EFFECTS OF VARIOUS PARAMETERS ON BINOCULAR RIVALRY

by

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ABSTRACT

EFFECTS OF VARIOUS PARAMETERS ON BINOCULAR RIVALRY

In daily life, the two eyes see similar images and there is no perceptual competition. The input from the eyes are compatible and the images are fused. On the other hand, binocular rivalry occurs when two eyes are presented with incompatible visual stimuli. In this condition, the perception alternates every few seconds from one monocular stimulus to the other or an untastable piecemeal mixture is seen. Binocular rivalry is affected by many parameters like contrast, form and motion velocity. In this study, effects of flickering frequency, duty factor, size and luminance of the monocular image on binocular rivalry were tested. It was expected that the rivalry percentage would be decreased when the stimuli is flickered compared to static stimuli and also it was expected that the rivalry percentage would be increased as the duty factor is increased, but would stay constant with respect to frequency. The visual rivaling stimuli used were a square and a disc. The results showed that the rivalry occurrence was reduced when stimuli were flickered, compared to static stimuli. However, the frequency or duty factor of the flicker did not have any effect on the rivalry time. Moreover, the location of monocular images were interchanged in order to test eye asymmetry effects. No such effects were found. Additionally, changes in the size and the luminance of the target did not cause any differences in the rivalry time. This type of stimuli can be used for binocular contrast experiments since the rivalry percentage is found to be reduced in flickering stimuli.

Keywords: Binocular rivalry, Binocular fusion, Flickering stimuli, Frequency, Duty factor, Luminance

ÖZET

ÇEŞİTLİ DEĞİŞKENLERİN BİNOKÜLER REKABET ÜZERİNDEKİ ETKİLERİ

Günlük yaşamda iki göz de benzer görüntüleri görür ve algılamada bir sorun oluşmaz; iki göze gelen uyarılar arasında çok az fark olduğundan bunlar birleştirilebilir. Ancak gözlere birbiriyle uyumsuz iki ayrı görüntü gösterilirse, algı birkaç saniyede bir değişir. Görüntülerden sadece bir tanesi ve ya ikisinin karışımı bir görüntü algılanır. Bu durumda binoküler rekabet oluşur. Kontrast, şekil ve hareket hızı gibi değişkenler gözler arasındaki rekabeti etkiler. Bu çalışmada frekans, darbe doluluk oranı, boyut ve parlaklık gibi değişkenlerin binoküler rekabet üzerindeki etkileri incelendi. Binoküler rekabet süresinin uyarının yanıp sönme frekansı ile değişmemesi fakat darbe doluluk oranının artışıyla artması beklenmiştir. Kullanılan uyarı bir daire ve bir kareden oluşmuştur. Çalışmanın sonuçları yanıp sönen uyarıda, sabit uyarıya göre binoküler rekabetin daha az olduğunu göstermiştir. Ancak yanıp sönme frekansının veya bir periyot içinde görüntünün gösterilme yüzdesinin rekabet süresi üzerinde etkisinin olmadığı bulundu. Ayrıca göz asimetrisinin ölçmek için göze gösterilen uyarıların yerleri değiştirildi;fakat bunun da bir etkisinin olmadığı görüldü. Test edilen diğer iki değişken olan dairenin boyutu ve parlaklığının da gözler arasındaki rekabet üzerinde bir etkisi olmadığı ortaya çıktı. Bu çalışmada kullanılan görsel uyarı (genelde bu tarz çalışmalarda kullanılan uyarıdan daha büyüktür) sadece bir gözün uyarısının baskın olmasının azaldığını göstermiştir. Ayrıca uyarının yanıp sönmesinin binoküler rekabet süresini azaltığının bulunması bu tür bir uyarının binoküler kontrast eşleştirme deneylerinde kullanılabileceğini göstermiştir.

Anahtar sözcükler: Binoküler rekabet, Binoküler füzyon, Yanıp sönen uyarı, Frekans, Darbe doluluk oranı, Parlaklık

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1. INTRODUCTION

1.1 Binocular Fusion and Binocular Rivalry

Visual system produces many complex and interesting phenomena. Some of these phenomena depend on there being two eyes instead of just one. Two eyes positioned in front of the head provide human binocular vision. The spacing between the eyes offers two slightly different views which are used to create stereopsis. Usually the information received by the two eyes are compatible and the brain combines their input in a way that yields a stable, unitary percept. This phenomenon is called binocular fusion.

However, if the two eyes view two dissimilar images (in an artificial way, using a stereoscope), the brain interprets these signals as coming from the same location in three- dimensional space. According to the natural constraint, two things can not occupy the same place at the same time in the observed world. Therefore, the brain can not fuse these incompatible images into a single percept and this gives rise to spontaneously alternating percepts. Only one eye's view dominates at a time and the other's view is suppressed. This phenomenon is called binocular rivalry.

Binocular rivalry has been studied psychophysically and neurophysiologically over the years and holds an important place in discussions of perception and attention because it was considered to affect visual awareness. Temporal dynamics and spatial characteristics of rivalry have been investigated psychophysically. Despite the intensive research, there is still a debate on the fundamental question: at what level and how the two dissimilar images are implemented in the brain?

1.2 Objectives

The objective of this study is to determine effects of various parameters on binocular rivalry. These parameters are frequency, duty factor, size and luminance of the target. The stimuli were different from the classical ones (Horizontal and vertical gratings) usually tested in rivalry experiments. A disc and a square were shown dichoptically to the subjects and their sizes were larger than targets used in previous studies. Therefore the rivalry properties caused by this type of stimuli will also be determined.

Another aim of this study was to compare binocular rivalry times in static stimuli and flickering stimuli. It is expected to have less rivalry percentage in the flickering stimuli compared to the static stimuli. Moreover, the flicker frequency and duty factor that maximize binocular fusion will be determined. The effects of eye asymmetry will be also tested in this study. It is expected that the rivalry time increases with the increasing duty factor but stays constant with increasing frequency.

A long-term goal of this study is to establish a suitable stimulation paradigm to study binocular contrast effects. In order to do contrast matching for binocular incompatible images in future experiments, the effect of binocular rivalry should be minimized.

The results of this study can also be of clinical relevance, since there is preliminary report that in contrast with healthy controls, schizophrenic patients can maintain binocular rivalry even at very high dichoptic stimulus alternation rates [1, 2]. Therefore, the fusion times of healthy and schizophrenic patients can be compared in future studies.

1.3 Thesis Outline

This thesis work consists of seven chapters. The first chapter gives an introduction to the subject of the study and its objectives. The second chapter presents a brief review of the anatomy and physiology of the eye, basics of central visual systems. Chapter 3 covers the history of binocular rivalry and summarizes previous work done including current neural theories and controversies. Chapter 4 explains the methods and materials used in the performed experiments. The results are given in Chapter 5 and discussed in Chapter 6. Conclusions are given in the Chapter 7.

2. BRIEF REVIEW OF ANATOMY AND PHYSIOLOGY OF THE EYE

2.1 Optics of The Eye

The eye is a complex organ that captures and focuses light. The eye consists of many parts that accomplish different optical functions. First, light enters the cornea. The cornea is the transparent portion of the shell and provides the eye much of its light focusing power. Behind the cornea, there is aqueous humor which is a cavity filled with a clear liquid. The fluid nourishes the lens, iris and cornea. Next, light passes through the pupil which is the opening in the center of the iris. The iris is the colored part of the eye and is embedded with tiny muscles that dilate and constrict the pupil to control the amount of light that enters the eye. Just behind the iris, light passes through the lens. The shape of the lens is controlled by the ciliary muscles attached to its edge. Light rays are further focused through the lens, which adjusts its shape and thickness to focus the image onto the retina, a nerve tissue layer that lines the back of the eye. In the center of the eye is a clear, jelly-like substance called the vitreous humor. This substance gives the eye form and shape.

The retina contains millions of light-sensitive photoreceptors which capture the light and converts it into neural activity. The information about the light striking the retina is sent to the visual centers of the brain through visual pathways.

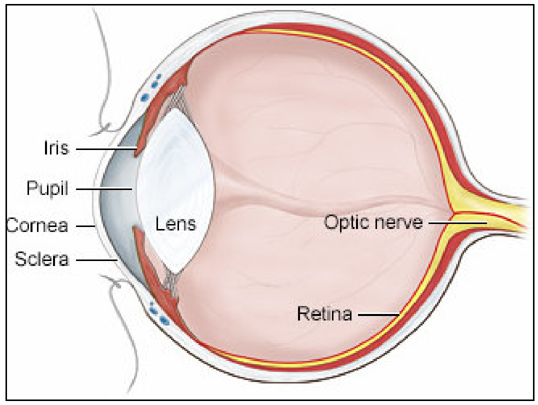

Figure 2.1 Anatomy of the eye [3]

2.2 The Retina

There are two classes of photoreceptor cells in the retina: rods and cones. Rods are longer cells that have rodlike ends and are more numerous than the cones. They are very sensitive to light and located everywhere except at its very center, fovea. The cones are shorter and have conelike ends and are less frequent. They are mostly found in the center of the retina and less sensitive to the light. Therefore, rods are exclusively used for vision at very low light levels and cones are responsible for vision under normal lightning condition and color vision [2].

Both rods and cones have two segments: the inner segment which contains the nucleus and cellular machinery and the outer segment which contains light-sensitive pigment molecules. The absorption of light by the visual pigments in the outer segment triggers a cascade of events and eventually produces electrical changes in the outer membrane of the receptor. These changes cause neurotransmitter release that affect the next neuron.

The output of the photoreceptor cells are further modified and processed by the other type of neurons; bipolar cells, horizontal cells and amacrine cells until they reach the ganglion cells. The ganglion cells are the output neurons of the retina. The axons of the ganglion cells leave the eye via the optic nerve.

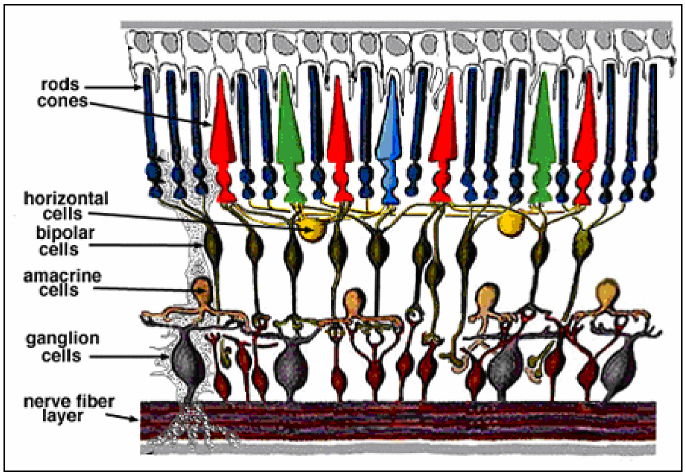

Figure 2.2 Cell types in the retinal organization [4]

2.3 Central Visual Pathways

The area that is seen without moving the head or the eyes is called the visual field. Each eye sees a part of the visual space that defines its visual field. The regions of the visual field are defined with respect to two retinas. The retina can be divided into a nasal hemiretina and temporal hemiretina. The nasal hemiretinal lies medial to the fovea and the temporal hemiretina lies lateral to the fovea.

The visual field can be divided into left and right hemifields. The left half of the visual field is called left hemifield and projects on the nasal hemiretina of the left eye and on the temporal hemiretina of the right eye. The right hemifield projects on the nasal hemiretina of the right eye and on the temporal hemiretina of the left eye.

Frontal placement of the eyes provides two visual fields with a large area of overlap. Light originating from this overlapping area enters both eyes. This region is called binocular zone and provides binocular vision. In both sides of the binocular zone, there are monocular zones where light coming from only the eye on the same side strikes. The nose blocks the light to project the contralateral retina. The Figure 2.3 summarizes the visual field organization.

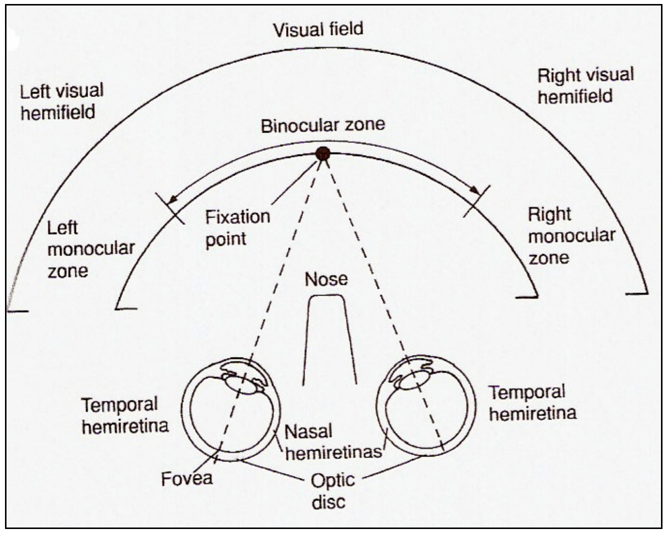

Figure 2.3 Visual fields. Light from binocular zone strikes both eyes, whereas light from monocular zone strikes only the eye on the same side. (Kandel, *Principles of Neuralscience*)

The axons of the ganglion cells exit the eyes via optic nerve. The optic nerves partially cross at the optic chiasm and form two optic tracts: left optic tract and right optic tract. Each optic tract combines inputs from the ipsalateral temporal hemiretina and the contralateral nasal hemiretina. In other words, the left optic tract carries a complete representation of the right hemifield of vision (Figure 2.4).

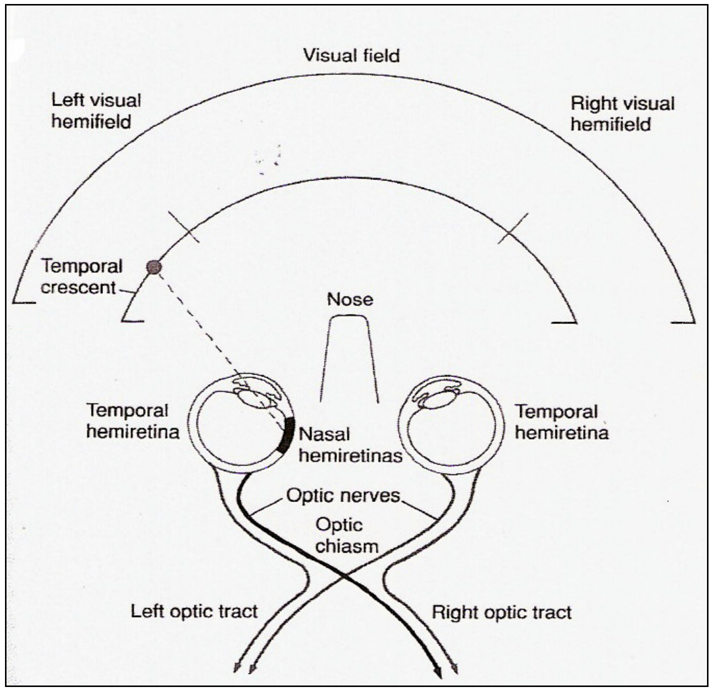

Figure 2.4 Optic tracts (Kandel, *Principles of Neuralscience*).

The vast majority of the axons of the optic tract terminate in the lateral geniculate nucleus (LGN), the principal subcortical region that processes visual information for perception. Fibers from the right half of each retina project to the right LGN and similarly fibers from left hemiretina of each eye project to the left LGN. The lateral geniculate nucleus is composed of six layers of cell bodies separated by intervening layers of axons and dendrites. The layers are numbered from 1 to 6, ventral to dorsal. The two most ventral layers are called magnocellular layers. The four dorsal layers are known as parvocellular layers. An individual layer in the nucleus receives input from one layer only. Fibers from the contralateral nasal hemiretina contact layers 1, 4 and 6; fibers from ipsalateral temporal hemiretina contact layers 2, 3 and 5 (Figure 2.5).

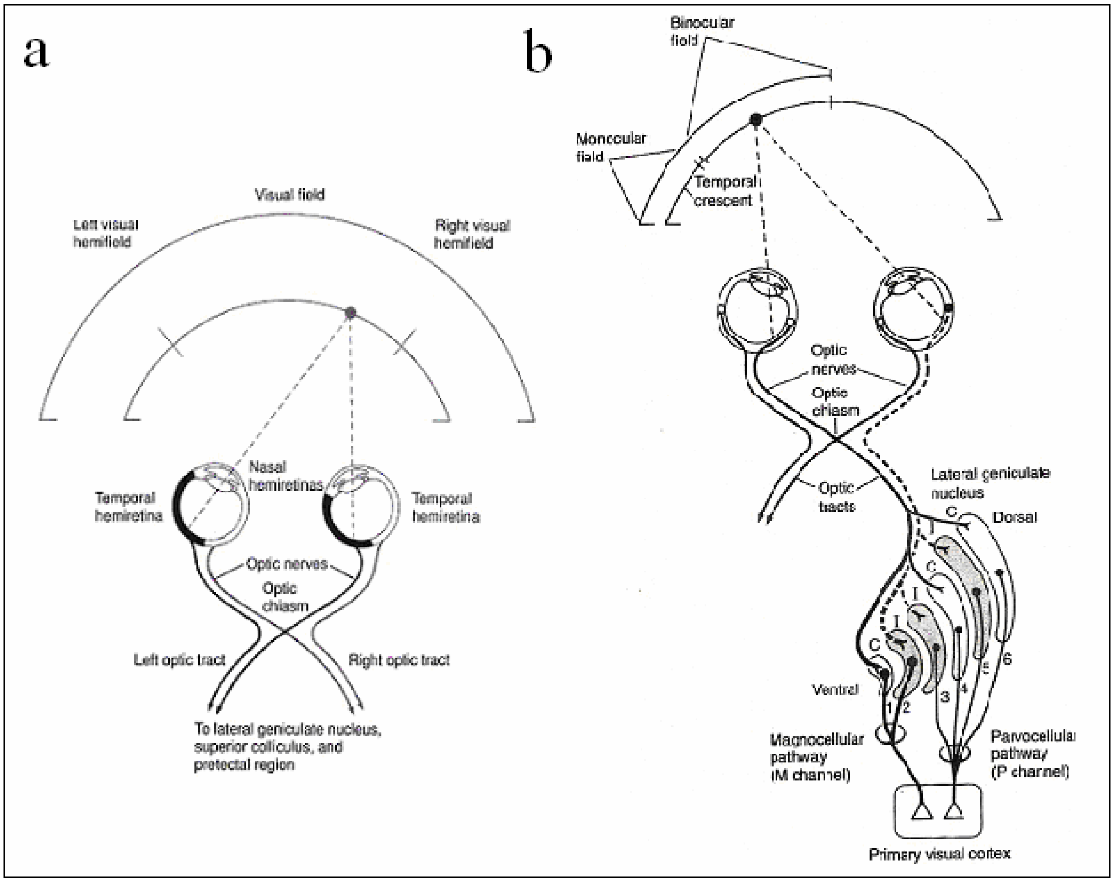

Figure 2.5 Visual fields and its projections **a.** The axons of the ganglion cells project to different brain regions. **b.** Fibers from the contralateral nasal hemiretina contact layers 1, 4 and 6; fibers from ipsalateral temporal hemiretina contact layers 2, 3 and 5 of the lateral geniculate nucleus. (Kandel, *Principles of Neuralscience*)

However, the axons of the retinal ganglion cells also project to several other brain regions (Figure 2.5). Some axons of the retinal ganglion cells extend to the superior colliculi, a paired structure on the midbrain. The superior colliculi help coordinate rapid movements of the eyes toward the target. Small bundles of the optic tract also project to the suprachiasmatic nucleus (SCN) in the hypothalamus. Cells in the SCN are involved in the control of circadian rhythms. Finally, optic tract axons from still other ganglion cells go to the pretectal area of the midbrain that regulates the pupillary reflexes.

The first cortical stage of visual processing is the primary visual cortex or visual area 1 (V1) which is located at the very back of the occipital lobe. It receives majority of the ascending projections from the LGN and is responsible for the first few operations of visual processing. Like the LGN, the primary visual cortex in each cerebral hemisphere receives information exclusively from the contralateral half of the visual field. The primary visual cortex contains an orderly map of the visual field (Figure 2.6). About half of the neural mass is devoted to representation of the fovea and the region just around it. This area has the greatest visual acuity [1].

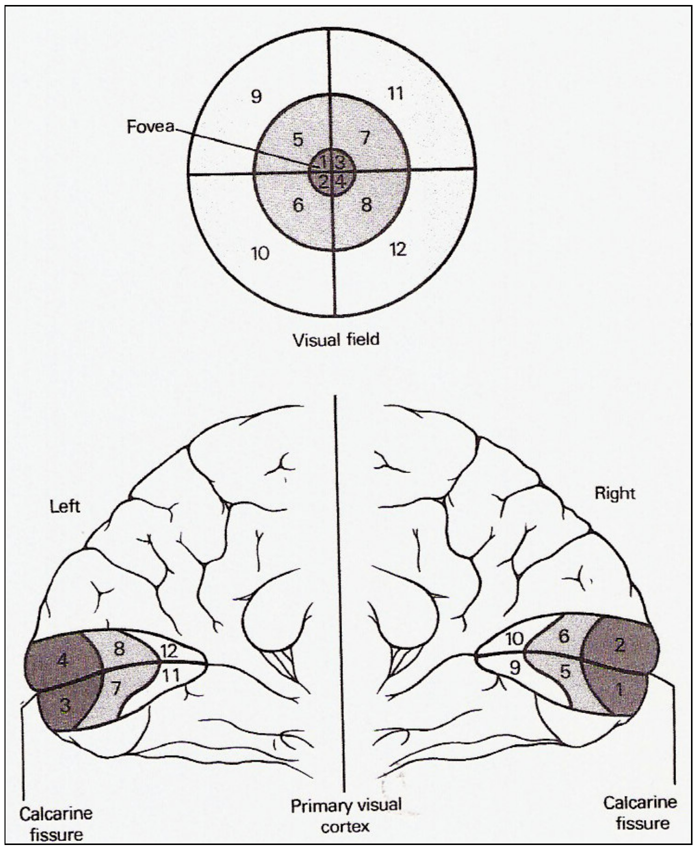

Figure 2.6 The primary visual cortex map (Kandel, *Principles of Neuralscience*)

3. BINOCULAR RIVALRY

There are many interesting phenomena in visual perception. One of these phenomena is binocular rivalry in which the perception alternates when two dichoptically presented images are incompatible. The observer experiences brief and intermittent periods of exclusive visibility of one or the other image. When the image in one eye is fully visible, called dominant, the image on the other eye is fully invisible, called suppressed. Therefore the stimulus is bistable and the perception alternates between two states. Between the periods of complete dominance and suppression, there are periods during which the observer sees mixtures of both images.

The duration of the perceived image is determined by many factors like contrast, color, contours, and dimensions of the stimuli. If there is a transient change in the suppressed parts or the images are interchanged, the perception also changes simultaneously.

Rivalry can be triggered by very simple stimulus differences and by complex differences. The differences in color, luminance, contrast polarity, form, size and motion velocity can create diverse stimuli that cause rivalry. On the other hand, there are few conditions that do not lead to rivalry; differences in flicker rate [5], differences in contrast level, large differences in left-and right-eye spatial frequency amplitude spectra [5].

Despite the early description of the phenomenon and many investigations, the nature of competitive interactions that effect binocular rivalry remain unsolved. Besides this, there is an on-going debate on neural bases of binocular rivalry; different monocular patterns rival as a result of neural competition among monocular channels or pattern representation.

3.1 History and Early Theories of Rivalry

According to Wade [6], Porta (1593) was the first scientist who did an unambiguous description of binocular rivalry. He put a partition between his eyes and looked at the pages of a book. He concluded that he could only see the words on the right page and the image coming from the left eye was suppressed. So his right eye was dominant. Porta argued that we only process one eye at a time. According to this theory, we do not normally notice the alternations between the two eyes because their images are too similar.

Another scientist who described the phenomenal alternations of binocular rivalry was Dutour [7]. Dutour view a piece of blue taffeta with one eye and a piece of yellow taffeta with the other eye. One might expect to have a combined expression of green according to optical combination rules. However, the perception of two monocular colors alternated between each other. Dutour concluded that the mind can catch only one of the two corresponding retinal points at any moment. This theory was often called 'suppression theory'.

Wheatstone further studied binocular rivalry and invented the stereoscope (1838), an optical device with mirrors, which is used to present different images to two eyes. Wheatstone found that stereo-image pairs with shifted local features can yield a stable, fused impression of stereoscopic depth and the effect was due to the difference of the images, not their similarity (Figure 3.1.a). In other words, in certain conditions the mind can combine information from both eyes. On the other hand, Wheatstone also showed that very different monocular patterns fail to fuse and lead to perceptual alternation as a result of binocular contour rivalry (Figure 3.1.b) [7].Wheatstone concluded that: 'The mind is inattentive to impressions made on one retina when it cannot combine the impressions on the two retiane together so as to resemble the perception of some external objects' [7, 8].

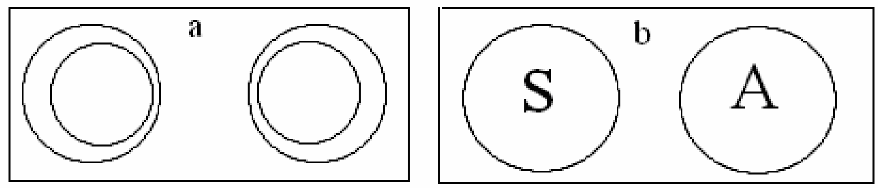

Figure 3.1 Fused and rivaling stimuli. **a,** Example of Wheatstone stereoscopic display. **b,** Example of binocular contour rivalry

Another scientist, Helmholtz proposed that rivalry arises from spontaneous fluctuations in visual attention. Helmholtz suggested that until the very latest stages of attentional selection, the images from both eyes are potentially available to awareness. He also found that the predominance of either rivaling pattern can be increased by attending to that pattern. The role of attention in determining rivalry predominance has been systematically studied by Lack [4]. Lack showed that not only blinking or accommodation but also central neural systems exert control over rivalry.

An additional phenomenon discovered by Helmholtz is monocular rivalry as named by Breese in 1899. When two objects are optically superimposed and presented to the same eye a weaker form of conflict occur. During prolonged viewing, one image becomes clearer than the other for a few moments, then the other image becomes clearer than the first for a few moments. These alternations in clarity continue at random for as long as one looks. Occasionally one image will become exclusively visible and the other image invisible [9].

For large rival stimuli, one does not experience alternating view of the stimuli but experience a fluctuating patchwork consisting of portions of both eyes' views [10]. This piecemeal rivalry suggests that rivalry occurs locally within spatially restricted zones and not globally between eyes. Rivalry, not piecemeal rivalry, can be obtained only when rival stimuli do not exceed about 0.1 deg visual angle [4]. However, Blake *et.al.* (1992) found that the incidence of periods of exclusive visibility of a given eye's rival target (pure rivalry) increased with decreasing target size, and for a given sized incidence of pure rivalry increased with retinal eccentricity [11]. O'Shea *et.al* (1997) showed that the spread of pure rivalry is large for low-spatial-frequency stimuli and small for high-spatial-frequency stimuli [12]. When the rival targets are seen at low light levels occurrence of piecemeal rivalry is reduced [4].

When the monocular images are not compatible, the binocular visual system requires some time to realize this. In this case, dissimilar monocular images appear to be fused for some period after their presentation. Wolfe called this phenomenon as false fusion. For example, orthogonal gratings shown dichoptically can be seen by the observer as a dichoptic plaid. However, extending viewing of the images leads to binocular rivalry. Wolfe reported that false fusion can last up to only 150 msec, on the other hand, Liu et al found that dichoptic images can be fused for several seconds depending on the spatial frequency and the contrast of monocular targets [13].

3.2 Current Research

3.2.1 Temporal dynamics of rivalry

In order to experience the complete dominance of one image, both stimuli must be simultaneously presented for at least several hundred milliseconds [4]. Incompatible monocular stimuli that are very briefly shown do not lead to binocular rivalry, but produce binocular partial superposition of the two stimuli [4].

The shifts in dominance and suppression are unpredictable. Moreover, the successive durations of dominance and suppression are independent. In other words, the duration of any given phase is unrelated to the duration of prior phases. One reasonable reason for the source of randomness was proposed by Levelt in 1965. He proposed that the microsaccadic eye movements trigger the shifts from suppression to dominance. However, stochastic analysis of rivalry fluctuations produced by afterimages invalidated this hypothesis [14].

Blake, Westendorf and Fox (1990) studied the temporal sequence of rivalry alternations under forced dominance condition. One eye was forced to return to dominance by introducing an abrupt change whenever it was suppressed. An alternation in sequential independence was expected because perturbation prevents excitatory and inhibitory processes and unbalances the interplay between them. Nevertheless, sequential independence of successive durations was maintained in all conditions and the temporal pattern returned to the nonperturbated values after only one cycle.

Many factors like luminance, spatial frequency, size can cause variations in alternation rate and in stimulus predominance. Predominance is defined as the total percentage of time that a stimulus is visible. The predominance of a rival target increases if it is stronger than the other stimuli. For example, the stimulus with higher luminance will have an increased predominance compared to the stimulus shown to the other eye with low luminance. This increased predominance is produced by decreases in the durations of suppression periods. If both rival targets are increased in strength, each target remains suppressed for shorter periods of time.

Binocular contrast difference is one of the factors that affect temporal dynamics of binocular rivalry. Mueller and Blake (1989) found that relative duty-cycles of the suppressed and dominant phases are determined by the binocular contrast differences. The eye which views the image with higher contrast dominates more in a complete cycle. However, the overall rate of alternation is increased by increasing monocular image contrast. As a result, there appears to be neural oscillator in which the relative time of each phases in determined by the binocular contrast input and reciprocal inhibition. Moreover, the oscillator increases its speed as the contrast increases [15].

Crassini and O’Shea (1984) have demonstrated that rivalry is disrupted if discrepant monocular stimuli are flickered rapidly and repetitively. Moreover, in 1986 Blake and O’Shea found that flickering stimuli influence binocular contour rivalry and dichoptic differences in sinusoidal flicker do not produce rivalry in the absence of contours [7].

A recent discovered phenomenon is stimulus rivalry. In 1996, Logothetis et.al. found that when orthogonal gratings are flickered at 18 Hz to mask the frequent reversal of the patterns every 333 ms, subjects reported that one pattern remains dominant for durations larger than the swapping time. However, Lee and Blake (1999) showed that stimulus rivalry can occur only within a limited range of reversal rates and only for low contrast stimuli [16].

The rivalry can be easily disrupted by transient stimulations. Setting suppressed stimulus in motion, increasing its contrast can bring the suppressed stimulus into dominance.

Another research area in rivalry is the process responsible for the alternations in monocular dominance over time. One classical concept for the underlying mechanism of binocular rivalry is the reciprocal inhibition within a neural network. This theory is based on the concept of fatigue and adaptation. During the dominance, the dominant eye's excitatory system weakens and can no longer be dominant. Once suppressed, the eye begins to recover from adaptation.

3.2.2 Neural bases theories of binocular rivalry

Currently there are two basic theories about rivalry: interocular competition theory and pattern competition theory.

3.2.2.1 Interocular competition theory

In 1962 Hubel and Wiesel discovered that inputs from two eyes are combined by binocular neurons in cat striate cortex. Levelt's theory suggests that inputs from two eyes directly compete with one another via reciprocal interocular inhibition. If the signal strength of one eye is stronger than the other, it suppresses the eye with weak signal.

Lehky (1988) proposed an interocular competition model. (Figure3.2). In this model, there is reciprocal inhibition between monocular channels. When a strong stimulus comes to one monocular channel, an inhibitory neuron is activated. This inhibitory neuron can entirely suppress input from the other eye. However, it can only last for a period because of adaptation, eventually the suppressed eye become dominant. This model can explain why the stimulus with increased strength decreases the predominance of the competing stimulus.

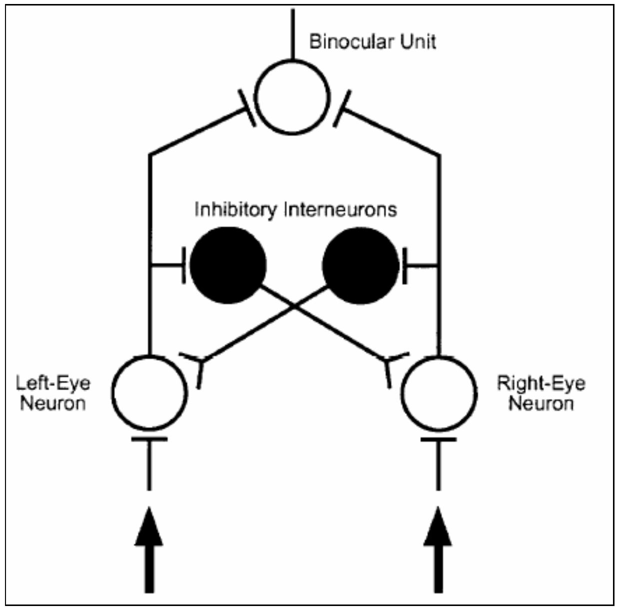

Figure 3.2 Example of neural network model of binocular rivalry (adapted from Lehky, *Perception*, 1988- cited by Tong, 2001).

This theory can easily be tested. For example, when the orthogonal gratings are shown dichoptically, the left eye horizontal grating is dominant and the vertical grating shown to the right eye is suppressed. A sudden exchange of the monocular patterns leads to the perception of left eye vertical grating [7]. Another experiment done to show eye dominance is the stimulus change procedure. Here the orientation or direction of a moving stimulus is changed while that stimulus is suppressed. The subjects do not notice these changes until the suppressed eye returns to dominance after some seconds. This again implies that an eye is suppressed not a particular pattern [7].

An additional finding that supports this theory is that stimuli presented to the temporal hemifield tend to dominate over stimuli in the nasal hemifield. [7]. This can be explained by the fact that ocular dominance columns in V1 show a similar asymmetry with greater representation of temporal hemifield than of the nasal hemifield.

There are also certain phenomena that interocular competition theory can not explain. One of them is the monocular rivalry in which interocular competition is absent. The monocular rivalry is a weaker from of perceptual alternation occurs but it shares similarities with binocular rivalry.

Another phenomenon that can not be explained by the interocular competition theory is visual adaptation. Adaptation studies showed that a suppressed rivalry stimulus can still lead to the development of visual aftereffects. These studies have shown that aftereffects are equally strong irrespective of whether the monocular adapting stimulus is continuously perceived or periodically suppressed by a rivaling stimulus [7]. Moreover, if the adapting stimulus that is suppressed is physically removed for duration comparable to the suppression period, the occurring aftereffects are much weaker. From these findings, it can be concluded that binocular rivalry takes place after adaptation. More important, suppression does not reduce the amount of interocular transfer for the spatial frequency or motion aftereffect [7]. Since the interocular transfer of aftereffects is likely mediated by binocular neurons, it can be suggested that rivalry suppression occurs after binocular convergence. However, there is an alternative explanation for these aftereffects. Since the monocular signals are greater during the dominance phase of rivalry than during the fused viewing, perception of an adapting stimulus for only half of the time can still lead to the same adaptation effects. Lehky and Blake (1991) found that when the adapting stimulus was perceived only 10% of the time, much weaker adaptation occurred, suggesting that rivalry suppression occurs prior to the site of adaptation. However, to completely reveal the aftereffects much more extensive suppression is required [7].

3.2.2.2 Pattern competition theory

The second current theory of binocular rivalry is proposed by Logothetis and colleagues; pattern competition theory. According to this theory, there is competition between incompatible pattern representations. This competition takes place well after the inputs from the two eyes have converged in V1. For example, in the case of orthogonal gratings, there is competition among perceptual representations of vertical and horizontal rather than competition among the eye channels.

This theory can again be represented by Lehky's neural model with the exception that reciprocal inhibition occurs between different pattern representations.

The pattern competition theory requires a much higher level form of competition between equally valid perceptual interpretations. According to this theory, binocular rivalry is a multistable phenomena such as ambiguous figures and the neural cause should be studied as the perceptual ambiguities.

The experiments done to measure rivalry-related activity in V1 of awake-behaving monkeys showed no evidence of competition among monocular V1 neurons. These findings support that competition at much higher levels of visual pathway causes rivalry.

The pattern competition theory can provide explications to the monocular rivalry and stimulus rivalry. These phenomena are characterized by alternations that are independent of the eyes. Moreover, perceptual grouping can also occur across image elements in the two eyes during binocular rivalry [16]. The pattern theory is consistent with this fact. In the experiment performed by Kovacs, a monkey face and a text were intermingled to obtain complementary patchworks. The patchworks were shown dichoptically and observers experienced alternation between monkey face and the text unlike alternation between two patchworks that would be predicted by the eye competition theory. Only pattern coherency can explain these interocularly grouped percepts.

On the other hand, the piecemeal rivalry can not be explained by the global pattern competition. In the piecemeal rivalry, there is not a coherent perception of only one monocular pattern but a dynamically changing mixture of fragments from each of the two monocular patterns.

Bonneh et al. (2000) showed that eye rivalry and pattern rivalry may exist mutually exclusively or at the same time with a dynamic and stimulus-dependent balance between different eye- and pattern-specific mechanisms, involving competition at different levels of visual processing. Therefore it seems that rivalry mechanisms can not be explained by a single paradigm.

4. MATERIALS AND METHODS

4.1 Subjects

Six subjects (three males and three females) with normal or corrected to normal visual acuity were tested. They were naive about the purpose of the experiment. All subjects provided written consent for their participation. Each subject spent approximately 10 hours to complete the experiment in 10 sessions.

4.2 Apparatus

The visual stimuli were presented on a calibrated CRT monitor (Samsung SyncMaster 551v). The subjects viewed stimuli from a distance of 43 cm through of a mirror stereoscope (Figure 4.1 and Figure 4.2).

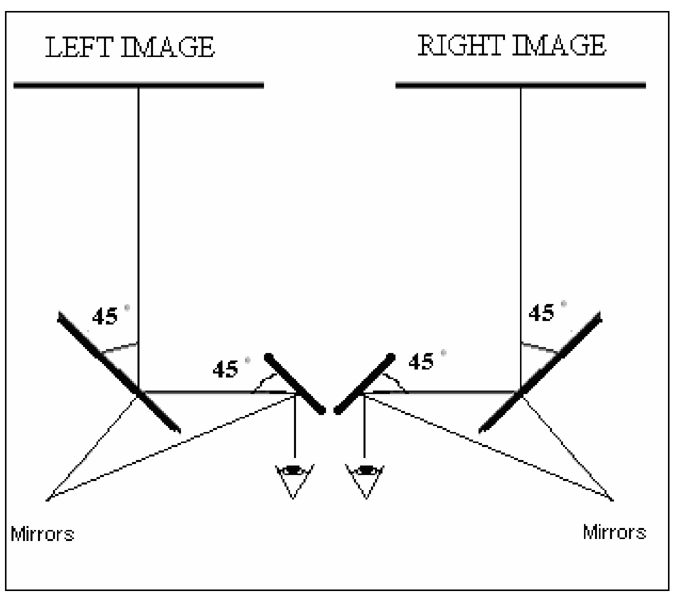

Figure 4.1 The mirror stereoscope

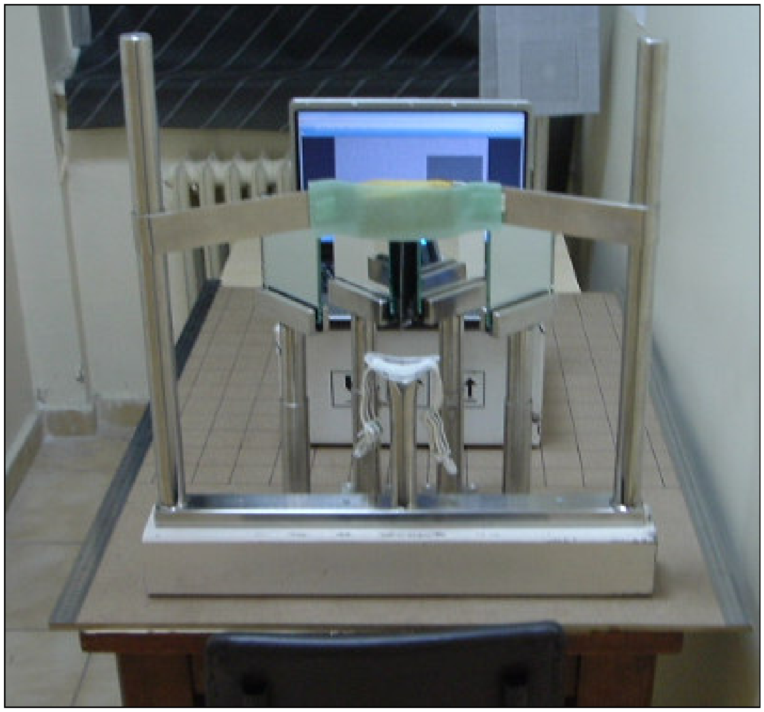

Figure 4.2 The picture of the mirror stereoscope

The head movements were minimized using a chin-rest and forehead-rest. The left stimulus was presented to the left half of the monitor and the right stimulus to the other half. The mean luminance of the monitor was 21.4 cd/m^2.

Before the experiments, the stimuli were calibrated. The luminances of the gray levels are shown in the Figure 4.3. The luminance between 20% and 80% can be considered linear.

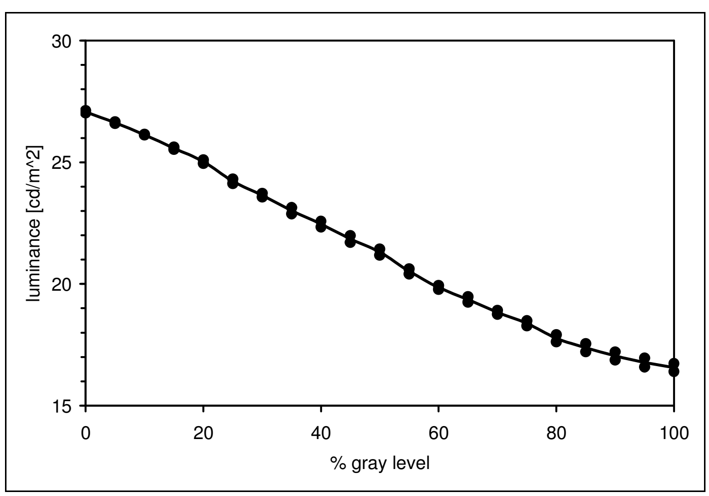

Figure 4.3 Calibration plot

4.3 Stimuli

The stimuli were generated on a PC and presented using a MATLAB program.

The target was a disc and was located in either the left or right of a black or white square. The background was a Gaussian noise pattern with a 50 % gray level mean luminance (21.3 cd/m^2).

When the stimulus was on, a disc and a square were shown to the subject. The two patterns shown to each eye—the disc and the square—were synchronized with each other. When the stimulus was off, only background was shown to the subject. Different disc sizes and luminances were tested in the experiments but the background luminance was fixed. For each case, the square was black or white and the target was presented either on the right or left side (Figure 4.4). All of the combinations were tested in the experiments.

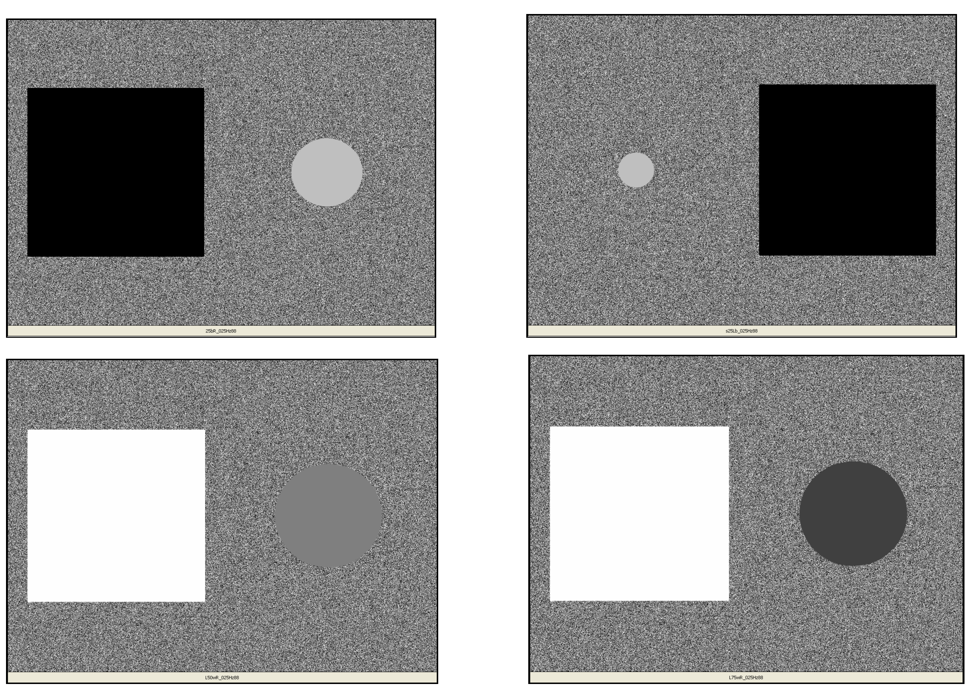

Figure 4.4 On-stimulus examples. Different disc sizes and luminances are tested. The square was black or white and presented either on the left or on the right of the screen.

The on and off stimuli were sequentially ordered and were shown as 5 minutes movies. Different frequencies and duty factors of on-times were tested in the experiments. Additionally, on stimuli was used as static images.

The frequency is the number of on-stimuli shown in one second. It can be calculated as 1 / (a+b), a and b being respectively the time periods of on and off stimuli. The duty factor is defined as on-stimulus time over the period: a / (a+b) (Figure 4.5).

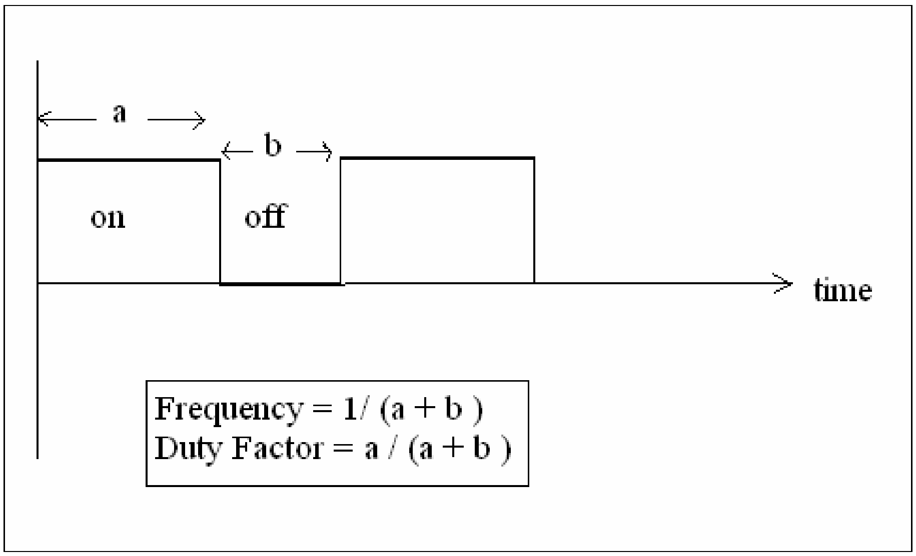

Figure 4.5 Frequency and duty factor of the stimuli

The frequency and duty factor values used in the experiments are given in the Table 4.1.

Table 4.1
Frequency and duty factors used in the experiments

Frequencies (Hz)	Duty Factors (%)
0.25	37.5, 50, 62.5, 75, 87.5
0.5	37.5 50, 62.5, 75, 87.5

4.4 Procedure

The study consisted of three experiments. Each subject was initially trained how to view images through the stereoscope.

4.4.1 First experiment: static stimuli

In the first experiment, the subjects watched static on-stimuli for five minutes. Each subject was instructed to press the mouse button when he/she saw a complete disc on the square, and release the button otherwise. The Matlab program recorded the mouse-key up/down times.

The duration of button down measures the intervals that the subject sees images from both eyes fused (the disc on the center of square). Although the term fusion is used for the superposition of the two compatible images, throughout this study it was referred as the superimposition of the disc on the square without any noise or blurring inside the disc. The fusion however can never be complete because of binocular rivalry. The aim was to determine the time periods where the disc was entirely seen within the boundary square. In other words, the contours of the square and the entire disc had be seen simultaneously but some parts of the square might be replaced by rivaling noisy pattern surrounding the disc (Figure 4.6).

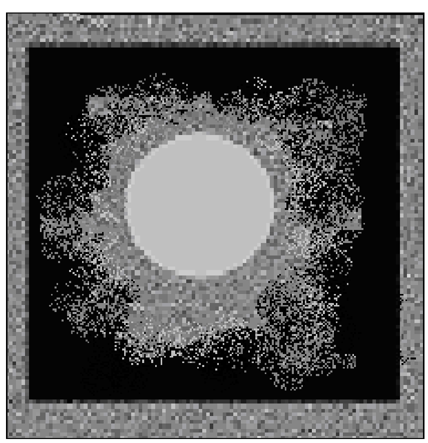

Figure 4.6 A description of a fused image

In this experiment, the disc diameter was 5 cm (6.65^{o}) and luminance was 50 % (21.3 cd/m^2). In each static image, the disc was on the left or right of a black or white square. All combinations required presentation of 4 movies.

By using the results of this experiment, the rivalry generated by static and flickering images were compared.

4.4.2 Second experiment : flickering stimuli at different frequencies and duty factors

In the second experiment, the frequency and the duty factor of the movies were varied. The aim of this experiment was to determine the frequency and the duty factor value that minimized the rivalry time and maximized the fusion during on-stimulus.

Initially the effects of reaction times were determined for different frequencies (0.25 Hz, 0.5 Hz, 1 Hz and 2 Hz). While the subjects observed the stimuli binocularly, not through the stereoscope, they were instructed to press the mouse key as soon as the on-stimuli were presented. The frequency values used in the experiment, however, were 0.25 Hz and 0.5 Hz, because, at higher frequencies, the subject’s response was too slow. Frequencies lower than 0.25 Hz were not tested because the results were expected to be similar to those obtained from static images.

The duty factor percentage values used in the experiments were 37.5, 50, 62.5, 75 and 87.5. As the duty factor percentage increased, the stimulus on-time is increased.

The time period that the subject saw the disc on the square was called fusion time. The rivalry time is defined as the time period that the subject saw only the square or the disc or none of them.

The rivalry time was determined indirectly. The subjects looked to the same movies binocularly. At this part, they saw the disc on one side of the screen, the square on the other side. They were instructed to press the key as soon as they saw the stimulus and release it when the stimulus was off. Since no rivalry occurs in binocular vision, the durations of button down periods should have to be equal to the stimulus on-time. However, the subject's reaction times create differences between stimulus on-time and the press time. The total time the subjects pressed the key when they view both the square and the disc without the stereoscope was called the binocular time.

The differences between binocular time and the fusion time gave the rivalry times. This method was aimed for eliminating the effects of reaction times for button presses.

Ten movies with randomly selected duty factors and frequencies were shown in each one hour session. Resting breaks were given between the movies. All combinations added up to forty movies.

4.4.2 Third experiment : target with different size and luminance

By using the results of the second experiment, the frequency and duty factor that minimized the rivalry time and maximized fusion time were determined. These parameters were fixed in the third experiment. Two other parameters are added in this part in order to determine the effects of the target size and luminance on the rivalry time. The gray level of the disc and its size changed. The gray levels used in the experiment were 25 % (24.2 cd/m^2), 50 % (21.3 cd/m^2) or 75 % (18.3 cd/m^2). The diameter of the disc was 2.5 cm (3.33^o), 5 cm (6.65^o) and 7.5 cm (17.84^o). The location of the target and the type of the square (black/white) were also interchanged. All combinations added up to thirty-two movies.

4.5 Analyses

In the first experiment, the stimuli were static. The subject released the mouse key whenever she/he saw only the square or the disc or none of them. Therefore the duration of button down gave the rivalry time. Each image was presented for 5 minutes. From the results, the percentage of rivalry of each movie is calculated.

In the second and third experiments the subjects watched flickering images with and without the stereoscope. In the stereoscope experiment, they released the mouse key when they experienced rivalry. The duration of the button down gave the fusion time. When they observed the same movies not through the stereoscope, they pressed the mouse key as long as the stimuli were on. This duration of button down gave binocular time. The difference between them is the rivalry time.

Rivalry time = Binocular time – Fusion time

The percentage of rivalry time was calculated according to the duty factors. As the duty factor changes, the stimulus on-time changes (Figure 4.7). All the time durations were in seconds.

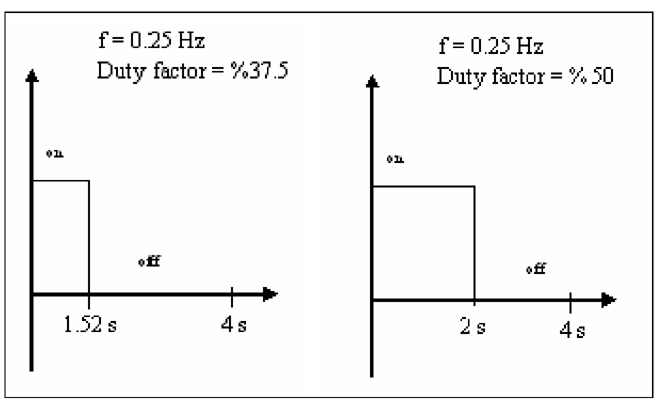

Figure 4.7 Duty factor effect

In the second and the third experiments, four main factors that could effect rivalry time were studied. Besides statistical t-tests, four-way ANOVA was performed in Matlab to determine interactions between factors and main effects.

5. RESULTS

5.1 First Experiment : Static Stimuli

The target used in this experiment was 50 % gray with diameter 5 cm. Five subjects experienced rivalry during static stimuli. The sixth subject was able to superimpose images continuously.

There were four possible combinations of images; black square on the right or left and white square on the right or left.

Table 5.1
Rivalry percentages of static stimuli

Square	S 1(%)	S 2(%)	S 3(%)	S 4 (%)	S 5(%)	S 6(%)
Black/Left (BL)	17.97	4.58	4.62	31.33	9.22	0
Black/Right (BR)	10.27	11.72	6.55	19.69	8.50	0
White/Left (WL)	17.70	9.78	11.47	20.91	19.31	0
White/Right (WL)	36.68	17.02	8.58	28.72	5.23	0
Average	20.65	10.77	7.80	25.16	10.56	0
St.deviation	11.26	5.14	2.92	5.73	6.08	0

The mean rivalry percentage value was 12.49 % ± 10.09 % (mean±SD, n=16).

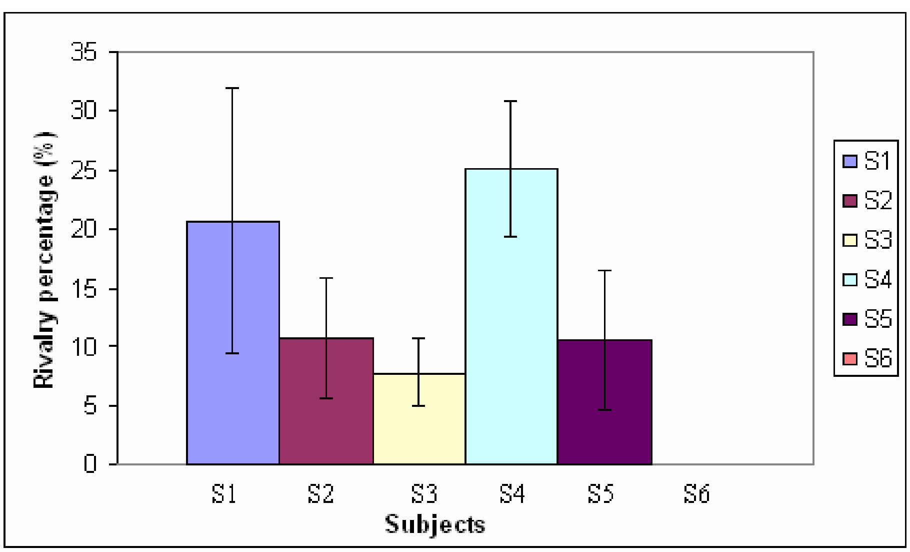

Figure 5.1 The graph of rivalry percentages of static stimuli. The subject 6 did not experienced rivalry.

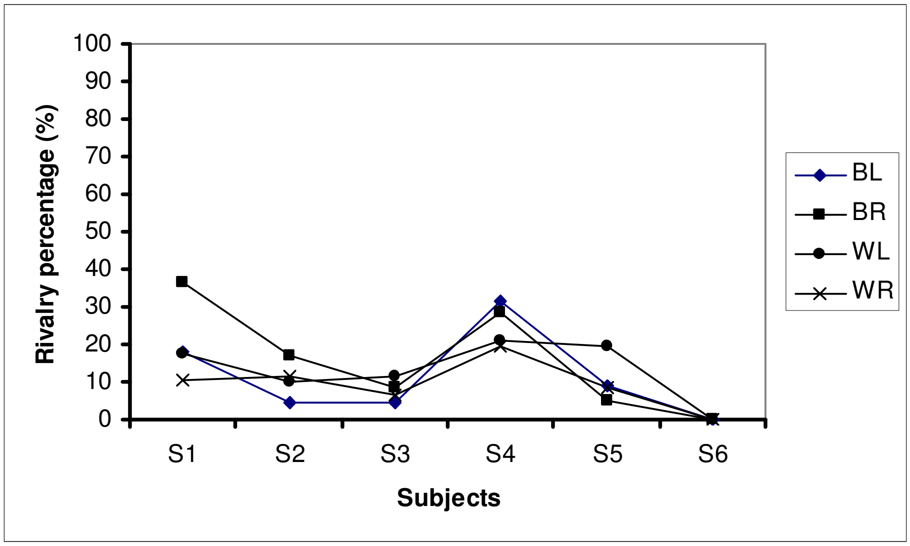

Figure 5.2 The graph of rivalry percentages of static stimuli for different types of square location and luminance

5.2 Second Experiment : Flickering Stimuli at Different Frequencies and Duty Factors

The target used in this experiment was 50 % gray with diameter 5 cm. The frequency and the duty factor values changed during this experiment.

In order to analyze interactions between factors, four-way ANOVA was done in Matlab. The factors given in Table 5.2 are frequency (X1), duty factor (X2), the luminance of the square (X3) and the position of the square (X4).

Table 5.2

Four-way ANOVA results of six subjects. There are no significant interactions or main factor effects except duty factor (X2). X1 is the frequency, X3 is the luminance of the square and X4 is the location of the square.

Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	0.88	1	0.8804	0.08	0.7834
X2	158.38	4	39.5949	3.41	0.0101
X3	1.96	1	1.9557	0.17	0.682
X4	0.6	1	0.5998	0.05	0.8205
X1*X2	51.87	4	12.9664	1.12	0.35
X1*X3	6.38	1	6.3837	0.55	0.4594
X1*X4	0.16	1	0.1589	0.01	0.907
X2*X3	35.09	4	8.7713	0.76	0.5557
X2*X4	6.21	4	1.553	0.13	0.9698
X3*X4	0.75	1	0.7454	0.06	0.8003
X1*X2*X3	18.56	4	4.641	0.4	0.8088
X1*X2*X4	15.57	4	3.8933	0.34	0.8541
X1*X3*X4	0.61	1	0.6108	0.05	0.8189
X2*X3*X4	5.81	4	1.4514	0.12	0.9733
X1*X2*X3*X4	19.79	4	4.9469	0.43	0.7899
Error	2323.24	200	11.6162		
Total	2645.85	239			

Constrained (Type III) sums of squares.

The results show that there are no significant main factor effects except the duty factor. This was caused by one subject (S 3) whose average rivalry time was more than 4 times higher than the others for the 0.25 Hz stimulus with 87.5 % duty factor (Table 5.2).

Table 5.3

Average rivalry times and standard deviations for 0.25 Hz and 87.5 % duty factor value

Subjects (%)	S 1 (%)	S 2 (%)	S 3 (%)	S 4 (%)	S 5 (%)	S 6 (%)
Averages (%)	0	2.25	14.43	3.30	1.49	2.66
Standard deviations (%)	0	0.81	10.62	1.52	1.79	2.71

Therefore this subject was considered to be an outlier and excluded in further analyses. Another four-way ANOVA was done excluding this subject (Table 5.3). There is no significant interaction or main effects among five subjects.

Table 5.4

Four-way ANOVA results of five subjects. One subject was found to be an outlier and excluded. There is no significant interaction or main effects among five subjects.

Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	0.11	1	0.1051	0.01	0.9114
X2	50.79	4	12.6971	1.5	0.204
X3	0.32	1	0.3245	0.04	0.8449
X4	0.18	1	0.1757	0.02	0.8855
X1*X2	14.49	4	3.6216	0.43	0.7879
X1*X3	0.54	1	0.5376	0.06	0.8012
X1*X4	1	1	1.0014	0.12	0.7311
X2*X3	14.29	4	3.5734	0.42	0.792
X2*X4	5.11	4	1.2779	0.15	0.9622
X3*X4	12.3	1	12.3022	1.46	0.2294
X1*X2*X3	8.23	4	2.0576	0.24	0.9133
X1*X2*X4	14.1	4	3.5259	0.42	0.7961
X1*X3*X4	0	1	0.003	0	0.985
X2*X3*X4	1.2	4	0.3005	0.04	0.9976
X1*X2*X3*X4	7.1	4	1.7745	0.21	0.9326
Error	1352.18	160	8.4511		
Total	1481.94	199			

Constrained (Type III) sums of squares.

Since there are not any significant interactions between the factors, the data can be pooled for further analyses. The mean value of rivalry percentage was found to be 2.07 % ± 3.77 % (mean±SD, n=120) for 0.25 Hz and 1.95 % ± 2.83 % (mean±SD, n=120).

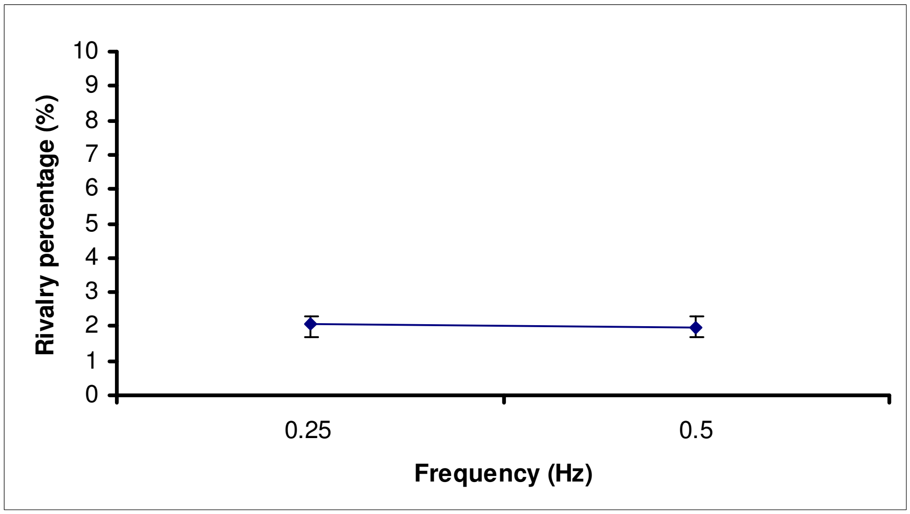

Figure 5.3 Rivalry percentages versus frequency graph. Error bars indicate standard deviations.

There is no significant difference between rivalry percentages of different frequencies (t-test; P= 0.36)

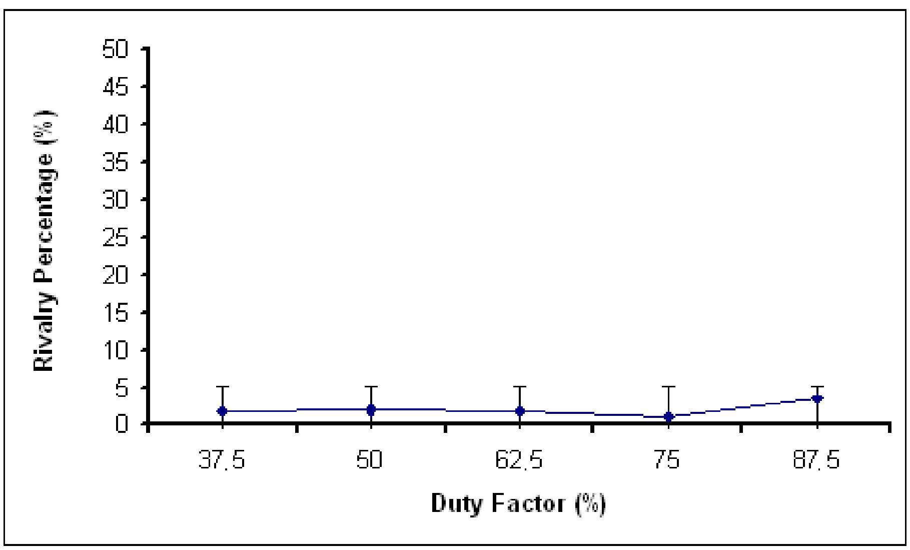

Figure 5.4 Duty factor vs rivalry percentage graph. Error bars indicate standard deviation.

The figure 5.4 is duty factor versus rivalry percentage graph. No significant effects were found. The Table 5.5 shows the average rivalry percentages and their standard deviations for different duty factors.

Table 5.5
The average rivalry percentages and standard deviations for different duty factors.

Duty Factor (%)	37.5 %	50 %	62.5 %	75 %	87.5 %
Average (%)	1.83	1.99	1.86	0.95	3.47
Standard deviation (%)	3.18	2.70	2.78	1.71	4.98

The luminance of the square (black/white) and the position of it (right/left) were other two factors that were tested in the experiment. From the ANOVA results, it was found that they do not effect rivalry time.

The aim of the second experiment was to determine the frequency and the duty factor value that minimizes rivalry time and maximizes stimulus on-time. The results showed that normalized rivalry time do not depend on the frequency or duty factor. Therefore in order to maximize stimulus on-time, the frequency and duty factor value that provided maximum stimulus on-time may be selected in future experiments as 0.25 Hz and %87.5 duty factor.

Moreover, the rivalry time in static movies and flickering movies can be compared. The mean rivalry percentage value of static movies was 12.49 % ± 10.09 % (mean ± SD, n=16). The mean rivalry percentage value of flickering movies was 1.97 % ± 3.30 % (mean ± SD, n=240). Without the outlier subject, the mean rivalry percentage value was 1.77 % ± 2.68 % (mean ± SD, n=200). The rivalry time in flickering stimuli is found to be significantly different from the rivalry time of static stimuli (t-test; $P < 0.005$).

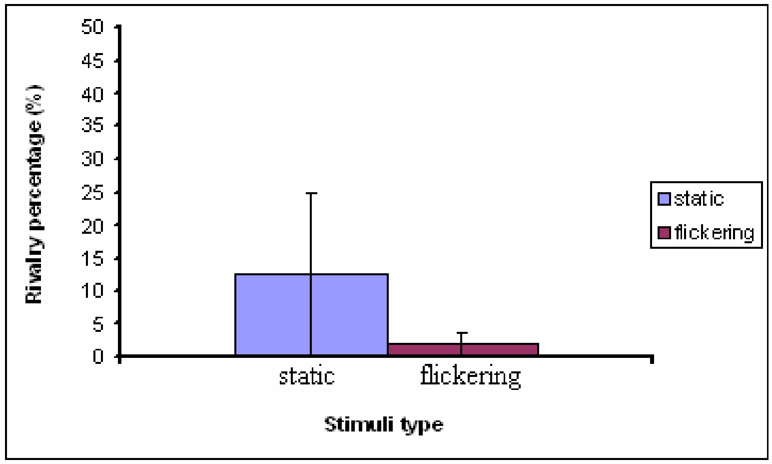

Figure 5.4 Rivalry percentages of static and flickering movies

5.3 Third Experiment : Target with Different Size and Luminance

In the third experiment the frequency of all movies was 0.25 Hz and duty factor was fixed as 87.5 %. In this experiment, the effect of target size and luminance was tested. The gray level of the target was 25 % (24.2 cd/m^2), 50 % (21.3 cd/m^2) or 75 % (18.3 cd/m^2). The size of the target was 2.5cm, 5 cm or 7.5 cm. The other two factor were same as previous experiment; the luminance of the square and the position of it.

Four-way ANOVA was done in Matlab in order to find out the effects of the factors on the rivalry time. The results are given in the Table 5.6.

Table 5.6

Four-way ANOVA results of the third experiment. X1 is the size of the target, X2 is the gray level of the target, X3 is the luminance of the square and X4 is the position of the square. There are not any significant interactions or main effects

Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	4.27	2	2.1353	0.11	0.8981
X2	26.85	2	13.4243	0.68	0.5099
X3	0.47	1	0.4674	0.02	0.8782
X4	3.68	1	3.6751	0.19	0.6676
X1*X2	137.92	4	34.4792	1.74	0.1439
X1*X3	37.5	2	18.7511	0.94	0.3909
X1*X4	31.1	2	15.55	0.78	0.4585
X2*X3	26.65	2	13.3262	0.67	0.5124
X2*X4	0.49	2	0.2469	0.01	0.9876
X3*X4	12.05	1	12.0545	0.61	0.4369
X1*X2*X3	32.98	4	8.2449	0.42	0.7975
X1*X2*X4	33.2	4	8.3003	0.42	0.7955
X1*X3*X4	18.42	2	9.2087	0.46	0.6297
X2*X3*X4	29.47	2	14.7365	0.74	0.4775
X1*X2*X3*X4	46.54	4	11.6348	0.59	0.6732
Error	3574.2	180	19.8566		
Total	4015.79	215			

Constrained (Type III) sums of squares.

There are no interactions or main factor effects on the rivalry time. The pooled data is presented in Figure 5.6 and Figure 5.7.

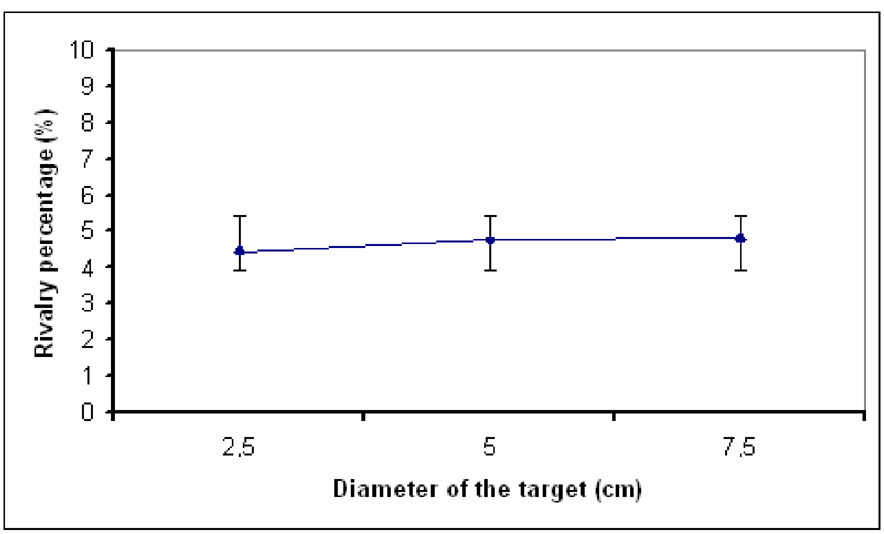

Figure 5.6 Diameter of the target vs rivalry percentage graph. The rivalry time do not depend on the diameter of the target (ANOVA; P= 0.89)

The rivalry percentage for the disc with 2.5 cm diameter was 4.46 % ± 3.64 % (mean ± SD, n=72), with 5 cm diameter was 4.74 % ± 4.37 % (mean ± SD, n=72) and with 75 % gray level was 4.78 % ± 4.90 % (mean ± SD, n=72).

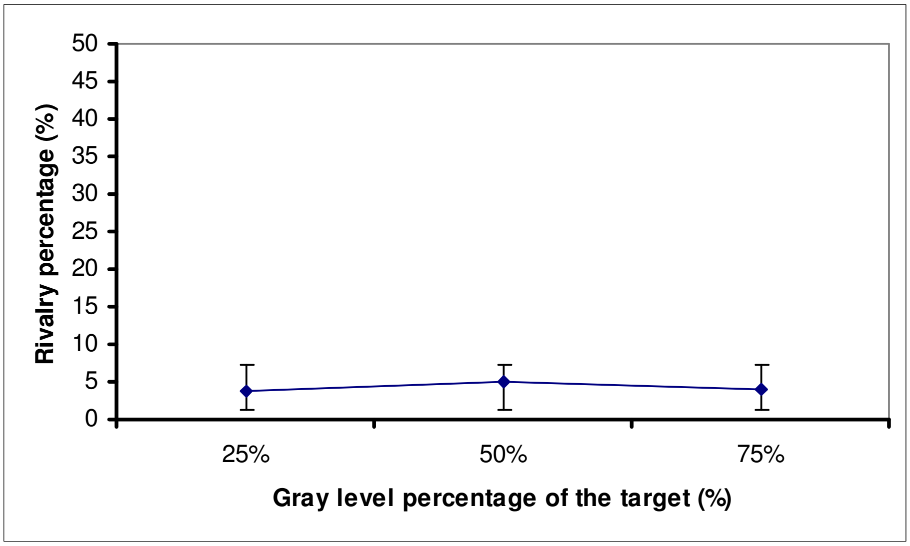

Figure 5.7 Gray level percentage vs rivalry percentage graph. The rivalry time do not depend on the luminance of the target (ANOVA; p = 0.50)

The rivalry percentage for the disc with 25 % gray level was 4.49 % ± 3.83 % (mean ± SD, n=96), with 50 % gray level was 5.15 % ± 5.48 % (mean ± SD, n=96) and with 75 % gray level was 4.17 % ± 3.36 % (mean ± SD, n=96).

6. DISCUSSION

In the present study effects of various parameters on binocular rivalry were tested. However, the stimuli used in the experiments were not horizontal and vertical gratings that were used in classical rivalry experiments. A disc and a square were rival targets in this study. Moreover, the luminance of the square was 0 % (white) and 100 % (black). In order to study eye asymmetry effects, the locations of the target disc and square were interchanged. This type of stimuli was chosen because a long-term goal of this study is to be helpful for binocular contrast experiments.

Furthermore, the image sizes were larger than the usual rivaling stimuli. For large rival stimuli, one experiences mostly a patchwork of the images of both eyes rather than alternating periods of exclusive dominance of one eye's view [17].

6.1 The Type of Rivalry

Although the subjects experienced rivalry, they reported that the target disc was much of the time superimposed on the square, without any noise inside it. According to piecemeal rivalry, a dynamic patchwork should have been seen. Since the disc was usually clearly superimposed on the square, the phenomenon that the subjects experienced can be false fusion. In false fusion, dissimilar monocular images appear to be fused for some period after their presentation because the brain needs some time to realize that the images are incompatible [6]. However, prolonged viewing of the images leads to binocular rivalry. Besides, in the false fusion, there is complete superposition of the two images. In this study, the disc was superimposed on the square with some background noise around it. Furthermore, the amount of noise was temporally changing. This condition is not consistent with the false fusion definition. Here the superposition is quite different. For example, in the case where left eye sees a black square and right eye sees the gray disc, in the center, the gray disc and the black of the square competes and gray disc can be superimposed on the square without any noise inside it. However, outside the disc region, the background noise and the black of the square are incompatible and the result is a dynamic patchwork. One reason for that can be the fact that foveally seen images are represented with high visual acuity. Here the disc is smaller than the square and the contours emphasize it. The region outside the disc becomes “unnoticed” compared to the center of the images. Therefore, the dissimilar monocular images are not simply combined in a manner equivalent to that occurring with matched monocular images. It was found that binocular matching can be accomplished in a fraction of a second [6]. For that reason, the visual system, which realizes incompatible stimulation quickly, generate a neural response which is quite different from that associated with compatible stimuli.

6.2 Temporal Dynamics of Rivalry

In the static stimuli experiment, the binocular rivalry times were high as expected. The dominance and suppression periods were random. When flickering stimuli were used rivalry times decreased. However rivalry time was not found to be statistically dependent on the frequency and on the duty factor. The reason of decrease in the rivalry time should have resulted from the fact that flickering is a transient that disturbs rivalry whatever the frequency and duty factors are.

The location of the square and the disc were interchanged in order to test eye asymmetry effects. No effects were found. Therefore, it can be concluded that the rivalry time do not depend on the eye of the subject. Neither the size nor the luminance of the disc was found to affect binocular rivalry time.

The results of this study showed that binocular rivalry incidence is reduced with this type of stimuli (a disc and a square). Therefore it can be used in binocular contrast matching experiments and the results can be compared to with previous contrast experiments.

7. CONCLUSION

Flickering stimuli decreases the rate of rivalry compared to the static stimuli. However, the frequency and the duty factor have no effect on the rivalry time. Moreover, the size and the luminance of the rival target do not change the rivalry percentages. No eye asymmetry effect was found.

The stimuli type used in this experiment is found not to eliminate rivalry but reduce its probability and retards its onset of exclusive dominance of one monocular image. In stead of this, it showed that the target disc can be superimposed on the square without any rivalry but the surrounding of the disc and the square produces a rivaling dynamic patchwork. Therefore neither the false fusion nor the piecemeal rivalry occurs completely.

This type of stimuli can be used for binocular contrast experiments since the rivalry percentage is found to be reduced in flickering stimuli.

Additionally, the results of this study can be used as controls for future studies with schizophrenic patients in order to compare binocular rivalry alternation rate.

REFERENCES

1. Kandel, E.R., Schwartz, J.H., Jessell, T.M., *Principles of neuralscience, 3rd ed.,* Appleton& Lange, USA, 1991.

2. Blake, R., 'A primer on binocular rivalry, including current controversies,' *Brain and Mind,* Vol. 2, pp. 5-38, 2001.

3. Munoz, D. P., Armstrong, I. T., Hampton, K. A., and Moore, K. D. 'Altered control of visual fixation and saccadic eye movements in attention-deficit hyperactivity disorder,' *J. Neurophysiol.* 90, 503-514 2003.Available: http:/brain.phgy.queensu.ca.

4. O'Shea, Robert P., Blake, R., 'Dichoptic temporal frequency differences do not lead to binocular rivalry,' *Perception& Psychophysics,* Vol. 39, pp. 59-63, 1986.

5. Logothetis, Nikos K., Leopold, David A., Sheinberg, David L., 'What is rivaling during binocular rivalry?,' *Nature,* Vol.380, pp. 621-625, 1996.

6. Tong, F., 'Competing theories of binocular rivalry: A possible resolution,' *Brain and Mind*, Vol.2, pp.55-83, 2001.

7. Whetstone, C., 'Contributions to the physiology of vision.Part the first. On some remarkable, and hitherto unobserved, phenomena of binocular vision,' Vol. 128, pp. 371-394, 1838.

8. Wikipedia, The free encyclopedia,'Monocular Rivalry,'2006. Available: http:/en.wikipedia.org.

9. Meenes, M., 'A phenomenological description of retinal rivalry', *Amer. J. Psychol.* Vol.42, pp.260-269, 1930.

10. Blake, R., O'Shea, R.P., Mueller, T.J., 'Spatial zones of binocular rivalry in central and peripheral vision,' *Visual Nueroscience*, Vol.8, pp. 469-478, 1992.

11. O'Shea, R.P., Sims, A.J.H., Govan, D.G., 'The effect of spatial frequency and field size on the spread of exclusive visibility in binocular rivalry,' *Vision Research*, Vol. 37, pp. 175-183, 1997.

12. Blake, R., Yang, Y., Westendorf, D., 'Discrimanting binocular fusion from false fusion,' *Investigative Ophthalmology & Visual Science*, Vol.32, pp. 2821-2825, 1991.

13. Blake, R., Westerndorf, D., Fox, R., 'Temporal perturbations of binocular rivalry,' *Perception & Psychophysics*, Vol.48 (6), pp. 593-602, 1990.

14. Mueller, T. J., Blake, R., 'A fresh look at the temporal dynamics of binocular rivalry,' *Biological Cybernetics*, Vol.61, pp. 223-232, 1989.

15. Bonneh, Y., Sagi, D., Karni, A., 'A transition between eye and object rivalry determined by stimulus coherence,' *Vision Research*, Vol.41, pp. 981-989, 2000.

16. Kovacs, I., Papathomas, T.V., Yang, M., Feher, A. 'When the brain changes its mind: Interocular grouping during binocular rivalry,' *Proc.Natl.Acad.Sci.USA*, Vol. 93, pp. 15508-15511, 1996.

17. Pearson, J., Clifford, C.W.G., 'Determinants of visual awareness following interruptions during rivalry,' *Journal of Vision,* Vol.4, pp. 196-202, 2004.

18. Leopold, D. A., Logothetis, N. K., 'Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry,' *Nature,* Vol. 379, pp. 549-553, 1996.

19. Roeber, U., Schröger, E., 'Binocular rivalry is partly resolved at early processing stages with steady and with flickering presentation: a human event-related brain potential study,' *Neuroscience Letters,* Vol. 371, pp. 51-55, 2004.

20. Weert, C.M.M., Snoeren, R.P., Koning, A., 'Interactions between binocular rivalry and Gestalt formation,' *Vision Research,* Vol. 45, pp. 2571-2579, 2005.

21. Kolb, H. Simple anatomy of the retina, 2005. Available: http:/webvision.med.utah.edu/sretina.

22. Frecska, E., White, KD., Luna, LE., 'Effects of ayahuasca on binocular rivalry with dichoptic stimulus alternation,' *Psychopharmacology (Berl)* , Vol.173, pp. 79-87, 2004.

23. Andersen, S. M., A hybrid neural network model of binocular rivalry, 2004. Available: http:/www.stenmorten.com/CogSci/readings.htm.

24. Lions Eye Health Program, 2006 Available: http://www.lehp.org/diseases.htm, Lions Eye Health Program.

25. Blake, R., Fox, R. and Westendorf, D., 'Visual size constancy occurs after binocular rivalry,' *Vision Research*, Vol.14, pp.585-586, 1974.

26. Palmer, S.E., *Vision Science photons to phenomenology,* The MIT press, England, 1999.

27. Blake, R., Yu, K., Lokey, M. and Norman, H., 'Binocular rivalry and visual motion,' *J.Cogn. Neuroscience,* Vol.10, pp. 46-60, 1998.

28. Blake, R., Lee, S., 'Rival ideas about binocular rivalry,' *Vision research,* Vol.39, pp.1447-1454, 1999.

29. Lehky, S.R., Blake, R., 'Organization of binocular pathways: Modelling and data related to rivalry,' Neural Computation, Vol.3, pp.44-53, 1991.

30. Fox, R., 'Rate of binocular rivalry alternation in psychotic and nonpsychotic patients,' Journal of Abnormal Psychology, Vol.70, pp.34-37, 1965.