Differences in the Chromatic Visual Event Related Potentials in Number and Non-number Plates of the Ishihara Colour Vision test

By

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Perbezaan potensi acara berkaitan visual kromatik dalam nombor dan bukan nombor daripada ujian penglihatan warna Ishihara

Oleh

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ERP	Event Related Potential
EEG	Electroencephalography
USM	Universiti Sains Malaysia
HUSM	Hospital Of Universiti Sains Malaysia
P	Positivity polar
N	Negativity Polar
PFC	Prefrontal Cortex
V4	Fourth Visual Area in Visual Cortex
WM	Working Memory
KCL	Potassium chloride
MS	Miliseconds
μV	Microvolt
ASCII	American Standard Code for Information Interchange
ISI	Inter-Stimulus Intervals
Sec	Seconds
GSN	Geodesic Sensor Net
RT	Reaction Time
Cm	Centimetre
Hz	Hertz
SPSS	Statistical Package for the Social Science

ABSTRACT

Event-related potentials (ERPs) are very small voltages existed within the brain structures in response to particular events or stimuli. Ishihara colour vision test is a test that made of a number of coloured plates that might be either number plates or non- number plates. In a recent study, we looked for the differences of chromatic visual ERPs in number and non-number plates during visual presentation session in trichromatic participants to discover furthermore about which plate design can elicit more cognitive processes like attention and memory wherein these differences might be used as a new clinical knowledge, which might be applicable clinically in the future. A total of 25 participants both males and females were used for our study. All of them were apparently healthy with normal colour vision. Firstly, we recorded the electroencephalography (EEG) when participants attended to the lab in the Hospital of Universiti Sains Malaysia (HUSM) from 19 electrode sites using 128 electrode sensors net which were applied on the participant's scalp according to 10-20 international electrode placement system. Then, we recorded ERPs through presenting a visual oddball task of number and non-number plates in a random order at inter-stimulus intervals (ISI) of 2 seconds. The latency and amplitude of the evoked N100, N200, P200 and P300 components were identified. To determine the statistical significance, the amplitude and latency of all components and the reaction time (RT) was analysed by using paired-t test. The results showed higher amplitudes of N100, P200 and N200 ERP components for number plates indicating that the participants had greater visual selective attention, visual searching perception and visual identification for number plates as compared to non- number. The results of longer latencies of N200 and P300 ERP components and the higher amplitude of P300 for non-number plates signifying that the participants were taking more time to identify and distinct visually the non- number plates and delaying in cognitive processing and attention for non- number plates as compared to number plates. About RT, the results showed

significant increasing in mean of the non- number plates as compared with number plates indicating that the participants responded to number plates faster than non- number plates. Therefore, we concluded that besides colour vision tests, in research fields, the plates of Ishihara colour vision test could be potentially used in studies that deal with cognition, attention and memory which has been evidenced through the differences of the latencies and amplitudes of N100, P200, N200 and P300 ERP components in number and non-number plates viewing in our study. The findings of this study might be translatable clinically in patients with neuropsychological and attention disorders to discover new findings that might give benefits to the patients, medical researchers and clinicians in the future.

Abstrak

"Event- related potentials" (ERP) merupakan voltan rendah yang wujud dalam struktur otak hasil tindakbalas sesuatu stimuli atau kejadian. Ujian warna Ishihara mengandungi beberapa plat berwarna samada plat bernombor atau plat bukan nombor. Dalam kajian yang terbaru, kami melihat kepada perbezaan visi kromatik ERP dalam plat bernombor dan plat bukan nombor semasa sesi paparan visual kepada peserta trikromatik untuk mengesan rekabentuk plat yang boleh merangsang proses kognitif seperti memori dan perhatian. Perbezaan ini seterusnya boleh digunakan sebagai pengetahuan klinikal yang baru dan boleh diaplikasi di masa hadapan. Seramai 25 orang peserta lelaki dan perempuan terlibat dalam kajian ini. Kesemua peserta mempunyai penglihatan warna yang normal dan berada dalam keadaan yang sihat. Elektroencephalograph (EEG) peserta direkodkan semasa peserta datang ke makmal Hospital Universiti Sains Malaysia. Sebanyak 19 tapak elektrod direkodkan menggunakan 128 elektrod net sensor yang diletakkan pada kepala peserta mengikut 10-20 sistem penempatan elektrod antarabangsa. ERP direkodkan menerusi paparan visual plat bernombor dan plat tidak bernombor yang berbeza secara rawak pada selang antara stimulus (ISI) selama 2 saat. Kependaman and amplitud komponen N100, P200 dan N200 yang dicetuskan dikenalpasti. Untuk menentukan kepentingan secara statistik, amplitud dan kependaman semua komponen di analisis menggunakan ujian berpasangan T dan Reaksi Masa (RT) juga dianalisis dengan ujian berpasangan t. Keputusan menunjukkan komponen ERP N100,P200 dan N200 bagi plat bernombor mempunyai bacaan amplitud yang lebih tinggi. Ini mencadangkan bahawa peserta mempunyai perhatian terpilih, persepsi pencarian visual dan pengenalan visual untuk plat bernombor berbanding dengan plat tidak bernombor yang lebih tinggi. Keputusan dari tempoh kependaman yang lebih lama untuk komponen ERP N200 dan P300 dan amplitude P300 yang lebih tinggi untuk plat tidak bernombor menunjukkan bahawa peseta mengambil masa lebih lama untuk mengenalpasti secara visual

plat tidak bernombor dan menyebabkan proses kognitif dan perhatian yang lebih lambat untuk plat tidak bernombor berbanding dengan plat bernombor.Keputusan untuk reaksi masa pula menunjukkankan terdapat peningkatan yang signifikan dalam min plat tidak bernombor dengan plat bernombor. Oleh itu, kami membuat kesimpulan bahawa dalam bidang kajian, penggunaan ujian warna Ishihara berpotensi untuk digunakan dalam kajian yang melibatkan kognisi, perhatian dan memori selain daripada digunakan untuk ujian visi warna. Bukti untuk kesimpulan ini boleh dilihat daripada perbezaan bacaaan kependaman dan amplitud komponen ERP N100, P200 dan P300 dalam pemerhatian kajian kami ke atas plat bernombor dan tidak bernombor. Keputusan kajian ini mungkin dapat digunapakai secara klinikal untuk pesakit yang mempunyai gangguan neuropsikologikal dan perhatian bagi mendapatkan penemuan baru yang mungkin boleh memberi manfaat kepada pesakit, penyelidik perubatan dan ahli Klinikal pada masa hadapan.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

1.1.1 Cognition

In a simple way, we can define the cognition as a mental process of knowing. Specifically, it is the mental process in which the inputs either internal or external are transformed, minimized, elaborated, stored, retrieved, and then utilized (Neisser, 1967). The cognition includes a diversity of functions like perception, attention, imaging, problem-solving, making a decision, reasoning, memory coding and recall, planning and executing action (Barsalou, 2014; Maria A. Brandimonte *et al.*, 2006; Mayzner, 1977). The study of how persons perceive, learn, remember, and think about such information like colours, shapes or learning language is called cognitive psychology(Anderson, 1990; Tversky and Kahneman, 1973).

In a term of body- mind association, cognitive neuroscience is the study that links the brain and other nervous system to cognitive processing and, eventually, to behaviour. The brain is the part in our bodies that most directly controls our thoughts, motivations, behaviours and emotions. Through nervous system in general, we have the ability to perceive, acclimate to, process, respond and interact with the external environment around us (Gazzaniga *et al.*, 1998; Robert J. Sternberg and Karin Sternberg, 2012; Rosenzweig and Leiman, 1989).

Anatomically, the cerebrum has a main role in human cognition, especially the prefrontal cortex (PFC) and the hippocampus. The PFC is included in higher-level cognitive processes under the name of executive functions that involve the keeping of attention, the regulation of inputs from many sensory modalities and the monitoring of information in working memory (WM) (Gazzaniga *et al.*, 2002; Jurado and Rosselli, 2007; Teffer and Semendeferi, 2012). Moreover, the PFC in its lateral region particularly specializes in the temporal forming of new and complex goal directed actions (Fuster, 1997; Luria, 1966). The PFC participates in the choice between alternatives in decision making, and in executing temporally formed action, therefore, this participation makes this cortex to be considered as "central executive''(Fuster, 2002; Müller *et al.*, 2002).

In addition to PFC, the hippocampus has an essential role in associative representations, in which the hippocampus is activated during the encoding of multiple elements and is more activated when participant is required to link the elements to one another (Aggleton *et al.*, 2007; Cohen *et al.*, 1999; Eichenbaum, 2004). Furthermore, the amount of hippocampal activation throughout the comparison and linkage of the elements predicted a good ability in recognition. The hippocampus also enables to demonstrate the way of where things are and how these things are spatially related to each other (Howland *et al.*, 2008; Robert J. Sternberg and Karin Sternberg, 2012). This function of hippocampus is known as relational memory. It is a memory for relations among the constituent elements, giving the ability to remember for example names with faces, the locations of different objects or individuals, or the order in which such events occurred. In our study as an example, the participants tried to recognise, differentiate and remember the plates with number design from the plates with non-number design of Ishihara colour vision test(will be discussed later on) during the presentation of plates.

1.1.2 Selective Attention

To a great degree, we live in stimulating world that contains a variety of stimuli around us. To be adapted in this complex world, we want to filter out behaviourally irrelevant, unimportant stimuli and selectively attend to relevant and most matter stimuli. So basically, selective attention is the process of focusing on relevant (target) information and neglecting irrelevant (distractor) information in the environment for a certain period of time (Eleftheria Kotsopoulos, 2009; Keulen *et al.*, 2002; Pashler and Sutherland, 1998). The selective attention has an important role in regulating cognitive processes (Miller and Cohen, 2001). Once we face plenty of sensory information and competition of response possibilities, the selective attention can facilitate the selection of the convenient response and that will be happened by filtering the information in the environment and guiding cognitive resources in the direction of the processing of goal-relevant information(Desimone and Duncan, 1995; Knudsen, 2007; Yuan Chang Leong, 2013).

In general, the selective attention which might be auditory or visual. Regard visual selective attention which is more significant in our study to discussing about, visual selective attention improves the visual perception and performance when we look at and pay attention to certain visual stimuli by modulation of sensory inputs at the early stage of visual processing (Mangun, 1995). The mechanisms of selective attention in humans mainly explored by measuring the effect of attention on performance. The visual selective attention is usually examined using visual reaction time tasks, for instance, the changes in reaction time (RT) to visual stimuli are considered as a function of attention so, the participants are faster to respond to stimuli at expected (attended) versus unexpected (unattended) visual stimuli (Moore and Zirnsak, 2017; Posner *et al.*, 1978). The core stone in the field of visual attention is determining when selection of relevant information justly take places. There are two theories regard the selection of information.

First one is early selection theories and second one is late selection theories. Early selection theories propose that just goal-relevant information is selected for attentional filter and further processing which take places soon after presentation of the information and irrelevant information is processed in a preparatory way or not at all and consequently does not affect upon goal-relevant behaviour (Cherry, 1953; Sperling, 1960). In contrast to early selection theories, late selection theories propose that the goal-irrelevant information is filtered out and the goal-relevant is selected just after all information have undergone full processing (Deutsch and Deutsch, 1963; Eleftheria Kotsopoulos, 2009).

Additionally to the theories of the selection of information, there are three attention networks that carry out special functions: alerting, orienting, and executive attention. The alerting network regulates the general condition of responsiveness to sensory stimulation. The orienting network selects a subdivision of sensory information for favoured processing. The executive attention network controls the thoughts and behaviours in adaptive manners. Executive attention is constantly required for making decisions, planning, the response is new or not well-learned, correcting mistakes and if the situations are dangerous (Daryl Fougnie, 2008; Fan *et al.*, 2005; Posner and Boies, 1971).

Top-down modulation refers to a modulation of neural activity in neurons, especially in lower-order sensory or motor areas depends on the intentional goals of subject. Top-down modulation handles the ability of attention by increasing activity in sensory areas for things that are relevant to goals and inhibiting activity for things that are irrelevant to goals. (Gazzaley and Nobre, 2012; Reynolds and Chelazzi, 2004)

1.1.3 Visual Perception

The dissecting an image into its different components and analyses them in various parts of the brain is one of the more interesting features of the visual system.Society of Dyers & Colourists (2004) and Kosslyn and Osherson (1995), reported that the visual perception is the process where we use our vision to obtain information about the surrounding environment or to recognise certain visual stimuli. There are four different aspects in which the people visually can perceive the world: brightness, movement, shape and colour. Visual perception is based on an inter communication between the eye and the brain(DeYoe and Van Essen, 1988; Köhler *et al.*, 1995).

According to how the visual information have been analysed, there are two pathways for visual analysis; the magnocellular and parvocellular pathways which are the main pathways of the visual system. These two common pathways represent many axons that leave the retina through the brain for the perception of vision, and as a result of their destruction, the vision will be lost (Liu *et al.*, 2006; Schiller *et al.*, 1990). Parvocellular ganglion cells are found mostly in the fovea. There are a one-to-one relation that found between the cones of the fovea and the ganglion cells, i.e. each cone is independently connected by a fibre in the optic nerve (PUMPHREY, 1948).

Parvocellular ganglion cells contains circular receptive fields which are small and sensitive to colour. These properties are suitable for the parvocellular system for the discrimination of fine detail and colour (Derrington and Lennie, 1984; Livingstone and Hubel, 1988). In contrast to parvocellular ganglion cells, magnocellular ganglion cells consist of large circular receptive fields that are sensitive to brightness and respond just in brief to stimulation. As an outcome of these properties, the magnocellular ganglion cells is specialized for brightness contrast and for motion (Graham, 1965; Ungerleider and Haxby, 1994)

1.1.4 Colour Vision

Basically and briefly, the trichromatic theory of colour vision depends on the presence of three types of receptors (cone cells), approximately sensitive to the red, green, and blue. Each cone cell has a distinct spectral sensitivities. The way of activity within the three mechanisms produces the perception of a certain colour (Coren, 2003; Kaiser and Boynton, 1996; Wald, 1964). Indeed, it depends on the results of a psychophysical mechanism called colour matching. Interestingly, one of the aspects of this theory is the possibility of matching all of the colours in the visible spectrum by convenient mixing of three primary colours (Linda Johansson, 2004). Each type of the three receptors consists of a different photo pigments, wherein the photo pigments are embedded in the infolded membranes of receptor cells that react to light, then initiate receptor potentials in the visual pathways (Boynton, 1979; Mollon, 1986).

The colour appearance significantly affected by many of cognitive visual mechanisms. These cognitive visual mechanism involve memory colour, colour constancy, discounting the illuminant, and object recognition. Memory colour assigns to the observable objects usually have a prototypical colour that is related with those objects. Colour constancy assigns to the everyday perception of the colours of objects is still unchanged even with significant changes in illumination colour and luminance level. Colour constancy is provided by the mechanisms of chromatic adaptation and memory colour. Discounting the illuminant assigns to an observer’s ability to spontaneously clarify the illumination conditions and perceive the colours of objects after the effects of illumination colour becomes discounted. Object recognition is mostly controlled by the spatial, temporal, and light– dark properties of the objects instead of chromatic properties. In this matter, once the objects are recognized, the mechanisms of both memory colour and discounting the illuminant can provide an appropriate colour (Arend *et al.*, 1991; Fairchild, 2005; Schirillo *et al.*, 1990).

1.1.5 Ishihara colour vision test

The Ishihara colour vision test is a test that made of coloured plates. The full test comprises of 38 plates, and each plate is a circle in shape which consists of a combination of primary and secondary dots. The primary dots are usually organised in a simple pattern that represent mostly a number like 7 or sometimes represent a non- number shape like thread, while the secondary dots are considered as a background of the plate. The plates are designed to be utilized correctly in a room, which is lit sufficiently by daylight. (Belcher *et al.*, 1958; Ishihara, 1960; Ishihara, 2001). Computerized or computer controlled Ishihara colour vision test have been suggested since 2002 with the goal of making this test more readily available (Richmond Products, 2012).

The most common indications for the test are protanopia or protanomaly which means missing or weakness of L-cone (red) and deuteranopia/deuteranomaly which means missing or weakness of M-cone (green) defects but it is not considered as a diagnostic test. The test does not screen for tritanopia/tritanomaly which means missing or weakness S-cone (blue) defects and is convenient for congenital colour blindness whilst inconvenient for testing acquired defects (Sharpe *et al.*, 1999; Smith and Pokorny, 1996).

All participants are asked to seat at a distance of 1 meter from the plates either if the plates presentation is hand held or on a computer. The examiner instructs the participant to tell him about the numbers that he can see while the examiner turns the pages. As well, the examiner tells the participant if you do not see the plate, I will turn to the next page. The examiner keeps control of the viewing time. Four seconds are approximately allowed for each plate. The healthy participant must be able to recognise primary dots correctly. Any participant who recognise two or more of plates wrongly is classified as impaired colour vision (Dain, 2004; Health and Safty Executive, 2005).

1.1.6 Event Related Potential (ERP)

Electroencephalogram (EEG) is the first method developed for direct and non-invasive measurements to evaluate brain activity from human subjects (Adrian and Yamagiwa, 1935; Berger, 1929; Jasper, 1937). Once certain stimuli are presented and tasks are performed, the raw EEG seems to characterize the changes in the state of electrical activity during sensory processing and the performance of simple-detection tasks (Walter, 1938; Woodman, 2010). Event-related potentials (ERPs) are very small voltages existed within the brain structures in response to particular events or stimuli (Blackwood and Muir, 1990; Cacioppo *et al.*, 2007; Kropotov, 2010; Luck, 2014). The ERP are considered as EEG changes which are time locked to sensory, motor or cognitive events; so they can be evoked by a broad diversity of sensory, cognitive or motor events (Handy, 2005; Petten *et al.*, 2005; Sur and Sinha, 2009).

The ERPs are an electrophysiological recording techniques which is generally safe, non-invasive and relatively inexpensive tool to study psychophysiological correlates of mental processes (Picton *et al.*, 1995). In spite of other modern neuroimaging methods, several advantages of the ERPs techniques carry on to make it one of the most frequent tools of choice for investigating the role of brain in the cognitive processing in various populations (Nelson *et al.*, 1998). The ERP waveforms are typically named under terms of positive (P) and negative (N) peaks and their approximate latency in milliseconds (ms) (Ibanez *et al.*, 2012; Kuperberg, 2008). For example, P100 ERP component refers to a positive deflection of the signal with a peak around 100 ms while N100 ERP component refers to a negative deflection of the signal with a peak around 100 ms. The ERP components are typically measured by the peak latency that measured by milliseconds (ms) or by peak amplitude that measured by microvolts (μV) (Treleaven-Hassard *et al.*, 2010).

Many various stimuli can elicit either auditory or visual ERPs. Regarding visual ERPs, the ERPs have been used to study like perception of colour and form (Rentzeperis *et al.*, 2012), attention (Rauss *et al.*, 2011), visual awareness (Grassini, 2015), facial expression processing (Luo *et al.*, 2010) and affective processing (Olofsson *et al.*, 2008). In the next section, we will describe the ERP components that used in our study.

1.1.7 N100 ERP component

N100 or sometimes known as N1 is a negative deflection which has a peak around 90-200 ms after the onset of stimulus (Başar, 2004; Sur and Sinha, 2009). N100 is commonly observed after presentation of an unpredicted or improbable stimulus (Ibanez *et al.*, 2012). In general, N100 is supposed to reflect selective attention to basic stimulus characteristics, initial selection for later pattern recognition, and voluntary discrimination processing (Rugg *et al.*, 1987; Vogel and Luck, 2000). It is a matching process; that's mean, whenever certain stimulus like colour or shape is presented , this stimulus will be matched with previously experienced stimuli (Delb *et al.*, 2008).

1.1.8 P200 ERP component

P200 or sometimes known as P2 is a positive deflection which has a peak around 100-250 ms after the onset of stimulus(Kenemans *et al.*, 1993; Stelt *et al.*, 1998). The P200 is typically evoked as a portion of the normal response to visual stimuli(Shelley *et al.*, 1991). The P200 is strongly associated with secondary processing of visual stimuli (Golob and Starr, 2000; Portella *et al.*, 2012). Commonly, P200 is assumed to reflect the sensation-seeking behaviour or sometimes known as visual searching perception and attention (Barceló *et al.*, 1997). Thus, the P200 component is evoked during the visual search paradigm that tests attention, response selection and feature detection. So, the P200 component might be considered as an indicator of mechanisms for feature detection like colour, orientation, shape and other early stages of item encoding (Lee *et al.*, 2012; Luck and Hillyard, 1994).

1.1.9 N200 ERP component

N200 or sometimes known as N2 is a negative deflection which has a peak around 200-350 ms after the onset of stimulus (Du *et al.*, 2014; Folstein and Van Petten, 2008). The negativity of N200 is a result from a deviation in form of a prevailing stimulus (Patel and Azzam, 2005). The elicitation of may be accomplished through an visual oddball paradigm (Hoffman, 1990). Interestingly, the N200 component is usually evoked before the motor response, suggesting its link to the cognitive processes of stimulus identification and distinction (Donchin *et al.*, 1978; Ritter *et al.*, 1983). The N200 in relation to visual stimuli has been identified to vary based on the task type and stimulus type, for instance written words, pictures of objects, or human faces (Key *et al.*, 2005).

1.1.10 P300 ERP component

P300 or sometimes known as P3 is a positive deflection which has a peak around 300 ms after the onset of stimulus (Picton, 1992; Smith *et al.*, 1970). The P300 is considered as the major component extensively in the field of ERP (Sutton *et al.*, 1965). The elicitation of much larger P300 ERP component mostly due to infrequently occurring stimulus classifications than for frequently occurring stimulus classifications (Desmedt, 1980; Hansenne, 2000). Furthermore, the elicitation of P300 ERP component is also observed in the oddball paradigm, in which the visual oddball stimuli evoke larger P300 (Patrick *et al.*, 2006). Additionally, the elicitation of much larger P300 ERP component was observed when the subject is paid an attention and respondent (overtly or covertly) to the stimuli (Polich *et al.*, 1994). Generally, the P300 is assumed to reflect cognitive processing associated with attention and memory mechanisms (Donchin *et al.*, 1978; Polich and Kok, 1995) .

1.2 Objectives of the study

General:

To study the differences of visual event related potentials (ERPs) during presentation of both number and non-number colour Ishihara plates in participants with trichromatic vision.

Specific:

1. To determine the latency and amplitude of N100 & P200 as early components of visual ERP among trichromatic participants during number and non-number colour plates presentation.

2. To determine the latency and amplitude of N200 & P300 as late components of visual ERP among trichromatic participants during number and non-number colour plates presentation.

1.3 Hypothesis of the study

1- The differences in latency and amplitude of N100 & P200 components might be existed during presentation of number and non-number plates of Ishihara colour test.

2- The differences in latency and amplitude of N200 & P300 components might be existed during presentation of number and non-number plates of Ishihara colour test.

1.4 Research question

1- Are there any differences in the latency and amplitude of N100 and P200 components of ERP during presentation of number and non-number plates of Ishihara colour vision test?

2- Are there any differences in the latency and amplitude of N200 and P300 components of ERP during presentation of number and non-number plates of Ishihara colour vision test?

1.5 Significance of the study

In this study, we are looking forward to demonstrate the differences in latency and amplitude of the chromatic visual ERP components which are N100,P200, N200 and P300, respectively during presentation of numbered and non-numbered plates of Ishihara colour test in healthy individuals with normal colour vision, hopefully, to discover furthermore about the cognitive processes in those differences in the chromatic visual ERP in number and non-number plates, in which the ERP technique has the ability to record electrical activity from the brain and utilise it to investigate cognitive processing. The variety of design of the plates (number or non-number) is predicted to establish different results regarding latency and amplitude of N100, P200, N200 and P300 components, respectively. Hence, the existing of differences may determine which plate would generate more attention and thinking in compare to other plate. As well, the differences may be used as a new clinical knowledge, which might be applicable clinically in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Neural Processing of Colour Vision

Colour vision is an essential feature of human perception. The visual cortex existed within the occipital lobe and contributes in processing of visual information (Goddard *et al.*, 2011). Among the visual cortex, several regions have been segregated, among these regions is the fourth visual area (V4) which is accountable for the conscious experience of colour (Schmolesky, 2000). The EEG integrated with ERP have a benefit of fine temporal resolution for precise measurement of brain response for each colour stimulus. The accurate measurement of the timing of the stimulus onset and the brain‛s response by using ERP is critical to represent temporal differential responses. By using ERP for investigation, there are possible factors that attributing to colour vision. First factor is that our visual cortex might have a chromatopography (hue topography) in V4, therefore the location of the firing neurons are accountable for colour perception (Zeki, 1980). Second factor may be due to a specific pattern of firing rate for each colour, wherein among a set of neurons, the firing pattern and frequency rates varied for various stimuli (Szatmáry and Izhikevich, 2010). Third factor is that in the visual cortex, the firing neurons might be developed to be red or blue cells to respond and process to the corresponding colour information.

Lee (2011), studied about the neural timing and patterns of colour vision, where they investigated how our brain encodes sensory information through using the colour as a target.

By using ERP, they tested 16 healthy participants aged between 18-26 years old, 3 out of 16 were male with normal colour or corrected to normal vision. They used 6 types of colour stimuli; red, green and blue in two types of luminance (light and dark for each colour) and 4 types of grapheme stimuli; an alphabet O or X on either the right or left side of the screen. The participants instructed with two main tasks: first task was viewing isoluminant coloured squares while focusing on a specific colour by pressing button (1). The second task was viewing coloured squares and graphemes while focusing on a certain grapheme to focus by pressing button (2).The results showed that the brain has a distinct pattern for each colour particular to amplitude of potential after 60 ms of onset. As well, their results gave a glance of V4 activation time and also the existence of the brain‘s mechanism to encode colours. They concluded that the encoding of colour might be regulated by the activation of different V4 neurons, the frequencies of V4 neurons, or location of the V4 neurons. Also, the colour effect on potential amplitude and activation timing varies on different activation time windows. Interestingly, between the passing of light through eyes and the perception of colour, distinct decoding mechanisms of colour sound to take place in various compartments of the brain.

2.2 ERP and Luminosity

Detection and identification of objects is the most crucial purpose of human visual perception. Object identification is a highly efficient and fast process. The visual processing lasts around 100 ms to approach high-level representational regions in the temporal cortex and this is enough for coarse and fast categorization (Liu *et al.*, 2009). The speed of object recognition sounds to a great extent be driven by luminance information. The luminance contours has a significant role; they let object representations to create an early impact on perception which assures that objects are preferentially determined figural status (Peterson, 1992; Peterson and Gibson, 1994).

Martinovic *et al.* (2011), studied about ERPs reveal an early advantage for luminance contours in the processing of objects, where they investigated the role of luminance and chromatic information regarding object processing by made a comparison on performance between familiar, meaningful object contours and novel, non-object contours. By using ERP, they tested 12 healthy participants aged between 21-40 years old, 6 out of 12 were male with normal colour or corrected to normal vision. They used 1077 pictures were obtained from existing stimulus sets. The pictures were about common, familiar and easily nameable objects from different semantic categories: ship, stapler, harmonica, grasshopper, etc. Non-objects were created by manipulating pictures of objects thus, they became unrecognizable. Full-colour stimuli consisted of both chromatic and luminance information, whilst luminance information was absent in the diminished-colour stimuli. The participants instructed to press the button once they respond to either full-colour and diminished-colour object (or non-object) contours. The results showed an advantage accuracy for full-colour stimuli over the diminished-colour stimuli but only if the contours depicted objects as opposed to non-objects. ERPs showed the neural correlate of this object-specific luminance advantage particularly with the amplitude of the centro-occipital N100 component where it was modified by stimulus class with the influence being driven by the presence of luminance information. They conclude that high-level discrimination processes in the cortex begin comparatively early and display object-selective effects only in the presence of luminance information.

2.3 Visual Processing of Colour and Motion

Two distinct functional pathways are responsible for visual processing of colour and motion, one of which processes colour (parvocellular pathway) and the other processes motion (magnocellular pathway)(Livingstone and Hubel, 1988). The processing of motion information has been suggested to be rather uninfluenced by colour (in some stages of the processing), nevertheless, it has been proposed that some magnocellular neurons respond to chromatic contrast, only without specific information about its sign (Dobkins and Albright, 1991). The colour processing mechanisms on various stages obtain their input from both magnocellular and parvocellular pathways (Shapley and Hawken, 2011). It is clear that parvocellular and magnocellular pathways are together interacted with each other and thus, the characteristics of one quality can affect the perception of the other (Cicerone *et al.*, 1995).

Murd *et al.* (2014), studied about ERPs to change in coloration of a moving bar to investigate whether the effect of motion is appeared at the cortical level of information processing by asking 7 healthy participants aged between 21-25 years old, 1 out of 7 was male with normal colour or corrected to normal vision, to detect changes in coloration of stationary and moving bars (rectangular bars were used with two colours either red or green). Their results revealed the reaction time (RT) to coloration changes was shorter for faster moving stimuli than more slowly moving or stationary stimuli. In contrary, the influence of velocity on ERPs was adverse to the result that found with RT. Unless for N100 amplitudes, the amplitudes of ERPs that evoked by the coloration change of faster moving objects were reduced than those evoked by the coloration change of slower moving or stationary objects. As well, the results showed a significant influence of velocity of the coloration changes on P200 latency only, especially in frontal region. They concluded based on previous findings, there appears to be considered that the effect of moving stimulus will be noticed on the cortical level of information processing.

2.4 Colour Differences in Adults

Visual processing is commonly included in detection of chromatic changes, for example, in case of looking for certain fruit (Mollon, 1989). There are two factors to establish, for example, a colour difference between fruit and leaves which are a simple hue difference and a category difference. The category difference has behavioural outcomes due to stimuli crossing a colour boundary (between-category) are simpler to differentiate than otherwise equally distant stimuli that drawn from among the same category (Bornstein and Korda, 1984).

Fonteneau and Davidoff (2007), studied about neural correlates of colour categories, where by using ERPs, they investigated the processing of colour difference in adults. They tested 25 healthy participants aged between 18-29 years old, 13 out of 25 were female with normal colour or corrected to normal vision. By using oddball paradigm, the task was six different blocks in which a green (G0) colour was presented in frequent or infrequent manners within different colour contexts. The participants were asked to detect infrequent cartoon icons that fixed within blocks of presented colour patches by pressing on a response button as quickly as possible. By made a comparison for the difference within the same colour category (G0 vs. green: G1) to the difference between colour categories (G0 vs. blue and G0 vs. red), the results showed a change-related positivity with similar scalp distribution. The magnitude of colour difference decreased the latencies of the change-related positivity. The change in colour category without a magnitude difference decreased the latency of ERP as well. They conclude that both colour difference and colour categorical information are utilized to discriminate visual events. In fact, colour categorization reveals to have a priority within visual analysis due to the latency of an ERP correlate was decreased compared with that of an otherwise equally distant colour discrimination.

2.5 Processing of Colour Categorization

Regard the effect of colour categories on perceptual or post-perceptual processes when same and different category colours are equally discriminable, He *et al.* (2014), stated that the colour categories can affect only post- perceptual processes when the same and different category colours are equally discriminable, where they investigated the time course of colour category influences in ERPs, when the discriminability of colours is precisely under control through the measurement of discrimination thresholds. They tested 20 healthy participants with mean age 21 years old, 2 out of 20 were male with normal colour or corrected to normal vision. By using visual oddball paradigm, there were two colour sets used from four colours (ABC or BCD). In each set, the colour in the middle was the frequent "standard" colour, and the two outer colours were the infrequent "deviant" colours. The participants were required to press the button C for standard stimulus and press the button M for deviant. Their results showed that the category effects were found only in latter ERP components like P200, N200 and P300 around 200 ms after colour presentation, which reflect post-perceptual processes like feature evaluation and context updating.

2.6 Brightness and Colour

The colour appearance of such object can be remarkably altered by the interaction between brightness and colour. Once there is colour contrast between the object and its surroundings, the object will become most colourful and most saturated with colour, but without brightness contrast. Therefore, once there is a large brightness contrast between an object and its surroundings, the saturation of perceived colour will be washed out almost totally (Faul *et al.*, 2008). So far, the interaction between colour and brightness is not clearly known where could be occurred in the cerebral cortex. One hypothesis is supposed that the colour and brightness contrast interact greatly within V1(Hurvich and Jameson, 1957).

Xing *et al.* (2015), proved the location of the interaction between brightness and colour in human V1 by chromatic visual evoked potential (cVEP). They tested 13 healthy participants aged between 17-70 years old, 8 out of 13 were male with normal colour or corrected to normal vision. They used red and green chromatic stimuli and surround luminances. The chromatic stimuli were presented five times for both red and green stimuli with five surrounds of gary background. Their results of cVEP reinforced the hypothesis that the interaction between brightness and colour emerges in a recurrent network in V1, in an inhibitory manner. Moreover, their results gave a direct electrophysiological evidence that the interaction between brightness and colour occurs very locally at the edges between the target (colour) and its surroundings. They concluded that this recurrent inhibition in local cortical circuits that found in V1 cortex has a great effect on colour perception.

2.7 Spatial Selective Attention and ERP

Neurophysiological studies of attention and also electrophysiological studies of spatial selective attention by using ERP have been proposed the existence of multiple attentional mechanisms. One of the neurophysiological studies of attention that had been studied by Moran and Desimone (1985), showed the responses of neurons in V4 were inhibited to unattended stimuli only once both the attended stimuli and unattended stimuli were located among the receptive filed of cell. Furthermore by using ERP, the attention to different stimuli resulted in changes in the ERP waveform at different latencies (Harter *et al.*, 1982). The initial effect of attention was for location (Eason *et al.*, 1969), then followed by the attention to simple features like colour, orientation and size (Harter and Guido, 1980), and followed lastly by the attention to conjunctions of features (Previc and Harter, 1982).

Luck and Yard (1995), studied to decide if the mechanisms of spatial selective attention are using during the detection of simple features and during discrimination of conjunctively determined targets. They tested 15 healthy participants with normal colour or corrected to normal vision. They used visual seeking arrays consisting of 14 grey objects and 2 coloured objects. The participants were asked to detect the presence or absence of relevant colour (detection of feature status), or the shape of relevant coloured object (the discrimination of conjunction status). The task was a presentation of the seeking arrays in which a task-irrelevant probe stimulus was flashed at the location of the relevant or irrelevant colour and the ERP elicited by this stimulus was utilized to estimate sensory processing at the probe location. Their results showed that the probes that presented at the location of the relevant colour were enhanced ERP components while the probes that presented in the opposite side of the display monitor of the relevant colour were inhibited ERP components. They conclude that these effects were noticed in both the simple feature detection and the conjunctions discrimination indicated that the spatial selective attention processes are utilised for both the simple feature detection and the conjunctions discrimination. Differently, the P100 ERP component showed these effects in the discrimination status but not in the detection status in which indicated that the conjunction discrimination uses extra attentional processes than for those needed for feature detection.

2.8 Multiple Attention in Spatial Location and Colour

Another electrophysiological study of spatial selective attention by using ERP showed the existence of multiple attentional mechanisms.

Hillyard and Münte (1984), studied to investigate whether hierarchical selections are used in a visual selective attention task in which stimuli differ in spatial location and colour (hue). They tested 14 healthy participants aged between 19-39 years old, 4 out of 14 were female with normal colour or corrected to normal vision. The task was to detect lightly smaller target vertical bars with a particular colour (red or blue) and location (right or left). The participants were asked to attend to particular coloured bars that flashed randomly to the left or right of fixation. Their results showed that the stimuli at an attended location were evoked a sequence of phasic components especially like P122, N168 and N264 which was strongly distinct from the sequence that correlated with selection on the foundation of colour especially like N150-350, P199 and P400-500. They concluded that focusing on spatial attention includes adjustment of evoked neural activity in the visual pathways, whilst colour selection is revealed by endogenous ERP components. Furthermore, once the locations of stimulus were broadly separated, the ERP signs of colour selection were hierarchically based on the prior selection for spatial location. In other side, once the locations of stimulus were adjacent to each other, the ERP signs of colour selection would be dominated over those of location selection.

2.9 Transient and Sustained Attention to Colour and Form

In opposite to the early ERP impacts for visual spatial attention, the attention to non- spatial attributes of visual stimuli like colour, contour and orientation influnceses ERP waveform mostly at a later period of time. In general, non- spatial visual attention was observed to produce a larger negativity evoked by attended stimuli which begins around 150 ms and might be extended upto 300 ms after the onset of stimulus (Aine and Harter, 1984; Kenemans *et al.*, 1993). When the selective attention is fluctuated between features that based on trial-by- trial fashion, this is known as transient visual attention. Once keeping the selective attention is focused on a particular feature for whole experimental trial, this is known as sustained visual attention.

Eimer (1997), studied to investigate the differences between transient and sustained attention according to the selection of non- spatial attributes of visual stimuli through an ERP study of transient and sustained visual attention to colour and form. They tested 12 healthy participants aged between 21-37 years old with normal colour or corrected to normal vision. The participants were asked to attend to particular attribute of the demanding stimuli (the red or blue colour in colour attention conditions, whilst squareness or roundness in the form attention conditions). Their results showed that both transient and sustained attention produced a larger negativity for attended as compared to unattended stimuli around 200 and 300 ms after the onset of stimulus. Interestingly, this influence was more obvious for sustained attention than for transient attention and more for attention to colour than for attention pointed to stimulus form. Only in the sustained, not in the transient attention condition, the colour attention conditions produced larger positivity for attended stimuli around 150 and 200 ms and in the P300 time range. They concluded that these effects are considered as a proof for the existence of non-spatial attentional selection processes that are highly functional for sustained attention conditions as compared with transient attention conditions and are distinct from visual-spatial attention processes. Furthermore, the findings suggest a distinctive condition for sustained attention to stimulus colour.

2.10 Colour and ERP in Relation with Gender Differences

Intense differences have been existed in visual processing systems in males and females. The rods and cones among the retina are various in structure between the male and female eyes (Sumner *et al.*, 2008). The male retina has commonly larger, thicker magnocellular ganglion cells, and easily in the field of vision, they can follow objects anywhere (Hollows, 2006). The female retina has dominantly the smaller, thinner parvocellular ganglion cells which are densely found in and around the fovea (Vaquero *et al.*, 2004).

Trikha (2010), studied to investigate gender and colour-specific differences in relation with event-related potentials (ERPs). They tested 108 healthy participants, 45 out of 108 were female with normal colour or corrected to normal vision. They used three colours (blue, red and green), where they presented the three colours in a random order and made a comparison between colours as one of them was a relevant stimulus. The participants were required to press a button once the relevant stimulus was presented randomly while ignored the presented irrelevant stimuli. Their results showed significant gender-specific differences in ERPs through colour task, in which the males constantly revealed higher amplitudes especially P300 component as compared with females, which indicated that there were a diversity of colour processing systems in males and females. The results did not showed any significant differences of any certain colour (blue, red or green) on modulating ERPs as the all three colours were presented as relevant stimuli, and all of them were equally evoked P300 amplitudes in males and females. These results indicated that the colour is not considered as a sign for elicitation of ERPs in normal participants.

2.11 Colour Vision and Memory

Checking the brain activity during the encoding and retrieval of actions that performed, observed, and imagined could be useful to illustrate why specific errors are possible. The actions those people usually perform are better than those that they just watch or imagine action, but at the same time, they also misremember doing actions those that they simply imagined or planned to do (source memory errors). Performed and imagined actions shared characteristics with each other, but seem to vary in the quality of the sensory experience and specificity of motor programmes (Fletcher *et al.*, 1996).

By viewing coloured photos of the objects, Senkfor *et al.* (2002), studied to investigate the similarities and differences in brain activity during the retrieval of different types of action and non-action memories. They tested 16 healthy participants aged between 18-30 years old, 8 out of 16 were female with normal colour or corrected to normal vision. They used 444 coloured familiar objects (like fork, or toy like lawn-mower). The participants were required to study real objects in one of four encoding tasks. First task was performing an action, in which they choose and perform a ‘’typical’’ action for the object. Second task was watching the experimenter performs a ‘’typical’’ action with the object. Third task was imagining an action with the object, in which they tried to imagine performing the action as possible. Forth task was non- action task (cost task), in which the participants estimated the object’s cost by giving a verbal estimate of how much that object does cost to buy. During the session, the participants viewed coloured photos of the objects and made source memory judgments about the initial encoding episodes. Their results showed that ERPs were similar for the three action retrieval tasks (perform, watch and imagine), in which different from the ERPs to the cost encoded objects at fronto-central electrode sites.