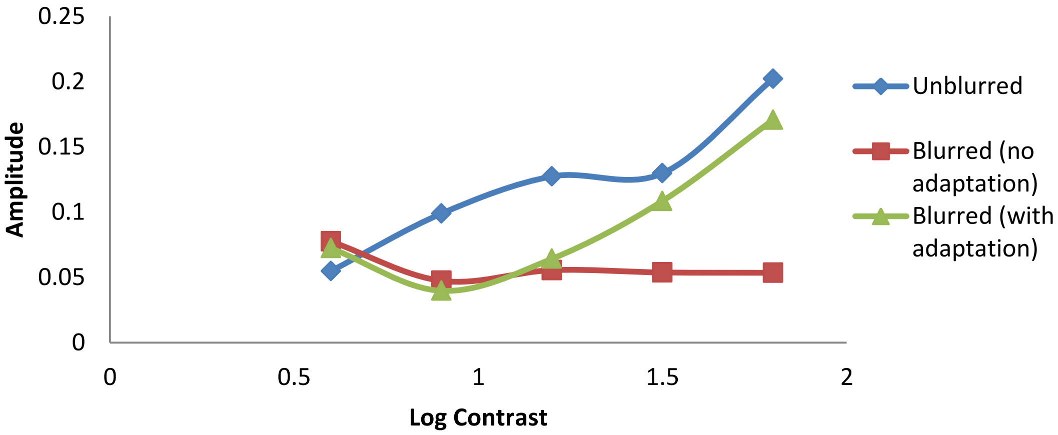

Figure 1. Difference in amplitude between P100 and N75 with increasing contrast level

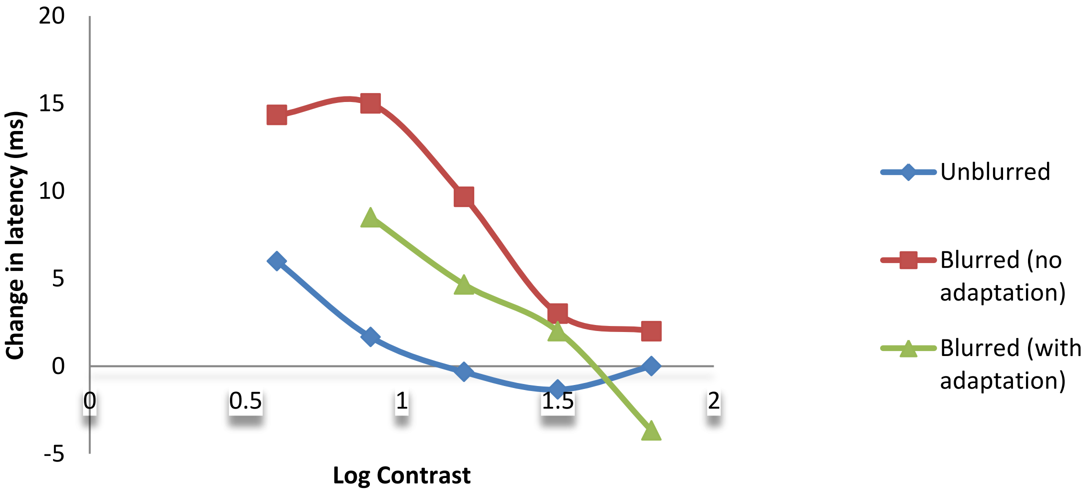

Figure 2. Change in Latency of the P100 response with increasing contrast level

Discussion

As the data show, the adaptation to blur data resulted in a clear improvement over the blur without adaptation in both latency and amplitude. In the case of amplitude, there were consistently small responses in the blur without adaptation data, while there were clear responses in the adaptation to blur data, a drastic difference that shows both the existence and large magnitude of effect of blur adaptation. The first values of amplitude for all three conditions disagree with this conclusion, but can be disregarded because at the first contrast level, the recordings yielded, shown in Figure 1, were just noise. The contrast was too low for any significant data, as the pattern was not very visible. Anecdotally, all participants reported that the pattern stimuli were difficult to discern at this level, consistent with the results. From the second value of amplitude onwards, the data suggest that the hypothesis was correct. The latency values also show the effect of blur adaptation, with a smaller change in latency compared to blur without adaptation, but also suggest that at high contrast levels, viewing images with blur adaptation may cause lower latency values for characteristic waveform peaks than viewing images without any sort of blur.

However, the study could be improved. The results, while definitive in the effect of blur adaptation, do not show exactly how much the adaptation has an effect due to a floor effect in the blur without adaptation condition. The amplitudes from the blur without adaptation condition did not differ from the baseline significantly, even at higher contrast levels. As a result, the contrast response function never rose to a significant level. The level of blur could be reduced in order to produce a rising contrast response function so the shifts in the function, which correspond to the size of the effect, could be computed. However, we can say that the size of the adaptation blur effect was at least 0.5 log units, as illustrated by the horizontal shift of the contrast response functions for both amplitude and latency.

In future studies, there are many other aspects of blur adaptation that can be researched. In this experiment, participants were adapted to blur with a checkerboard pattern (with both horizontal and vertical edges), and recordings were taken when they viewed a sine wave grating (horizontal edges only). The specificity of blur adaptation could be tested in the future by adapting patients to either blurred horizontal or vertical edges, and then having them view the opposite orientation during recording.

The results of this experiment also pertain only to binocular blur. A future topic of interest could be the transfer of blur adaptation across the eyes, and whether adapting to blur in one eye will cause the other eye to also have adaptation. Though past research suggests that there may be some degree of interocular transfer, quantification of the properties of the adaptation process remains elusive (Mitchell & Ware, 1974; Kompaniez et al., 2011; O'Shea et al., 1994).

Examining interocular transfer of blur adaptation could also yield information about how to better prescribe optometric lenses. If people with different degrees of correction adapt to different amounts of blur in each eye and there is adaptation, the current form of prescribing eyewear may need to be revised. Presently, prescriptions are filled out for each eye separately without considering interocular activity. If interocular activity occurs, it may be more prudent to find an average prescription between the two eyes may be more optimal.

Conclusions

It can be concluded that the VEP can provide an objective measurement of the degree of blur adaptaion. Blur decreases the electrophysiological response of neurons in the visual cortex. Blur causes both a reduced response and an increased latency – there is a smaller response, and it occurs later. Blur adaptation lessens this effect. There is still a slight reduction in response and increase in latency, but the changes are much smaller than the changes in blur without adaptation.

The results of this experiment suggest that blur adaptation occurs at some point between photon absorption in the retina and the visual cortex. The VEP also provide quantitative data, which can be compared across human populations. Having quantitative data also allow for easy comparison with results in future research.

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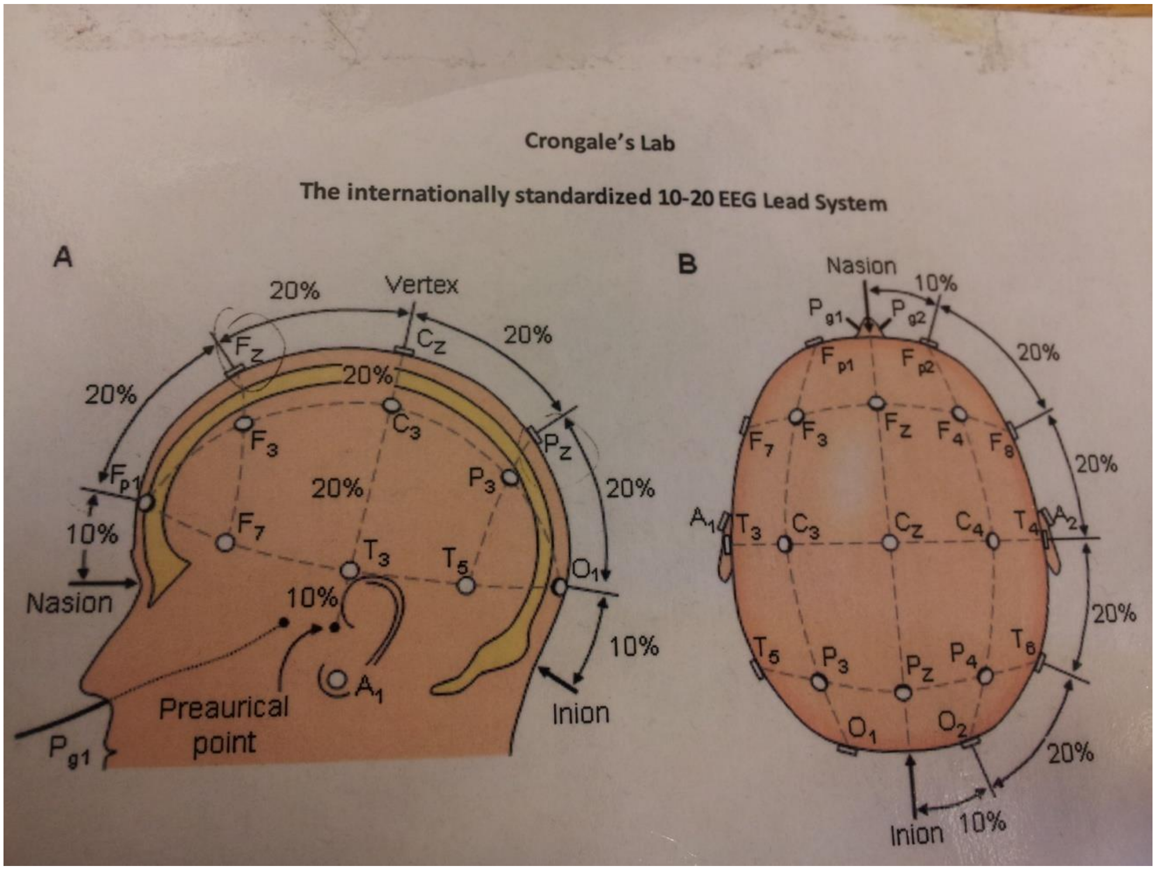
Appendix A:
Visual Evoked Potential Electrode Placement
(Crognale, Michael (2011) UNR Lab document)

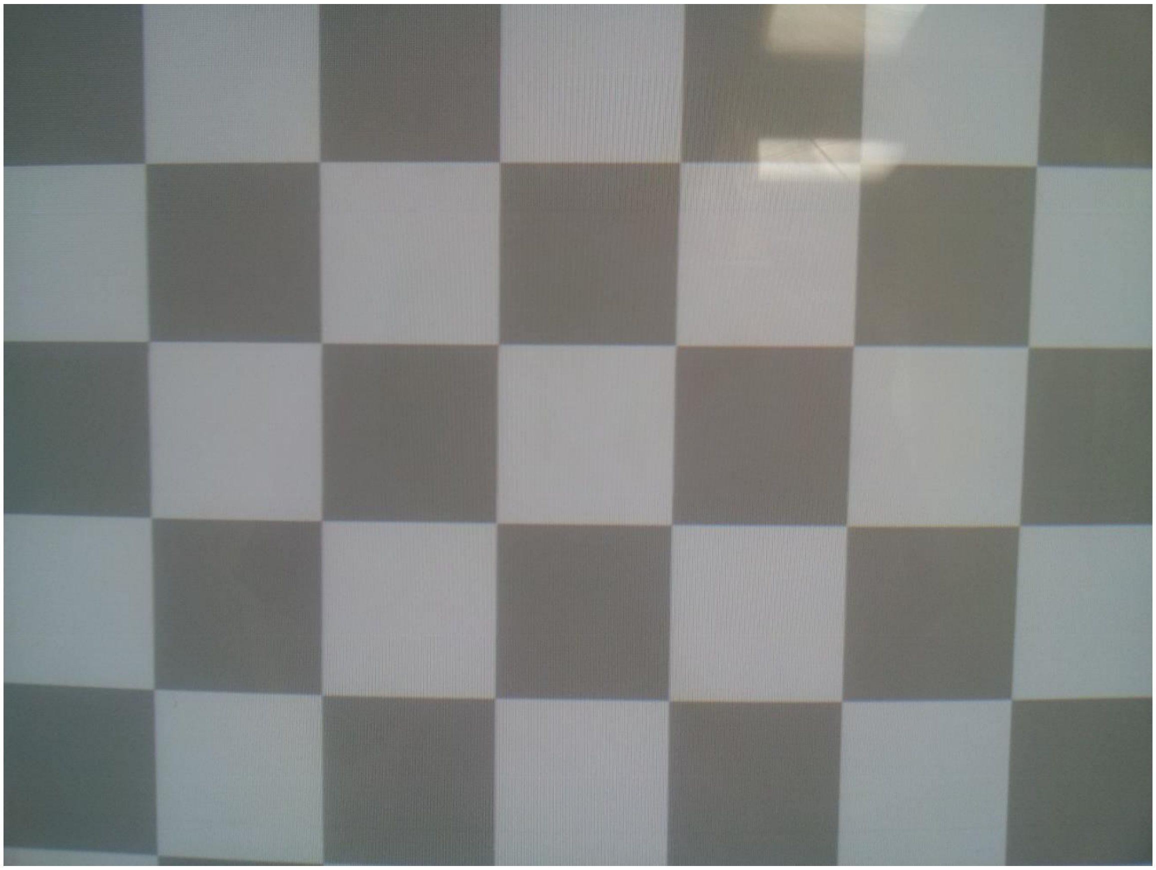


Crongale's Lab

The internationally standardized 10-20 EEG Lead System

Appendix B:

Checkerboard Stimulus



Appendix C:

Sine-Wave Grating Stimulus

Appendix D:

VEP Example Waveform