Declaration

I have read and understood The University of Edinburgh guide lines on plagiarism and declare that this written dissertation is all my own work except where I indicate otherwise by proper use of quotes and references.

Stereoacuity in processing near or far stimuli

1878747

MSc Psycholinguistics

The University of Edinburgh

2010

Acknowledgements

Time flies, words cannot describe how this year in Edinburgh has influenced my life. First of all, I would like to thank my supervisor Dr. Richard Shillcock for all the help with my experimental design. He provided me with interesting topics as well as giving me comments on the draft. Thanks also go to the expert of haplscope, Dr. Mateo Obregón who offered a lot of help with my statistics and experimental design. Specifically, I would like to show my appreciation for my dad and mom. Without your support, I would not have been able to solve the obstacles encountered in my master life.

Abstract

The experiment compared stereoacuity with Chinese characters when they appeared at different visual field, depth, and time duration. Character in front of the horopter was presented in LoVF, which induces crossed retinal disparities (CRD). In contrast, character behind the horopter was presented in UVF, which induces uncrossed retinal disparities (URD). The results showed that males were superior to the information presented on the UVF, while females did not show significant bias. Moreover, males were more sensitive to the size constancy illusion in which a far thing appears larger (e.g., character behind the horopter) under short and long timescales, while females were sensitive to character in front of the horopter under long timescales. The results supported earlier claims that female brains were less lateralized than male brains, and two genders showed different strategies in processing the stereoscopic stimuli.

Contents

1. Introduction

1.1 Spatial performance fields in processing near or far stimuli

The quality of visual processing relies on the information projected to diverse visual locations in the brain, and the asymmetries in visual resolution reflect the relative importance across different visual fields. Recent behavior studies have demonstrated inconsistent behavior across right visual field (RVF)/left visual field (LVF) and upper visual field (UVF)/lower visual field (LoVF). For example, Carrasco, Giordano, and McElree (2004) measured stimuli's processing speed and acuity when they were located at different visual locations but fixed eccentricity. It was found that the information accrual was the fastest for stimuli in the RVF and LVF, intermediate for stimuli in the intercardinal position, slow for stimuli in the UVF and LoVF, and the slowest when stimuli were presented to the north location. The uneven processing capacity termed horizontal-vertical anisotropy denotes better performance in the RVF/LVF than in the UVF/LoVF (Carrasco & Frieder, 1997),which possibly results from the retinal cone density dropping faster along the UVF/LoVF than it does on the RVF/LVF. The asymmetry functions of these spatial performance fields influence the acuity in stereoscopic vision, which has been reported in different visual tasks like contrast sensitivity (Cameron, Tai, Eckstein, & Carrasco, 2004) and spatial resolution (Talgar & Carrasco, 2002).

To interpret different performance across RVF and LVF, it was generally believed that RVF was superior to the word perception task (Goldstein & Babkoff, 2001). This visual laterality reflected the hemisphere specialization. When information was projected to the RVF, it was imaged in the left cerebral hemisphere, whereas information of LVF was projected to the right cerebral hemisphere. The superiority of RVF in processing word perception task may due to better processing of verbal material and high spatial frequencies in the left hemisphere, while the inferiority of LVF may originate from the nonverbal processing and low spatial frequencies mediated by the right hemisphere (Dehaene, et al., 2001). Although the superiority of RVF reaches general consensus, whether the UVF is superior to the LoVF is debatable. Many researches used lexical recognition tasks to exam the differences. For instance, Mishkin and Forgays (1952) asked people to classify words from non-words presented to different visual fields, and found the superiority in LoVF over UVF. On the contrary, Goldstein and Babkoff (2001) demonstrated an UVF advantage over LoVF, while Hagenbeek and Van Strien (2002) found no differences between LoVF and UVF in the decision task. Due to the inconclusive result of the previous literature, the present study tries to explore the acuity differences as the stimuli presented to the LoVF and UVF.

Regarding the influential factor between LoVF and UVF, most research did not take depth information into account. The theory of naso-temporal asymmetry (NTA) gave insight of the superiority of horizontal and vertical visual fields in processing stimuli in the 3-D world. It was suggested that people processed near things in the nasal visual field (LVF of the left eye/RVF of the right eye), while far things were processed in the temporal visual field (RVF of the right eye/LVF of the left eye). As for processing visual information in the LoVF and UVF, people process near objects in the LoVF and far objects in the UVF. Due to the absent research concerning the stereoacuity in processing near and far stimuli, we take a further look at how LoVF and UVF visual fields cooperate with each other in stereopsis.

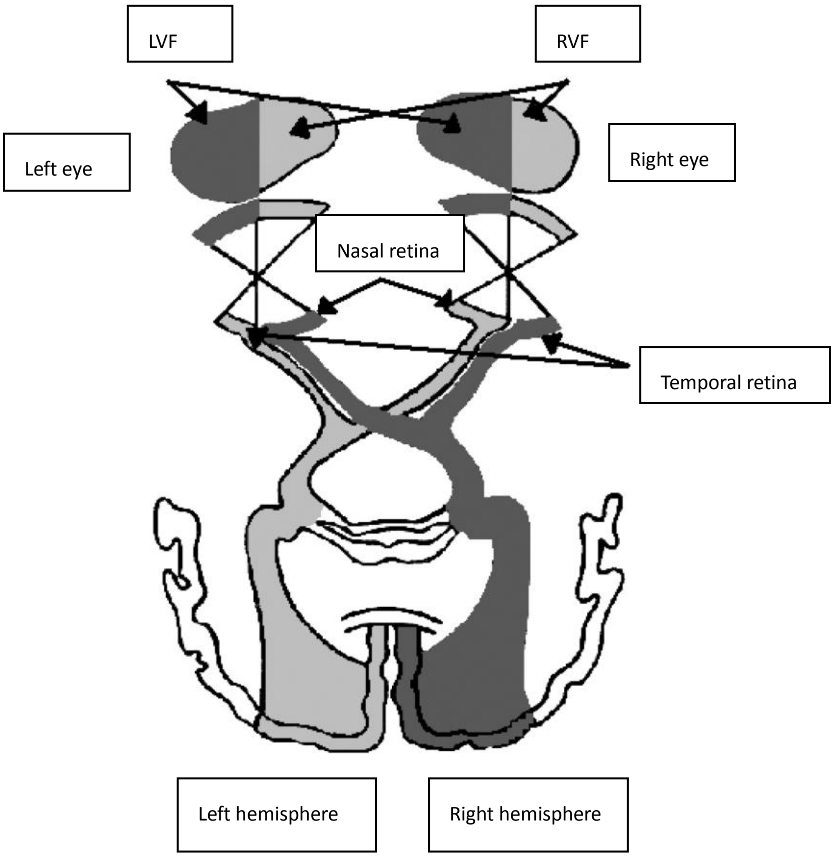
The present paper is divided into five sections. The first section begins by evaluating existing literature about partial performance fields (e.g., RVF/LVF and UVF/LoVF). The second section examines the temporal performances fields, investigating how short and long stimuli duration may affect the acuity. The third section introduces how people perceive size and depth in 3-D world. Fourthly, in the present experiment, the interaction between size and depth results in the Ponzo illusion is discussed. Lastly, we investigate how both genders perform differently under illusion perception.

1.1.1 RVF and LVF in processing near or far stimuli

The theory of naso-temporal asymmetry (NTA) provided anatomical basis to the asymmetry in processing stimuli that is either near or far away in reference to the point people fixate at. In order to decide each visual field's performance in detail, monocular testing was often used so that it is easier to compare the development of either the nasal or temporal visual field. The result demonstrated that under the monocular condition, there is temporal visual field (e.g., nasal retina) bias for human beings, especially for non reading tasks like contrast discrimination and visual acuity tasks (Harris & Fahle, 1996).

When the object is between the viewer and the fixation point, the visual axes are uncrossed. The information is thus likely to be projected in the temporal visual field (RVF of the right eye/ LVF from the left eye). On the other hand, when the object is beyond the fixation point (e.g., farther away from the viewer than the fixation point), the visual axes are crossed. The information is thus likely to be projected in the nasal visual field (LVF of the right eye/ RVF of the left eye). The visual information from the temporal visual field will then be projected to the nasal retina, while the information from nasal visual field will fall on the temporal retina (see Figure 1). The process is made possible by the hemidecussation of axons from ganglion cells in the optic chiasm. The image can be processed by the axons that travel across the retina, and then pass the optic chiasm into the optic tract. For example, in the RVF of the right eye (e.g., temporal visual field), the image is projected onto the nasal retina. The axons of ganglion cells in the nasal retina cross in the optic chiasm, so the image is conveyed through the left optic tract and projected contralaterally (left hemisphere). Conversely, the information from the LVF of the right eye (e.g., nasal hemifield) will be projected onto the temporal retina. Axons from the temporal retina do not cross, and thus information carried into the right optic tract will remain ipsilateral (right hemisphere). Information originating from each half of the visual scene was processed contralaterally. That is, information from RVF (temporal visual field of the right eye/nasal visual field of the left eye) is conveyed to the left hemisphere, whereas information from LVF (nasal visual field of the right eye/temporal visual field of left eye) is conveyed to the right hemisphere.

Figure 1. Neural pathway in processing visual stimuli



Source: Lavidor, Alexander, and McGraw (2009)

Traditional NTA is based on the fundamental, anatomically based, visual asymmetries. On the basis of acuity differences between the temporal and nasal fields, Lavidor, Alexander, and McGraw (2009) found the asymmetries in visual anatomy affected the recognition of the stimuli. They displayed a four letter string at different eccentricities under monocular vision conditions. Participants were asked to judge the stimuli as “darker” or “lighter.” The stimuli were randomly presented to one of five different visual fields; that is, fovea, nasal and temporal hemifield of the left eye, nasal and temporal hemifield of the right eye. Consistent with low-level NTA predictions, threshold data demonstrated that the temporal visual field (nasal retina) was more advantageous than the nasal visual field (temporal retina), no matter which eye viewed the stimulus.

The different acuity in processing stimuli in temporal/nasal visual fields may result from different developmental speeds and processing pathways. Lewis and Maurer (1992) compared infants' visual acuity development in the nasal and temporal visual fields throughout the first year of life, trying to explore whether the visual acuity was parallel to the naso-temporal asymmetry. By using the behavioral technique to examine infants' fixation preferences, the results suggested that infants' visual field perception gradually expands during early infancy, and the development of their temporal retina lagged behind the development in the nasal retina. They explained the slow temporal retina development as relatively late maturation of cortical input to midbrain. Despite the developmental differences of nasal and temporal retina, up to two to three times greater density of the ganglion cells on nasal hemiretina in human (Curcio & Allen, 1990) was found. Therefore, the superiority of the nasal part of the retina can be considered better in perception than the temporal part of the retina.

1.1.2 UVF vs. LoVF in processing near or far stimuli

Previous research found the superior performance in the RVF/LVF than the UVF/LoVF. However, regarding the superiority of UVF or LoVF, a series of lexical decision tasks conducted so far was inconsistent. Mishkin and Forgays (1952) found the superiority in LoVF over UVF in the word recognition task, but Goldstein and Babkoff (2001) demonstrated an UVF advantage over LoVF. Unlike these two studies, Hagenbeek and Van Strien (2002) found no differences between LoVF and UVF.

According to the research by Mishkin and Forgays (1952), LoVF was more accurate in word identification than in the UVF. However, their results should be carefully interpreted. For example, the stimuli they chose were long words (eight letters). Compared to right hemisphere that was sensitive to the number of letters in the string, it has been suggested that letter processing in the left hemisphere was relatively unaffected by word length (Young & Ellis, 1985). Therefore, the long word length was likely to induce bias results.

Contrary to the results proposed by Mishkin and Forgays (1952), Goldstein and Babkoff (2001) found better performance in the UVF than LoVF through lexical decision tasks. Lexical decision tasks of judging words and non-words have often been applied to the investigation of various visual fields' functions. The recognition of words and non-words was divided into word level, syllable level and letter level routes (Allen, Wallace, & Weber, 1995). In a lexical decision task, a word will be processed in the word level channel, which has top-down support from the mental lexicon. Conversely, non-words may result in the letter level input processor that cannot use the top-down support. In the research carried out by Goldstein and Babkoff (2001), they asked participants to do the lexical decision task. They were asked to classify 50 stimuli as "words" or "non-words" after they were presented to different visual fields for 150 ms duration. The response time and accuracy of the characters were recorded and analyzed. It was found that there was an advantage to the UVF over LoVF. The mean response time was faster in the UVF and there was a trend for a slight advantage to the upper over the lower visual field in word accuracy. This gave the evidence that word discrimination is performed better in the UVF than in the LoVF. However, only words but not non-words were respond faster and more accurately when presented to the UVF. The findings suggested that the high level lexical factors were involved in the upper-lower asymmetry, and this asymmetry may be the consequence of better top-down information flow to the visual areas that are represented in the UVF.

Since literature about visual performance on LoVF and UVF shows diverse results, Jordan, Patching, and Milner (2000) inferred the inconsistency to the covert and overt bias. Covert bias referred to the fact that the initial letter of a word would enjoy greater visibility than the final letters in processing word recognition. In contrast, overt bias concerns words that are influenced by partial word information, which may exacerbate covert bias if the partial word derived from the more visible word portion. In order to rule out the potential bias, the present experiment did not use an alphabetic system like English. Instead, a single Chinese character was used as stimuli so that participants would be less affected by covert and overt bias of each letters. Moreover, the research by Goldstein and Babkoff (2001) employed four and eight locations, which may make subject more uncertain as to which location would be stimulated. To reduce the distraction of the visual attention that may lead to a reduction in the visual field differences, we presented stimuli in two locations (e.g., LoVF and UVF) in the present experiment.

1.1.2.1 Neural Correlation between LoVF and UVF

To explain the neural correlates between LoVF and UVF in these lexical recognition tasks, Bryden and Underwood (1990) stated that the different performance between LoVF and UVF mapped well onto RVF and LVF, except that the visual fields had been twisted by 90 degrees. However, hemispheric asymmetries used to interpret RVF and LVF were only one of many determinants of visual field differences (Sereno, et al., 1995), which is not sufficient enough to interpret the asymmetry of LoVF and UVF.

Asymmetry between LoVF and UVF stems from different parts of visual fields being mapped in anatomically separated portions of the visual cortex. The different cortical response strength between LoVF and UVF result from two main pathways projecting from early visual areas. LoVF reflects a bias in processing information in the dorsal stream while information from

UVF tends to process in the ventral stream (Danckert & Goodale, 2001). Two streams were separated by the calcarine fissure in V1 where LoVF presented above the fissure in V1 and UVF presented below the fissure (Jenkins, Pickwell, & Abd-Manan, 1992). The visual information from LoVF is projected to the dorsal stream (also termed “where” stream) that focuses on the spatial aspects of the object, while UVF visual information is projected to the ventral stream (also termed “what” stream) which specializes in processing visual features such as shape, pattern, texture and color. The results have been observed in monkeys after bilateral resection of the temporal lobe and parietal lobe. Those monkeys with lesions on parietal lobe has difficulty in landmark discrimination (e.g. picking the food well closer to certain place), while those with lesions in the temporal lobe have difficulties in object discrimination (e.g., picking the correct shape) (Ungerleider & Mishkin, 1982). It can be concluded that perceptual processing like visual search shows the superiority of LoVF, while the object recognition shows the superiority of UVF.

The neural processing pathway also influences the function segregation of LoVF and UVF. Previc (1990) attempted to support the hypothesis that LoVF is specialized in global visual information and UVF in local information. As mentioned above, information to LoVF is conveyed to the dorsal stream. When people use LoVF to process objects in near space, the spatial perception and visuomotor manipulation, like reaching and grasping are required. Therefore, LoVF has become specialized in the global processing in order to deal with the optically degraded visual input. Alternately, when people use UVF to see far objects, the processing of finer details of form and visual search task, like object recognition are required. Therefore, UVF has evolved to specialize in high spatial frequency and local processing. Similar results have been yielded by Christman (1993) who examined the processing of local versus global visual information presented to LoVF and UVF. The empirical evidence was provided that the responses to global information were more accurate in the LoVF, while responses to local information were faster and more accurate in the UVF.

LoVF and UVF not only show difference in lexical recognition tasks, but the asymmetry also happens in processing stimuli in the 3-D world. In general, LoVF was specialized in near stereoscopic vision, while the UVF was in favor of far stereoscopic vision (Previc, 1990). According to the detection of random dot stereograms proposed by Breitmeyer, Julesz, and Kropfl (1975), it was found that detection duration thresholds were distributed equally between the RVF and LVF, but unequally between LoVF and UVF. LoVF appeared to be more efficient in detecting the sterograms for near stimuli, but faster in the UVF for far stimuli. In order to know more about how different visual fields and stereoscopic information may affect the acuity, the current experiment manipulates Chinese character that was nearer from the viewer in the LoVF or farther away from the viewer in the UVF. If there is a different effect in recognizing the character between LoVF and UVF, we may conclude that depth is another source of asymmetry.

1.2 Temporal performance fields

In spite of exploring spatial performance fields across visual quadrants, we also tried to discover whether different stimuli exposure duration may influence the acuity. In stereopsis, vergence movement was required when we aim to see the near or far target. Near targets presented to LoVF result in convergence, while far stimuli presented to UVF result in divergence. In the present experiment, we make the timescales short enough for actual convergence or divergence impossible to occur. Therefore, we refer “converge” or “diverge” as the visual stimuli going to each eye at the level of the cortical representations. Existing research regarding differences in latency between convergence and divergence reached contradictory results. For example, Hung, Zhu, and Ciuffreda (1997) examined the dynamic characteristics of horizontal convergence and divergence eye movement in response to symmetric stimuli. Four variables inclusive of time to peak velocity, latency, time constant, and total duration time between convergence and divergence were examined. The results showed that the slope of peak velocity as well as the amplitude curve was twice for convergence than divergence, and the initial fast component for convergence showed larger amplitude (25%) than divergence. As for the overall fast and slow component response, the constant and total duration of time were both shorter for convergence than divergence. However, a recent study by Yang, Bucci, and Kapoula (2002) investigated the latency of eye movements in 15 children and 15 adults. They found that in the adult group, the result was significantly longer for convergence than divergence (with the mean difference approximately 20 ms). For most of the children, the research also found shorter latency for divergence than convergence.

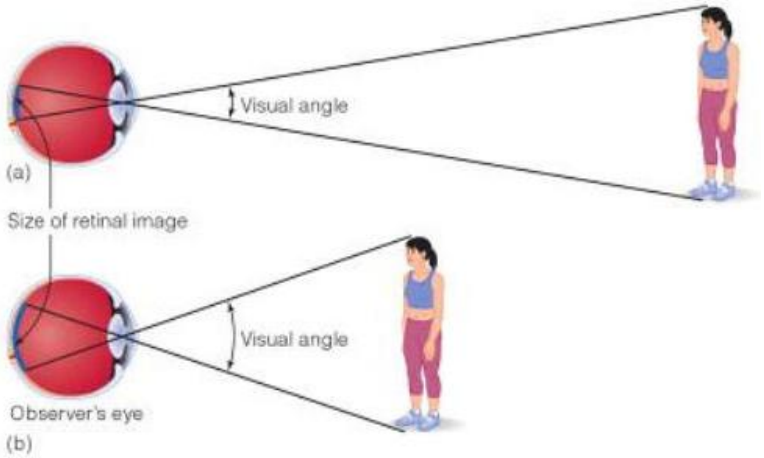
In the current experiment, short or long stimuli presentation durations were manipulated. If participants have higher correctness in processing far stimuli (e.g., making divergence) under short timescale, we can assume that divergence is more efficient in fusion under brief exposure. On the other hand, if participants have higher correctness in processing near stimuli (e.g., making convergence) under long timescales, we can assume that convergence is more efficient in post-fusion. Moreover, Held et al.(1980) reported that infants evaluating with CRD had better stereo acuity than with URD. It was easier for infants to cross their visual axes than diverge, and we wonder whether the bias seen in childhood will last to adulthood, when individuals were more mature in making vergence. By examining the temporal performance fields, we can know more about the mechanisms in processing near or far stimuli.

1.3 How we perceive size and depth in 3-D world

In spite of spatial and temporal performance fields that may affect stereoacuity, size also plays an important role. Generally speaking, the bigger the object is, the clearer we can see it. However, to deal with the information in the 3-D world, depth sometimes can incorrectly affect our perception to object's size and further influence the stereoacuity. In what follows, the way in which we perceive size and depth information will first be introduced, and subsequently size constancy illusion will be discussed.

To deal with the visual information in the 3-D world, a human being's complex visual system is required to come into action. For example, if you want to pick up a pencil, it is necessary to estimate the pencil's size so that you can hold it appropriately. You have to measure the distance between you and the pencil so that you can stretch the hand to the right position. Given that we do not always bring a ruler along, how can we process the 3-D information without much effort? In fact, estimating the size and distance of the object involves different computational resources. In terms of estimating the object size, the cue mainly comes from different subtending visual angles. Every object has its physical length and width. By extending the light of the object to the lens of the observer's eye, the image projected onto the retina will depend on the angle between the lines (e.g., visual angle). The size of retina image provides important clues for judging the object's actual size. Big objects project bigger image onto the retina, whereas small objects project smaller image. Additionally, the proportion of projected retina image gives the depth information. That is, bigger objects are closer to us while smaller objects are farther away from us (see Figure 2).

Figure 2 (a) The visual angle depends on the size and the distance from the observer (b) When The woman is closer to the viewer, the visual angle and the size of retina image increases



Source: Goldstein (2009)

However, although the retina projection gives us basic clues about depth information, the cues are still insufficient for us to estimate the distance correctly. To perceive the depth in detail, both absolute disparities as well as relative disparities are required. Absolute disparity is the distance of the objects in relation to our body (egocentric distance). Relative disparity is independent of fixation depth, referring to the distance between two different objects. Marr (1985) explained that stereopsis matching could be implemented by processing absolute and relative disparities serially: (1) local matching of the retinal images to obtain absolute disparities of objects which eyes are fixating and (2) a more perceptually useful representation on the relative disparities between different objects. However, in stereoscopic vision, we heavily rely on relative depth differences between objects rather than absolute distances in depth from where our eyes fixate. The “contextual information” provided by relative depth difference enables us to compare the depth of the object more accurately.

Literature on the neural basis for stereopsis emerged mainly in the late 1960s. Barlow, Blakemore, and Pettigrew (1967) published the first report concerning highly specialized neurons in the primary visual cortex V1, or area 17 of anesthetized cats. Later on, Cumming and Parker (1997) further found that most V1 neurons are selective for absolute disparities, while relative disparity is represented in extrastriate regions like V2, aiming to encode relative disparities (Thomas, Cumming, & Parker, 2002). The cortical units of V1 and V2 can integrate the horizontal non-corresponding image on the retina. After the disparities information is initially processed in V1, the primary visual cortex, viewers detect the different images projected to two eyes (e.g., retina disparities).

In addition to retinal image, absolute disparities and relative disparities being important for depth perception , the retinal disparities processed by the visual system is also vital. People's two eyes are separated horizontally, the design enabling each eye to view the word from different vantage points by making vergence (i.e., convergence and divergence). Different eye vergence causes the non-corresponding position of the retina (e.g., retinal disparities), and it is the different image perceived by two eyes that enables us to perceive depth information. Retinal disparity is a condition in which the two eye's line of sight does not intersect at the fixation point, but either in front of or behind the fixation point. In processing the nearer object, the visual axes converge, and the visual projection from an object in front of the fixation point results in crossed retinal disparities (CRD). On the other hand, in processing the far object, the visual axes diverge, and the visual projection from an object behind the fixation point results in uncrossed retinal disparities (URD).

The misalignment of visual axes (i.e., CRD and URD) affected the stereoacuity in processing stimuli in the 3-D world. Jenkins, et al.(1992) proposed the effect of induced fixation disparities on binocular visual acuity, and it was observed that the presence of induced fixation disparities reduced binocular visual acuity. They artificially created fixation disparities by prisms, and obtained the data from base-out prisms that induced crossed disparities and base-in prisms that induce uncrossed disparities. In order to test the stereoacuity of the participants, the measure of Log MAR score was conducted. Participants needed to read the letters on charts that were placed 4m in front of them. A value of 0.02 points was given to each letter called correctly, and the aggregate correctness score was recorded and analyzed. Similar to the design of the present experiment, participants were asked to recognize Chinese characters under the condition of CRD and URD, and their overall correctness percentage will also be recorded and compared. The results by Jenkins, et al. (1992) demonstrated that as fixation disparities increases (e.g., the viewing distances become shorter), the visual acuity will decline, falling to monocular level. In other words, increased fixation disparities (e.g., induces CRD aiming to process near object) decrease the stereoacuity. Additionally, it was found that URD affects steroacuity more than the CRD, which can be attributed to the different neural pathways that will be discussed below. Due to the different stereoacuity performance of CRD and URD that has been reported, we tried to induce participants' CRD and URD by manipulating the near and far stimuli, exploring how different retinal disparities may influence the stereoacuity.

In the following paragraph, we introduce how people use relevant depth cues in judging the distance between objects. Three types of depth cues including monocular cues, binocular cues, and oculomotor cues are discussed. After the information of depth is perceived, these depth cues also incorrectly influence our perception of object size, termed as size constancy illusion that will also be introduced below.

1.3.1 Depth cues-monocular cues

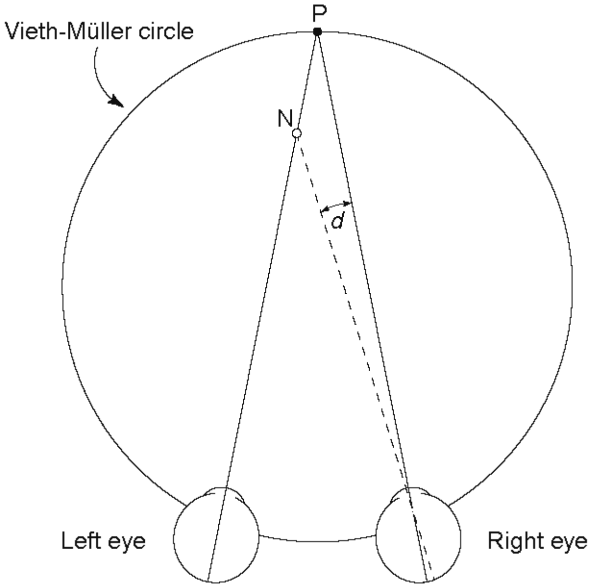
We can perceive the depth with monocular eye, but most depth cues are from the pictorial impression that we used to create on a flat surface. For instance, when an object is overlapped by the presence of the other object, we will interpret the blocking object as the one that is far from us. We can also observe the distribution of the light and shadow displayed on the surface to judge the depth information. Besides, since far objects produce smaller retinal images than near objects, the larger image of two same objects tends to be perceived as closer than the smaller one. Other influential cues include the texture gradients that differ depending on the distance. As the surface recedes, the texture elements' size decreases and density increases.

1.3.2 Depth cues-binocular cues of retina disparities

Despite the monocular cues in perceiving depth, Wheatstone (1838) proposed the first research of people's ability in perceiving binocular cues. It was suggested that humans judge the distance depending on the positional differences between corresponding images projected on the retina, termed binocular disparities. From the 2-D images formed on the right and left retina, the retinal disparities provide crucial information for our brain to synthesize the information to a 3-D layout and lead to stereoscopic perception.

In horizontal disparities, if a viewer fixates on a point, then the images will fall on the corresponding place of two foveas, which is the center region of the retina with the best spatial perception. The object in space that is projected onto corresponding retina points is the horopter (Howard & Rogers, 1995). From the surface of the empirical horopter, there are two parts in the geometrical horopter, the first part being is the Vieth-Müller circle that contains the fixation point and the eye's nodal points, the second part being is the line of sight that intersects with the circle (see Figure 3). Horopter is the points in space imaged with zero disparities by definition. Geometrically speaking, the fixation point located on the horopter serves as the reference plane, and people make different vergence in processing objects inside or outside the horopter. People converge the visual axes in processing near objects, while diverge visual axes in processing far objects. Both converge and divergence results in the non-corresponding position on the retina which provides important cues for stereopsis. Such vergence error disparities amount to a few minutes of arc, and thus the images will be fused in the Panum area so that viewers will not experience double vision from fixating on a certain thing in a 3-D world.

Figure 3. Empirical horopter



Source: DeAngelis (2000)

1.3.3 Depth cues-oculomotor cues

Despite the horizontal disparities that help people to perceive depth, Trotter, Celebrini, Stricanne, Thorpe, and Imbert (1992) found that some cells in V1 of monkeys adjusted the response while the viewing distances changed. The evidence showed that retinal disparities alone cannot determine the characteristics of all cells' underlying disparities processing in early visual pathways; it is also necessary to incorporate information about oculomotor cues.

Oculomotor cues include vergence and accommodation. As we fixate on the target that is near, the eye axes will converge, and thus the muscles will tighten to hold the lens focusing on the near object. On the other hand, as we fixate on the far target, the eye will diverge, and the curve degree of the lens will thus be inflated.

Binocular vision requires the vergence angle between two visual axes to be adjusted for proper fusion, and the vergence angle specifies the actual viewing distance. As we fixate on a certain thing in a 3-D world, the line of sight will be adjusted to project on the fovea of each eye to ensure the quality of the image in ideal binocular vision. (i.e., the fovea is the center region of the retina with the best spatial resolution). All these optimal fixation points comprise virtual horopters that can be regarded as the reference plane for people to judge the distance between objects. Deviation from the optimal state may change in response to different viewing conditions. The horizontal vergence movement allows people to process near or far objects. When the target is closer to the viewer, the CRD occurs. In contrast, when the target is farther away from the horopter, the URD occurs.

According to Hershenson's (1999) explanation of retinal disparities, URD and CRD could be perceived as we close either the right or left eye alternatively. If you raised the finger in front of a tree that is far away, the image between the left or right eye will be different depending on the change of fixation point. If you fixate on the far tree and look at the finger with different eyes, the finger will locate the tree's right side from the left eye, and the tree's left side from the right eye. The phenomenon is termed CRD that the finer images cross with the tree image. On the other hand, if you fixate on the finger and look at the far tree concurrently, you see the image of the tree is located on the finger's left side from the left eye, and the finger's right side from the right eye. In this case, the images are uncrossed and the URD is produced. In all, when people look at the object in front of the horopter, the point of crossed convergence will be closer to the viewer, so the visual axes are likely to be crossed and induce CRD. Conversely, when you look at the object behind the horopter, the point of uncrossed convergence will be far from the viewer. The visual axes are likely to uncrossed, inducing URD.

1.3.4 Separate mechanisms in processing near or far stimuli

In processing stereoscopic information, some neurophysiological research found groups of disparities selective cells in the primary visual cortex. Poggio, Gonzalez, and Krause (1988) discovered four basic classes of neurons: (1) Tuned-excitatory neurons responded best to object that are very near the horopter (zero disparities) (2) tuned-inhibitory cells responded best to all disparities except zero disparities (3) Near cells were responsible for objects in front of the horopter (CRD) (4) far cells were responsible to objects beyond the horopter (URD). The neural basis gave the evidence for there being separate mechanisms in processing things that were both near and far away from us.

The separate mechanisms of CRD and URD also came from the research on vergence and stereopsis. Retinal disparities and motor fusion shared the common stimulus of binocular disparities, but after visual information was integrated in the V1, the primarily visual cortex, how retinal disparities interact with motors to form depth perception remained uncertain. In the research by Poggio, et al. (1988), the causal relationship between vergence responses and fixation disparities was found. Some observers showed anomalies convergent (CRD) in response to near stimuli, while others displayed anomalies divergent (URD) in response to far stimuli. In other words, the stereoanomalous individuals who were not able to discriminate depth also accompanying the loss of vergence eye movement. These findings demonstrated that convergence and divergence may be independently operated in the normal observer, and the vergence anomaly results from a functional deficit in one of these components. Therefore, the vergence error during binocular fixation can be attributed to different neural pathways for convergence in response to CRD or divergence in response to URD.

The evidence of separate mechanisms of CRD and URD can also be observed in the human developmental differences. Held, Birch, and Gwiazda (1980) used preferential looking techniques to evaluate the normal development of infants' stereoacuity. It was reported that the development of stereoacuity occurred between the third through sixth months of life, and infants evaluated with CRD had better stereoacuities relative to infants of the same age who were evaluated with URD. Additionally, CRD was developed earlier than URD but at approximately the same rate. The developmental differences addressed the evidence that there were two separate mechanisms in processing CRD and URD, that is, one for crossed disparities detection and the other for uncrossed disparities detection. Furthermore, the earlier development of CRD suggested that it is easier to converge the visual axes instead of divergence in response to URD. The result confirmed previous studies which showed that the temporal retina was developed in relatively late maturation of the cortical input to midbrain, and thus the absent input from cortex to midbrain influenced infants in orienting toward the temporal retina (divergence) than orienting toward the nasal retina (convergence). Therefore, only if infants were able to make precise divergence or convergence, can stereopsis be better perceived. Neonates' pronounced advantage in processing crossed stimuli may evolve from the inherent preference in processing things that are nearer to us. Certain tasks like tool using, feeding, and detailed viewing all require us to process CRD, so it may be more efficient for us to converge the visual axes. In comparison to processing things that are far away from us, the lack of immediate need can explain why it may be slower to process URD. However, whether this pattern from childhood will last to adulthood is worth investigation. Since adults are more mature in making vergence, we examine how adults and children may behave differently by manipulating the stimuli duration as short or long.

1.4 Size illusion in processing near or far stimuli

It is well established that visual sensitivity is scaled depending on the size of retinal images (Banks, Geisler, & Bennett, 1987). Nonetheless, it is not clear whether visual sensitivity is also scaled depending on illusory size changes. This question is worth investigating since viewing distance is taken into consideration when determining apparent size. Consequently, the same physical dimensions of the object could appear to represent different-sized objects (i.e., the Ponzo illusion), while different images projected onto the retina could appear to represent the same size. For instance, it often occurs to people that although the retina image differs as viewing distance changes, we do not feel the size of the object change. For example, when the person stands 30 meter away from the viewer, the image projected onto the retina is smaller, but at a distance of 5 meters from the viewer, the perceived image is bigger. However, in estimating the object size, our brain does not solely depend on the projection onto the retina. Instead, the cues with the angle subtended on the retina can be combined with viewing distance and our prior knowledge of the object size. Therefore, people do not seem to shrink as they move away from us, or grow as they move toward us, despite the fact that retinal images of people do shrink and expand. This phenomenon is what we refer to as the law of size constancy.

The law of size constancy suggests that depth cue is crucial in judging an object’s size. Holway and Boring (1941) conducted an experiment trying to explore when the visual angle was set (so that the projection onto the retina is identical), and how the far clues affect the size constancy. Participants were asked to sit in the intersection of two diagonal hallways. On the right hallway, a test circle ball was placed in the range of 10 to 100 centimeters. The small circles were located close to the observer and larger circles were located farther away, but all circles had a visual angle of 1 degree. On the left hallway, the comparison circle was placed at the 10 centimeters. The task of the participants was to adjust comparison circle size to match the actual size of test circles at different distances. If participants were given many depth cues helping them to judge the distance of the test circles, then even though the retinal images projected were the same size, they could accurately judge the physical sizes of the circles, which corresponds to the law of size constancy. On the other hand, when the depth cues were eliminated (i.e., viewing the circle with monocular eye, viewing the circle through peephole, or adding drapes to decrease the influence of shadows and reflection), participants could only rely on the image size projected on the retina. The insufficient depth cues thus result in incorrect estimation in judging the size of the object. Similar phenomenon occurred as we observe the moon and sun in the sky. Although the physical size of the sun and moon are radically different, they are too far for us to distinguish the depth, so we perceive the size as similar. Consequently, we judge the size according to the projection onto the retina (i.e., if we calculate the visual angle between the sun and moon, it is 0.5 degrees for both). The inaccurate size judgment tells us that in estimating the size of the object, we not only depend on the subtended visual angle, but also the distance between observer and the stimulus.

Emmert (1881) used afterimage to illustrate the principle of size constancy. In the experiment, the black hollow circle with a white hole at its centre was used. In the middle of the white hole, there was a fixation point for people to look at. Participants were asked to fixate on the black circle for about one minute. When the afterimage was produced, they were asked to move their eyesight to another white paper at a different distance. The afterimage projected onto the paper differed according to the distance, and it was found that the farther the paper was, the bigger the afterimage. On the other hand, the nearer the surface was, the smaller the afterimage. He equated the relationship between the perception of afterimage (Sp), the distance of the paper (Dp), and the retinal image (Sr) to the formula: $Sp=K (Sr \times Dp)$. According to this formula, under the condition with the same visual angle, as the distance between the fixation point and the retina increases, corresponding increases were made in the size of the stimulus. In other words, close objects were perceived smaller than further objects that look bigger, and we could see that there was an important interaction between depth perception and size perception. Gregory (1966) termed depth cues that influence the size constancy mechanism as the constancy scaling mechanism, or size distance scaling.

The principle of size constancy enables us to identify the object size appropriately, but sometimes the inappropriate constancy scaling produces distortion of visual perception. For example, in the Ponzo illusion shown in Figure 4, both lines have identical length and visual angle, but the object that seems to fill a bounding outline looks larger than the same object within a larger outline. According to the explanation by Gregory (1966), the misapplied scaling resulted from the depth information provided by the converging rail track. Therefore, the scaling mechanisms correct the object size for apparently increased depth, so people perceive the upper line as longer.

Figure 4. Example of Ponzo illusion

Source: Retrieved July 30, 2010, from

www.cas.buffalo.edu/classespsy/segal/2472000/Illusions.html

Recent functional resonance imaging (fMRI) studies proposed by Murray, Boyaci, and Kersten (2006) further demonstrated that the neural processing in the early visual cortex can be modified in V1 (e.g., the early stages of the human visual system) in which far characters appear to occupy a larger portion of visual field that activates a larger area in V1 than the closer character. This rescale gave us some evidence that when judging the size of the object, people did not solely depend on the image projected on the retinal images (e.g., angular disparities). Instead, viewing distance was a more crucial property in size judgment.

Previous literature showed that illusion can influence the reaction time in responding to the stimuli. Sperandio, Savazzi, and Marzi (2010) designed an experiment similar to ours, but which aimed to test participants' reaction time. Participants were firstly asked to gaze at the fixation point at the centre of the screen, and then they were given upper/lower lines with a Ponzo background. Only a single line was presented each time with an exposure of 120 ms, and participants were asked to respond to the onset of the stimuli as quickly as possible. It was found that people's reaction time was sensitive to the Ponzo illusion since the upper line appeared to be longer and thus they can respond more quickly. Therefore, it was concluded that this reaction time paradigm was controlled by perceptual rather than physical parameters of the stimulus.

Since illusion affects people's reaction time, we wonder whether the acuity is affected by visual illusions as well. The present rationale of conducting a simple accuracy paradigm was based on the finding that as distance increases, the visual acuity gets better under the same visual angle (Schindel & Arnold, 2010). Our present experiment was therefore based on the Ponzo illusion. We positioned the character either below (e.g., near in reference to the fixation point) or above (e.g., far in reference to the fixation point) the fixation point at which participants was looking at. Both characters were identical in size (e.g., 50x50 pixels) and were at the same visual angle.

Due to the size constancy illusion, the far character will be more expanded than the near object under the same visual angle. We thus speculated that if character naming was sensitive to illusions, then character perceived as bigger should provoke more accurate responses than those perceived as smaller despite an identical retinal size.

1.5 Gender differences in processing illusion

In observing the gender differences in processing illusion, past research has not reached consensus. Dewar (1967) found males to be superior to females in the Müeller-Lyer illusion. Furthermore, Miller (2001) explored gender differences as they related specifically to Ponzo illusion susceptibility. It was found that females were more susceptible to the illusion, while males were not susceptible at all. In contrast to both studies, Porac, Coren, Girgus and Verde (1979) investigated 13 common illusions, but did not find any gender difference. Despite the various types of illusions tested in the previous literature, the present experiment was similar to the Ponzo illusion. Existing reviews have found illusion was more prone to be deceived than the left hemisphere (Houlard, Fraisse, & Hecaen, 1976), so the different performance of both genders may probably result from the different hemispheric specialization.

It was found that the brain lateralization was more pronounced in males, while females presented a more symmetrical brain organization. Davidson, Cave and Sellner (2000) employed a letter memory task and a spatial memory task designed to selectively activate the left or right hemisphere combined with attentional probe tasks. The probe task primarily measured how hemispheric activation will affect attention to different visual fields. For both male and female participants, the probe performance for dots task was greater than the letter task, and the response time was faster in the dots task than the letters task. Males responded faster to the probes in the right visual field than those in the left visual field during the letters task, whereas left and right response times were almost equal for the dots task. On the other hand, females did not show interaction between the two primary types of interaction. The result corroborated earlier claims that female brains were less lateralized than male brains. Male participants' outperformance on the right visual field may due to the letter task being a generally a left-hemisphere activity, and this activation limited the right hemisphere's ability in processing lexical information. In the present study, participants were asked to recognize the Chinese character presented either on LoVF or UVF. Since both genders have different degrees of brain lateralization, we will investigate how different hemisphere specialization may affect the performance in the present cognitive task.

1.6 The purpose and hypothesis of the present experiment

To explore the sensitivity of character recognition, participants were asked to distinguish the character that was either nearer or farther away in reference to the cross they were fixating at. Based on previous research about how different visual fields (i.e., LoVF vs. UVF), depth cues (i.e., processing near stimuli in LoVF requires convergence in response to CRD vs. processing far stimuli in UVF requires divergence in response to URD) and timescales (i.e., short or long) that may influence stereoacuity, the present experiment design included three variables: performance fields, depth cues, and stimuli presentation duration. There were four research questions under investigation:

(1) Does asymmetry performance exist on LoVF and UVF?

(2) Is stereoacuity affected by processing depth cues that result in illusion?

(3) How do temporal factor affect participants' stereoacuity?

(4) Are there gender differences in processing stereo information?

Based on the previous literature, we presumed that UVF is superior to LoVF. LoVF was specialized for global and low-spatial frequency processing, while UVF specialized in high-spatial frequency and local processing (Goldstein & Babkoff, 2001). Since reading was a task requiring high spatial frequency stimuli (i.e., Chinese characters) and a local processing strategy, it could be hypothesized that people should perform better on the character recognition task located on the UVF.

Additionally, since the experiment design was similar to the Ponzo illusion, we suggested that UVF was superior in processing far stimuli while LoVF was superior in processing near stimuli. According to the size constancy illusion in processing stimuli in the 3-D world (Murray, et al., 2006), the depth cues may create the Ponzo illusion so that stimuli located on UVF seems to be bigger. We wonder whether the introduction of an illusory size change had impact on the ability to detect the character.

As for the temporal factor, the correctness percentage in processing stimuli for a long duration time should improve since they have a longer time to recognize the character. For the size constancy illusions created in the present experiment, we wonder since the illusion is easier for recognition, participants may probably have stronger effect over longer timescales.

Lastly, gender difference in processing illusion probably exists since the brain functions differently for both genders. If males performed consistently on this cognitive task, it further confirms their brain lateralization in processing illusion. On the other hand, if females perform differently under different conditions, it may indicate their symmetric brain lateralization responds to illusion differently under different conditions.

2. Methodology

The purpose of the present study was to explore the spatial and temporal visual fields in processing near and far stimuli. During the experiment, participants were asked to constantly fixate on the cross in the middle of the screen during each trial. This cross served as reference point. As participants looked at near stimuli in reference to the cross, the information is projected to LoVF and the visual axes are likely to converge and thus induce CRD. In contrast, when people looked at far stimuli in reference to the cross, the information is projected to UVF and the visual axes are likely to diverge and thus induce URD. Therefore, we manipulated the Chinese character that was either below (presented to LoVF) and near in reference to the cross, or above (presented to UVF) and far in reference to the cross. Moreover, the temporal factor was taken into consideration, and stimuli were presented on the screen with both slow and fast timescales. To measure the stereoacuity, participants were asked to distinguish the character presented under different conditions, and letters correctly or incorrectly read were recorded and analyzed. By observing the correctness percentage of participants, we were able to gain insight of different mechanisms in processing near and far stimuli.

2.1Participants

A total of 36 Taiwanese students (14 men, 22 women) from the University of Edinburgh were recruited after informed consent. They had a mean age of 28 years with SD=4.42 years. Since the characters were all presented in their traditional form, the participants we recruited were all users of traditional Chinese characters. All subjects had normal binocular vision, which indicated by good visual acuity (either uncorrected or corrected with contact lenses) and stereo vision. They were not told the purpose of the experiment.

2.2 Apparatus

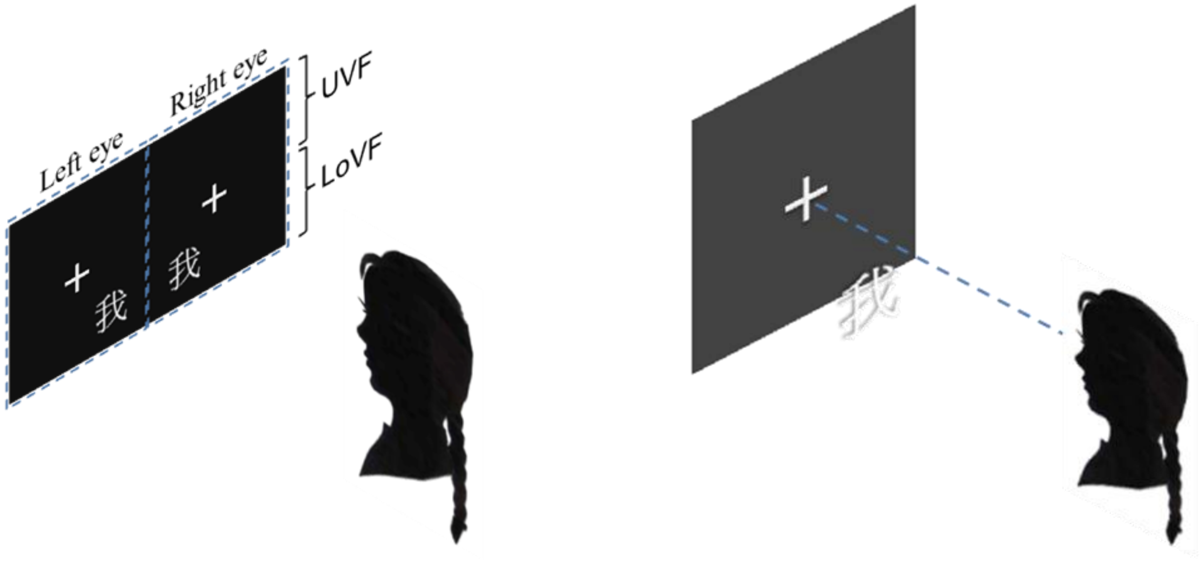
We used haploscopic device in the present study about fixation disparities. The characters (50x50 pixels) and the cross (20x20 pixels) were presented on the 17 inches (40x30 cm) monitor (Model IIYAMA, Vision Master Pro 413) with 1024 x768 pixels resolution. This monitor is natural flat.25 pitch with a 16 bit color depth of 32 x 24 cm. The viewing distance between participant and monitor was 135 cm, with all the stimuli projected to the fovea. To create the character's depth perception, the dichoptic viewing was achieved by redrawing every 14.28 msec via the dual head graphics card (Matrox 450), refresh rate 70 Hz. Stimuli including the character and cross were presented on the completely black background screen. The color of those stimuli was light grey instead of white, preventing people from feeling the harshness of the contrast. Furthermore, in order to reduce the interference of the light that may affect people's perception in recognizing the word, the experiment was conducted in an eye-tracking lab which was surrounded by black wallpaper.

2.3 Materials

A total of 72 Chinese characters of traditional form were used as testing materials. Participants were first trained with four trials, to familiarize themselves with the experiment format. Subsequent to 12 practice trails, they were then asked to do 60 formal trails. Four variables were used to generate the experiment: (1) x offset and (2) y offset used to create the depth perception of the stimuli, (3) short time duration and (4) long time duration used to manipulate the stimuli timescale.

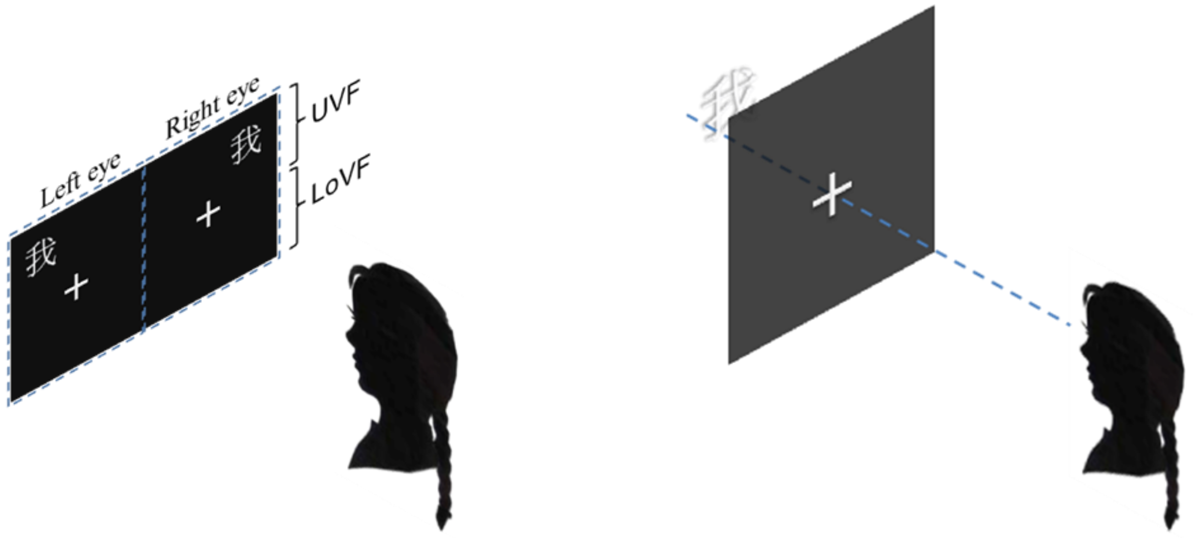
Each trial was presented with a single character either nearer or farther away in reference to the cross. In order to create the depth perception of the character, the dichoptic viewing was achieved by manipulating different x offsets (e.g., 20 pixels) and y offsets (e.g., 35 pixels) on the 1024 x 768 pixels screen. By operating different images for the right and left eye, the disparities will provide crucial cues in judging the distance. In order to make people perceive the cross in the middle of the screen binocularly, the cross of the left eye is put in the middle of the half of the left screen, which is 50% from the top (384 pixels), and 25% from the left (256 pixels). On the other hand, the cross of the right eye is put 50% from the top (384 pixels), and 75% from the left (768 pixels). After viewing the cross binocularly, it will appear in the middle of the screen. In the near case, two characters were presented 35 pixels below the cross but were moved 20 pixels close from each other. The left character is 276 pixels from the left, and 419 pixels from the top, and right character is 748 pixels from the left and 419 from the top. As we receive the image from the right and left eye, the final perception will make the character nearer in reference to the cross (see Figure 5). In the far case, two characters were presented 35 pixels above the cross and move 20 pixels away from each other. The left character is 236 pixels from the left and 349 from the top, and the right character is 788 pixels from the left and 349 pixels from the top. Similar to the near case, the image from the right and left eye will be combined so the character appears farther in reference to the cross (see Figure 6). The 2-D retinal images perceived by right and left eye image were created, and after receiving different right and left eye perception concurrently, the brain integrates the information to 3-D information. Therefore, participants' final perception of the Chinese character will be either near or far in reference to the cross.

Figure 5. (a) Left panel refers to the character manipulated on the screen, which is similar to the image projected on our retina. (b) Right panel refers to people’s final perception that LoVF stimuli look nearer in reference to the cross.


(a)

(b)

Figure 6. (a) Left panel refers to the character manipulated on the screen, which is similar to the image projected on our retina. (b) Right panel refers to people’s final perception that UVF stimuli that looks far in reference to the cross.


(a)

(b)

In order to observe how temporal factors may influence people in processing near or far stimuli, the character is presented on either a short or long timescale. However, participants' performance in distinguishing the character differs from person to person. Some viewers were sensitive in detecting the character while the others were not. Therefore, it was necessary to make either short or long versions for people with different extents of stereoscopic perception. The screen refreshes 70 times per second, and each refreshing time requires 14 msec. In order to let character be displayed clearly, the speed was manipulated according to the multiple of 14, and we controlled the difference of practice, short and long version within 43 msec.

12 practice trials (short timescale: 55 msec/long timescale: 95 msec) were used to estimate people's performance in distinguishing the word. People have an accuracy level of above 50% in the fast timescale, they will do the fast version (short timescale: 40 msec/long timescale: 80 msec). On the other hand, those whose accuracy level is below 50% in the slow timescale were asked to do the slow version (short timescale: 65 msec/long timescale: 110 msec). All stimuli were exposed below 150 msec to ensure that the stimuli were sufficiently short enough to minimize re-fixation. Taken together, word will be presented with four conditions: (1) farther character with short timescale, (2) farther character with long timescale, (3) nearer character with short timescale, and (4) nearer character with long timescale. To avoid the possible serial effect, the ordering of four different conditions was counterbalanced. Each participant will be tested through four conditions, but the presentation ordering of condition and time duration was also counterbalanced.

Given the possibility that the frequency and complexity (i.e., strokes) of Chinese character will affect the accuracy in recognizing the word, words were selected from the range of 500 most frequently encountered words based on the Sinica Corpus (Academia Sinica Institute of Linguistics). Furthermore, the stroke counts were also taken into consideration. To counteract the possibility that the frequency and complexity of Chinese character will affect the ease with which the participants recognize the word, the number of strokes ranged from 3 to 9, and were distributed evenly.

2.4 Procedure

Participants were asked to sit in front of the haplscopic device in an adjustable chair so that their head could rest on the frame to avoid head movement, and their eyes could be placed in front of the screen. There were 76 trials in total, including 4 training trials and 12 practice trials. The experimenter used the same experimental script for the explanation. Participants were instructed at the very beginning to use the right and left thumb to press the buttons simultaneously to begin the trial or activate the next trial. This was to make sure that both hemispheres were processing the motor task, avoiding possible preferential effect to a certain hemisphere. During the training and practice session, the experimenter monitored the process and ensured that all the participants had fully understood the experiment procedure by the time they had finished the practice trials.

The screen firstly presented a cross on the middle of the screen, and participants were told to fixate on this cross, which would be displayed at each trial. The main reason to fixate on the cross was to let every participants have the same conjoint fixation point on the horopter in distinguishing the character that was either near or far away from the viewer, ensuring the consonance between the accommodation of vergence and binocular input. After they were prepared, they were asked to press the bottom to begin the trial, and there would be a pause ranging from 200-300 msec between the cross and the trial for the brain to settle down. The trial showed on the screen contains the cross in the original place but with a character that is presented either nearer or farther in reference to the cross under short/long timescale. After the presentation of the stimuli, the location of the character will immediately be replaced by a symbol, which serves to clear participants' retinal image. The duration of the back mask was made short enough to avoid awareness, and long enough to cause interference. The screen would then go black, and participants then need to report the stimuli seen on the screen as soon as possible, and the experimenter would then record their response. After recording the responses, the cross would again appear on the screen. Once participants were prepared, they could press the bottom to begin the next trial. The percentage of the correctness responses was recorded and analyzed.

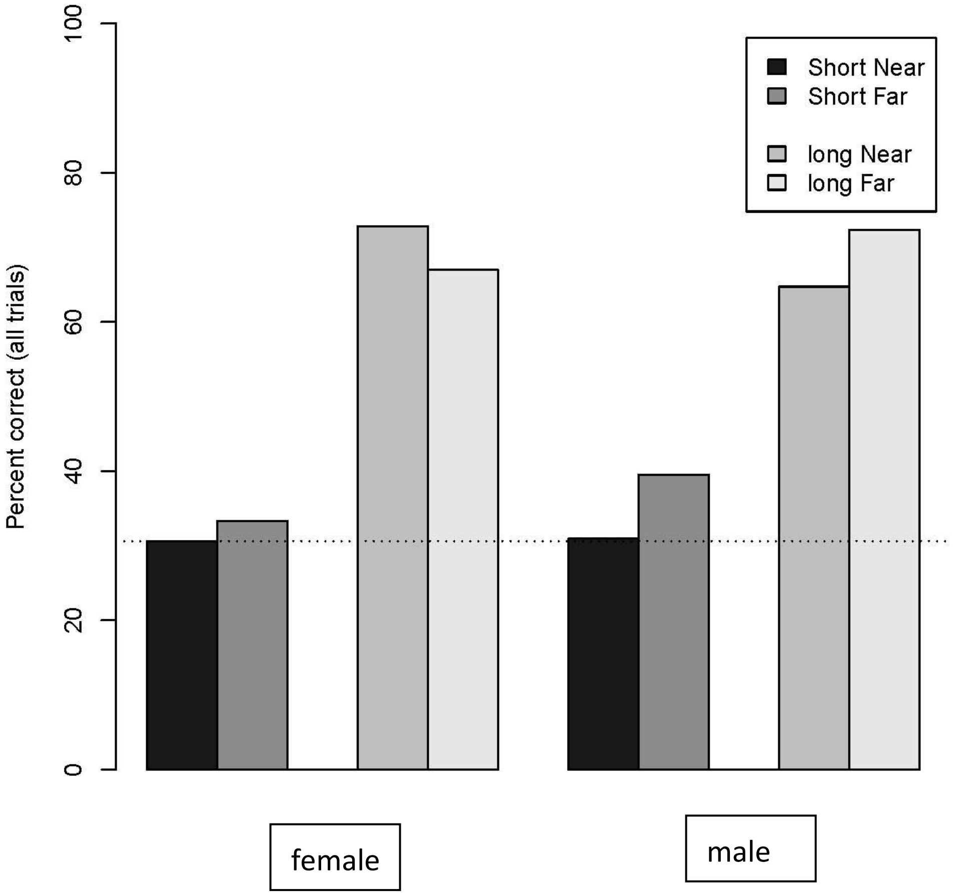
2.5 Data analysis

Analyses were carried out by comparing the stereoacuity in near/far conditions, and under short/long timescales. If participants cannot distinguish the depth of the character, the data may not reflect the actual disparities mechanisms, so any data points that were above or below two standard deviations from the mean of all the subjects' average were discarded. Results were only analyzed from subjects whose performances were acceptable during the four conditions, and were not affected by the movement of the head.

3. Results

As we analyzed the performance of all the participants under different conditions, the results did not show statistical significance. Although the trends revealed that participants in general performed better on the far stimuli, it was possible that many influential factors canceled each other out, and thus influenced the result. However, after analyzing data according to genders, we not only found statistical significance in their performance, but also interesting interactions between males and females. The overall correctness percentage of trials for both genders under each condition is depicted in Figure 7.

Figure 7. Accuracy of report: below-near vs. above-far, short and long presentation durations



As could be expected as high correctness under presentation duration, there was on average up to two times more correctness on long compared to than short presentation duration. Critically, the performance of males showed a similar trend across near and far conditions with respect to the short durations for females. In other words, males performed better on the far character under both the short and long durations, while females performed better on the far stimuli under short durations, but better on the near stimuli under long durations. The inverted result between both genders under long durations suggested that gender behavior is relevant in these tasks, and this will further be discussed below.

To assess the statistical reliability of the variable interaction effects, a linear mixed effect model was used. This model incorporated fixed and random effects, taking individual differences into consideration. Consequently, this model was more powerful than the traditional ANOVA approach assuming all variables were fixed effect. By specifying participants, frequency, and stroke as crossed random factors, and including experimental manipulations of fixed effect of sex, condition and duration, we were able to quantify the effect of condition (e.g., near/far, short/long) between the genders. The results provided us with a positive or negative subject-related correlation between these three variables. Analyses were carried out by using R, an open programming statistics software, and in particular the lme4 package is for linear mixed effects models. The estimated effect size (b), standard error, z value, and p values were reported. Furthermore, the correctness percentage of females under the far condition and slow duration was estimated as intercept. After specifying this intercept and comparing it to the performance under other conditions, we were able to estimate the associated correlations between different variables.

3.1 Different performance in processing stimuli under short/long timescales

Looking at the results from the potential influence of duration, we see that there was a negative correlation of the females' performance under the near/long condition (intercept), compared to the near/short timescale. Consistent with our prediction, the high statistical significance (b=-2.0199, SE=0.1567, z value=-12.887, p<0) suggested that under the fast time condition which was more demanding, it was hard for people to correctly recognize the word, and thus there was a negative correlation. On the other hand, the longer duration of stimuli presentation enabled participants to recognize the word better. Furthermore, as we compare the trend of females' performance under the long timescale with that of short timescale in processing near and far stimuli, we found females behave significantly differently. Under long timescales, females performed better than men under the near/long condition (intercept) than far/long condition. However, we found females outperform in the far/short conditions than near/short conditions under short timescales. Females' different performance under short and long timescales have reached statistical significance (b=0.5014, SE=0.2161, z value=2.321, p<0.05).

3.2 Different performance in processing near and far stimuli

One of the present study goals aims to find the gender differences in processing near and far stimuli. For females, the correctness under the near/long condition (intercept) correlates negatively with the effect of the far/long condition, which reached statistical significance (b=-0.3225, SE=0.1752, z value=-1.841, p<0.05). In other words, under slow duration, females perform worse under far than near stimuli. As we compared the females' performance under the near/long condition (intercept) with male's performance under the near/long condition, the performance of both genders did not differ from each other, and thus there is no statistical significance (b=-0.2729, SE=0.3529, z value=-0.773, p>1). However, if we compare the trend of both genders' performance under the near/far stimuli difference, we found interesting correlations. As we discovered above, females perform worse under the far/slow condition in comparison to the near/slow condition (intercept). If we compare this trend to males' performance under the near/slow and far/slow condition, we found that males perform more positively (b=0.6025, SE=0.2226, z value=2.707, p<0.001) than females. In other words, while females performed worse on far stimuli, the results were inverted for males who performed better on far stimuli. Males' outperformance for far stimuli thus resulted in a positive correlation to females. This finding suggested that gender does play an important role in distinguishing the characters that was either nearer or farther away from the point on which the viewer fixates at. Despite the temporal and spatial factors that may influence the acuity, we also examined whether frequency and strokes influences participants' performance. Results showed that the less strokes the character has, the more effectively people will recognize the character, but the frequency did not influence the outcome as much. In the following discussion section, we will explore possible influential factors which may account for why the genders performed differently under different conditions.

Table 1. Result from the linear mixed effect model

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.0444	0.4229	2.470	0.0135 *
(Condition, ref = "Near")Far	-0.3225	0.1752	-1.841	0.0656 .
(Sex, ref = "female")male	-0.2729	0.3529	-0.773	0.4394
(Duration, ref = "Slow")Fast	-2.0199	0.1567	-12.887	<2e-16 ***
(Condition, ref = "Near")Far:relevel(Sex, ref = "female")male	0.6025	0.2226	2.707	0.0068 **
(Condition, ref = "Near")Far:relevel(Duration, ref = "Slow")Fast	0.5014	0.2161	2.321	0.0203 *

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

4. Discussion

4.1 Spatial performance field

Past studies used the lexical decision task (i.e., distinguishing words from non-words) to test the hypothesis of LoVF and UVF function, while the present experiment used a word recognition task, investigating how different spatial performance fields may affect the percentage of correct recognition. In contrast to the results of Hagenbeek and Van Strien (2002), who failed to find any difference between LoVF and UVF, we found participants' higher correctness in recognizing characters posited on UVF, which was in accordance with the UVF superiority proposed by Goldstein and Babkoff (2001). In the following paragraph, we interpreted the outperformance of UVF from the viewpoint of different segregation of LoVF and UVF function.

Previous research reported that LoVF was better at basic sensory capabilities like recognizing low spatial frequency stimuli (i.e., luminance based visual stimuli). Therefore, we presumed an LoVF advantage of global strategy for processing all types of visual stimuli. In contrast, UVF was more appropriate for object recognition like discrimination of high spatial frequency stimuli (i.e., characters and words) and thus we expected that UVF was more appropriate in local strategy. The present experiment required participants to name the Chinese character presented on the LoVF or UVF. Since naming relied on the recognition of high spatial frequency stimuli (e.g., Chinese characters) and local processing strategy, the higher correctness in recognizing character presented to UVF was broadly in keeping with the effect of the local strategy characterized by UVF.

In spite of the influential factor of spatial performance fields on acuity, we also aimed to find out whether depth cues affected people's performance on word recognition task. In terms of stereopsis, the UVF had an advantage for perception of far stimuli, whereas LoVF had the advantage in processing near stimuli. Therefore, the characters presented to UVF were manipulated far away in reference to the cross on which the viewer fixated, and characters presented on LoVF were brought nearer in reference to the cross. Although some studies suggested that the superiority of LoVF in recognizing visual stimuli was based on contrast, hue, and visually guided pointing movements as faster and more accurate (Danckert & Goodale, 2001), regarding the discrimination of the visual stimuli based on apparent distance from the observer, it was found that UVF outperformed the LoVF (Levine & McAnany, 2005).

In the current experiment with obvious distance between near and far stimuli, different neural pathways in processing near and far stimuli may account for the superiority of UVF. In stereopsis, processing far stimuli required the divergence of visual axes that induces uncrossed retinal disparities (URD), while processing the near stimuli required the convergence of visual axes that induces crossed retinal disparities (CRD). In the present experiment, the durations for stimuli exposure will be short enough so that the vergence movements of the eyes did not have time to be carried out. Therefore, we talk about being "converge" or "diverge" at the level of cortical representations. Generally speaking, the present results confirmed the naso-temporal asymmetry (NTA) hypothesis that the bias in favor of nasal retinal ganglion cells results in better acuity performance on the URD. In CRD, the image will be projected onto the temporal part of the retina where ganglion cells were less condensed in perceiving the image. On the other hand, in URD, the image will be projected onto the nasal retina with denser ganglion cells. The denser receptors may be responsible for cortical magnification that reflects the general prioritization in processing far stimuli presented on UVF.

4.1.1 Gender differences in spatial performance fields

The influence of spatial performance on word perception was highly influenced by individual differences (McCann, Folk, Johnston, 1992). However, while much was known about the spatial differences of visual field (i.e., RVF vs. LVF), the existence of gender differences within the topic of LoVF vs. UVF was less investigated. In the current result, the overall data showed a trend for participants' better performance on UVF, but the results did not reach significance. Nevertheless, males showed a pronounced preference in processing far stimuli presented in the UVF under short and long durations, whereas females showed a slight preference in processing near stimuli presented in the LoVF on average. The robust behavior of males in better processing far stimuli not only accounts for their bias in UVF, but also indicates their superiority in spatial ability.

The trend of males' and females' general outperformance to UVF bias may originate from the preferential processing of UVF stimuli. Pflugshaupt et al. (2009) conducted the visual search task concerning the spatial distribution of fixations and reaction time. The images of everyday scenes of landscapes, buildings, or rooms were used. Participants were required to find predefined single targets embedded in images. Whenever they found the target stimulus, they had to respond with a mouse click as soon as possible. Experimenters found that both genders showed biases of fixation and viewing time to the upper image half during the visual search. Furthermore, there were gender differences in performance. When searching for the predefined targets, males made more fixations and spent more viewing time in the central and the upper image half, which exhibits males' overrepresentation for upper image half. The findings suggested that the functional specialization of visual fields has implications for spatial fixation distribution during visual searches. However, in examining the functional specialization of the visual fields, participants were not required to fixate on the fixation point for the stimulus presentation, primarily to ensure the stimuli were exclusively processed in the LoVF and UVF.

Instead, Pflugshaupt et al. (2009) investigated this issue from a more dynamic viewpoint, as they instructed participants to search the images with eye movements. The study suggested that the visual field specialization can also be observed in the visual exploration with eye movements. Although the design was too atypical for us to compare it with the present experiment, this search paradigm provides valuable information about both genders' bias in viewing UVF within the everyday scene.

Furthermore, in terms of males' robust performances on the UVF, previous research found the similar outcome as the present result. Davidson et al.(2000) designed an experimental paradigm presenting the fixation stimulus on the center of the display. Though it is different from our experimental design using word recognition task, the research nonetheless showed the way in which letter memory task and spatial memory task may affect the recognition of probes presented on LoVF or UVF. The probe task required participants to identify the digits presented in four different visual fields (e.g., upper right, upper left, lower right, lower left). The four digits were presented for 30 msec on the screen. As soon as the digits disappeared, subjects needed to retained the most recent letters in their memory and reported them. It was found that the bias in performance fields was gender-specific. Males were faster for probes in the UVF than in the LoVF. On the other hand, females did not show significant differences between LoVF and UVF. The functional differences of LoVF and UVF for both genders may have evolved as an adaption to specific requirements. In the following paragraph, the ecologically effect will be further discussed.

Far thing are often towards the top of the visual field. For instance, Previc (1990) indicated that LoVF was specialized for processing objects near the viewer, while the UVF specialized in processing far objects. Gaulin and Fitzgerald (1989) claimed that for the polygynous species, males conducted a reproductive strategy so that they can defend their territories. The competition for mates results in the larger spatial navigational ability. A similar evolutionary account can be traced back to the early labor division of human society, with ancestral males doing hunting, and females gathering. The sex differences in labor promoted differences in visual spatial skills. To be good hunters, males needed to be capable of analyzing the spatial coordinates that helped him to prey. The requirement of aiming, throwing a spear, and hunting over large spatial domains enhanced their spatial ability for long range navigation (Sherry & Hampson, 1997). On the other hand, females were estimated to be superior in processing near stimuli, and typically excel at precision manual tasks. As a gatherer, a good memory for the location of plants and certain fine tasks like separating seeds was required. Therefore, it was indicated that the LoVF was more sensitive to such fine tasks, whereas the UVF concerned object recognition so that people can avoid danger. It is possible that the nature skills in spatial ability could be prevalent in modern humans. Some of the most cited genders differences in spatial ability processing was mental rotation task (Marr, 1985), which measured the speed and accuracy in recognizing how objects will appear when rotated in two or three dimensions; and maze performance (Astur, Ortiz, & Sutherland, 1998) in learning routes through a three dimensional computer. Males' outperformance demonstrated by these tasks provided evidences that males may be embedded with better spatial reasoning ability.

4.2 Temporal factors in processing near and far stimuli

Different timescales were manipulated since we wanted to know how people perform under short and long timescale. The results found that the correctness percentage was statistically significant under the long duration, and participants performed much better than under the short duration. The outcome was not surprising. It is likely that the brief stimulus exposures impaired people from recognizing the character. On the contrary, extended viewing duration was less demanding, so people had more time to recognize the Chinese characters correctly.

We also aimed to examine whether different vergence resulted in different dynamic characteristics. In stereopsis, near targets presented on LoVF result in convergence, while far targets presented on UVF result in divergence. Semmlow and Wetzel (1979) found a shorter latency for convergence (180 msec) than divergence (200 mesec), with relatively small variability among subjects. On the other hand, Krishnan, Farazian and Stark (1973) found a longer latency for convergence (250 msec) than divergence (210 msec). Similarly, Yang et al. (2002) observed that the latency of convergence is longer than divergence between adults and children. The present results found that under the short duration, both genders showed superiority in making divergence and yielded to higher correctness for far stimuli. This correlates with the result that latencies for convergence were greater than for divergence.

Different latencies between convergence and divergence may originate from different motor signals and unique neural processing pathways for vergence. Mays (1984) examined the neurophysiological mechanisms involved in the initiation of convergence and divergence, and it was demonstrated that divergence cells provided a vergence signal to abducens motoneurons, while convergence cells provided abducens motoneurons with an inhibitory vergence signal. In the brain stem level, fewer neurons were identified in divergence than in convergence. Consequently, the visuomotor process and neurons involved in the preparation of these two types of eye movement result in shorter latency for divergence.

Some literature suggested that infants evaluated with CRD had better stereoacuities than those evaluated with URD (Held, et al., 1980). Infants' pronounced advantage in processing crossed stimuli may evolve from the inherent preference in processing things that are nearer to us. Nonetheless, the present result did not find such an inherent preference among adults. It is probably because adults are more mature in making vergence, so all participants did better on the divergence during the short duration.

Furthermore, the present paper also showed that the thresholds for dynamic stereopsis were distributed unequally between CRD and URD. For both genders, the uncrossed disparities were detected at consistently short durations for URD presented in the UVF. Under longer duration, while males perform better on URD, the preference was reversed for females as they perform better on CRD. Females' superiority in convergence under the long duration indicated with shorter latency for convergence than divergence. The results can be confirmed by the research of Zaroff, Knutelska and Frumkes (2003), suggesting that females' preference in processing convergence was more efficient than male. They carried out a rectangular roandom-dot stereograms task (e.g., pedestal stimulus) presented at different retinal disparities. Participants perceived the test stimulus as either appearing to pop out in front of the surrounding pedestal or as receding into the screen. They then needed to press the appropriate button to decide the location of the testing stimulus. This result demonstrated that females exhibited a lower threshold for perceiving crossed case in a random dot stereogram, so they were more sensitive to convergence that resulted in CRD. Despite the temporal factor that may affect us in processing near and far stimuli, it can also be suggested that there were at least two anatomically and functionally dissociable processing domains to CRD and URD. The asymmetry in spatial as well as the temporal resolution of processing CRD and URD indicates the evidence that CRD and URD may be mediated by mechanisms that have different spatiotemporal response properties, and that these may constitute separate neural disparities.

4.3 Size constancy illusion

Inconsistent with the research by Jameson and Hurvich (1959) who found that retinal maps and the visual cortex were fixed, the present results observed character recognition reflected perception rather than mere retinal image. Participants were in general more correct when characters were presented as far in reference to the fixation point. The results may stem from perceiving the far one being physically larger and thus recognize more correctly.

Previous literature showed that illusion can influence the reaction time of the participant in responding to the stimuli. For example, Sperandio et al. (2010) observed people's reaction time was sensitive to the Ponzo illusion since the upper line appeared to be longer. We found that the acuity also to be affected by visual illusions in the present study. Furthermore, both genders showed different sensitivity of illusion. Males were more sensitive to illusion since there was high correctness in processing the far stimuli under either the long or short timescale. On the other hand, females performed better on the near stimuli under the long timescale. This phenomenon suggested that males were more sensitive to the size constancy illusion than females, confirming different degrees of brain lateralization in processing illusion for both genders. In what follows, we will interpret the results by discussing the possible relationship between gender, laterality, and illusion.

4.3.1 Illusions and laterality

Previous studies have supported the view that two hemispheres played different part in processing the visual information, but there were different results regarding which hemisphere is dominant. Bertelson and Morais (1983) used a variation of the Ponzo distortion illusion but did not find hemispheric dominance. Still, a majority of studies showed that illusion was more likely to deceive in the right than left hemisphere. Houlard et al. (1976) tested normal participants and patients with unilateral cortical lesions on their susceptibility to Ponzo illusions. It was found that while normal participants could recognize the illusion, patients with left hemisphere lesions could also perceive the illusion. However, patients with right hemisphere lesions reduced the strength of the perceived illusion, consistent with the hypothesis that hemisphere differences influence the perception of the Ponzo illusion. Therefore, it was often implied that the right hemisphere was likely to activate under illusion perception.

The most common prediction regarding the right hemisphere in illusory perception may result from the right hemisphere processes the incoming information in a global, holistic way, while the left hemisphere does it in an analytical or sequential manner. Moreover, the right hemisphere is specialized in dealing with various kinds of non verbal visual spatial features (Grabowska, Szymanska, Nowicka, & Kwiecien, 1992), whereas the left hemisphere is more focused on the verbal information (Mcglone, 1977).

4.3.2 Gender and laterality

Although the performances of both genders overlap to a large degree, extensive reviews of gender differences in cognitive abilities reported that males perform better in some spatial cognitive tasks like mental rotation (Halpern, 1986) and maze learning (Moffat, Hampson, & Hatzipantelis, 1998), whereas females generally score higher on verbal tests like grammar, verbal fluency, and verbal production. With regard to right handed males, males' left hemisphere is dominant for speech and the right hemisphere is dominant for spatial tasks (Bryden, 1982). Males' stronger lateralization of higher perceptual functions was also discovered by Iaccino (1993), suggesting that males were superior to nonverbal materials like photographed faces in LVF in which information will be processed in the right hemisphere, and better at verbal materials presented in RVF in which information will be processed in the left hemisphere. On the other hand, females represent language in both hemispheres, which improves communication but impedes their spatial ability (Levy, 1976). Taken together, these researches provided indication that brain lateralization was more pronounced for males, while females exhibit more symmetrical functional cerebral organization, and the different degree of lateralization showed right hemisphere is more specialized in males for certain visuospatial processing tasks than females. The varied performance may reflect sex differences in hormone levels during development (Kimura, 1992). Nonetheless, the conclusion was not accepted by all researchers. Buggery and Gray (1972) found the contradictory result that males showed greater bilateral representation, whereas females were more specialized in the right hemisphere for visuospatial abilities. The incongruity drawn from these studies indicated that in spite of the influential factors of sex difference, the relationship between cortical organization and the efficiency of psychological functions may also affect the results. Therefore, the present study provided further evidence regarding how hemisphere specialization between males and females can influence the visuospatial functions.

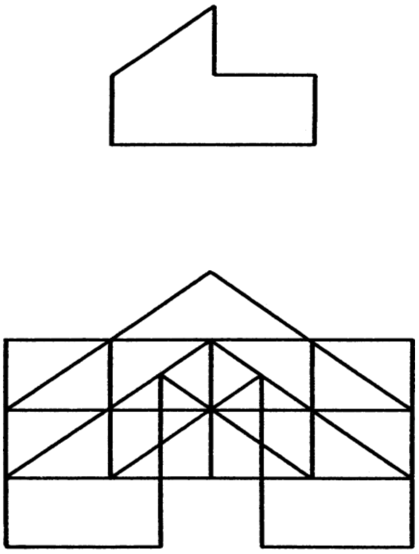
4.3.3 Illusions and gender

Hemispheric dominance and gender is an influential effect in illusion perception.
The present results showed that males were sensitive to the illusion since they performed better on the far stimuli under both short and long duration. Males' strong brain lateralization can account for their robust performance in illusion perception which dominants in right hemisphere. In contrast, since females exhibit more symmetrical hemispheric activation, this accounts for their various performances under different conditions.

Although we found that males perceive illusion more robustly, Miller (2001) found that females appeared to be more susceptible to the Ponzo illusion than males. In their experiment, the Ponzo illusion was administered using a 35 mm slide which was projected onto the screen, and participants had to record which of the two horizontal lines was longer. There was no significant difference when both genders were presented with the simple Ponzo illusion (i.e., only two radiating lines), but the difference emerged in processing complex Ponzo with more radiating lines. Since different illusion versions are influential enough to arouse different behavior, we wonder the divergent conclusion compare to our study can be attributed to different types of Ponzo illusion used in the experiment. Miller (2001) provided a pictorial line to reflect the depth information, while the present study required participants' retinal disparities to judge the depth information. Unlike pictorial information which can be processed monocularly, our experiment requires binocular viewing so that retinal disparities can be generated. To perceive the depth cues, participants can only rely on the grey fixation cross located in the middle of the black screen and the binocular disparities. Therefore, it can be speculated that in our experiment, more spatial resources were required in judging the depth information. To put it simply, females may do better at detecting the pictorial line in the experiment by Miller (2001), but may not be sensitive to the stereoscopic vision employed in the current experiment.

Miller (2001) explained the result by stating that females were more field dependent than males, who were more field independent. Field independence refers to the ability to separate simple visual forms that are embedded in a perceptually compelling, more complex visual field. A test of such embedded figures is shown in Figure 8. The embedded figures test (EFT) required participants to find the simple figure hidden in the more complex figure. The more quickly a participant can find the simple figure, the more field independent they are. Since females were more field dependent than males, as the research suggested that female cannot judge the relative lengths of the horizontal line accurately. On the other hand, males showed the field independent skill, showing an inclination to ignore the effects of the radiating lines, so they were more likely to judge the two lines as the same length. Nonetheless, the possible relationship between EFT and the Ponzo illusion is worth investigation. If EFT had an influence on people’s performance, males who score high on the EFT should be more susceptible to the Ponzo illusion than those who score lower. However, Miller (2001) did not find any correlation between EFT and Ponzo for males, so we cannot use EFT performance to relate the Ponzo illusion performance. Although those females who score higher do perform in a more susceptible way to the illusion, the absent effect for males may indicate that instead of relying on spatial ability required in EFT, the illusion perception difference may result from different strategies being adapted by both genders under different spatial tasks.

Figure 8. Example of embedded figures test



Source: Miller (2001).

Sex differences in spatial navigation reflect different behavior in processing stimuli in a 3-D world, and these sex differences may emerge in children between 5 to 12 years of age (Choi & Silverman, 2003). It was found that in the goal directed navigation, females utilize the landmark strategies, while males utilize a combination of orientation strategies, and the research reaches a large effect size for cross sex shift in navigation strategy (Rahman, Andersson, & Govier, 2005). They termed landmark strategies as using environmental information and descriptors, such as the location at which to turn right or left (e.g., “turn right at the church”). On the other hand, an orientation strategy relies on spatial representations and descriptors, inclusive of cardinal directions and distance information (e.g., “the bar is 5 miles in an easterly direction”). The current experiment presents participants with a 3-D scene (e.g., a character presented below/near or above/far in reference to the cross presented in the middle). Since females navigate an environment using a landmark strategy, they were more likely to rely on landmark cues, detecting the character as below or above. The decreased depth magnitude for females’ perception may well be interpreted as they perform negatively on far stimuli in comparison to the near one under long duration. On the other hand, the spatial skill is more pronounced for males than females, thus males were more prone to detect the character as near or far. As the depth magnitude increases, male may perceive more strongly the Ponzo illusion than female. In other words, the better perception of increased depth cues make males overestimate the size of the far character, so the far character appears clearer and easier to recognize.

4.3.4 Illusion, gender and laterality

The early stages of visual cortex processing are separated into left and right hemispheres, with each hemisphere taking responsibility for the contralateral side of visual fields. Past research has shown different degrees of visual field lateralization as well as brain distribution between males and females.

Rasmjou, Hausmann and Gunturkun (1999) conducted the first experiment observing the interaction of gender differences in the lateralized perception of illusions. Participants were present with the illusory trapeze to the RVF and LVF. It was found that the male group demonstrated significant LVF perception, whereas the female group displayed almost no asymmetrical perception. It was concluded that the right hemisphere was more readily deceived, especially for male. In the present research, males perform consistently on the illusion regardless of whether the duration was short or long. Although characters were not presented with RVF and LVF but LoVF and UVF, it can be interpreted that since the brain of males is more lateralized to the right hemisphere in which illusions are processed, they appear with robust illusion perception. On the other hand, the brain of females is more symmetrical, and thus their illusion perception differs depending on the length of presentation time.

4.4 Implications for future research

Overall, the current experiment provided evidence that UVF showed superiority over the LoVF, but in terms of gender differences regarding spatial performance fields, further investigation is required. Kimura (1992) reported that the cognitive patterns between males and females may be influenced by sex hormones. There are as yet a few reports pertaining to the hormonal effect on eye movement measures, so we need further report concerning the hormonal elements underlying gender differences in visual information processing. Furthermore, the sample we used in the present study was not balanced when it came to the gender distribution, so future studies will need to factor in sexual orientation regarding the above bias in detail.

In the present experiment, participants were often instructed to fixate upon the central fixation point prior to the stimulus presentation, so as to make sure that the stimuli were exclusively processed in the LoVF and UVF. However, it has been shown that participants rarely comply with such instruction (Jordan, Patching & Milner, 1998). Therefore, the way in which the eye tracking apparatus can be used to adequately control the fixation point might thus be a further interesting topic for future studies.

5. Conclusion

The goal of the present experiment was to explore how acuity may be influenced by spatial performance fields, stereopsis, temporal performance fields, and gender. To observe the interaction of these variables, we presented participants with characters located on the UVF (e.g., farther in reference to the cross) and LoVF (e.g., nearer in reference to the cross) under short and long time durations. Participants were asked to recognize the character as quickly as possible. Taken as a whole, these results have implications for the four research questions we have posed.

First of all, the current results identified the nature of horizontal visual field asymmetry, which is compatible with studies about UVF superiority (Goldstein & Babkoff, 2001). The general prioritization in processing far thing that are often towards the top of the visual field may attributed to ecologically plausible effect.

Secondly, the stereoacuity was affected by the depth information provided by the experiment. The improvement in acuity for far stimuli located on the UVF can be related to neural pathways as well as the size constancy illusion. In processing the far stimuli, the projection to the nasal retina with dense ganglion cells can improve the quality of the image perception. Moreover, the greater correctness in recognizing far characters confirmed that our visual system extracts distance information to estimate the physical size of an object. Since the far character seems bigger, the cortical magnification enables us to recognize the character more accurately.

Thirdly, as for temporal performance fields, previously we presume participants may have stronger effect on illusion over longer timescales. However, the inverted behavior of both genders suggesting that gender is an influential factor in illusion processing. On the other hand, under the short durations, the present results found that both genders showed superiority in making divergence and yielded to higher correctness for far stimuli. Therefore, we can conclude that the latency of convergence may be longer than divergence in general, requiring longer stimuli durations to evolve.

Lastly, gender differences in processing stereo information emerged in the present study. Males showed consistent superiority on UVF regardless of short or long time duration. Conversely, although females performed better on the UVF stimuli under short time durations, they performed better on the LoVF stimuli under long time durations. Males' superiority in processing far stimuli located on UVF may be enhanced for human hunter society as well as the navigation strategy they often adapt to. Furthermore, the gender differences may result from different degrees of brain lateralization in response to the illusion. Illusion was generally being processed on the right hemisphere. As the brain of a male is more lateralized in right hemisphere, it was very likely that they performed more robustly on illusion than females.

With regard to the privileged visual locations in terms of discriminability, temporal dynamics, and gender differences, these behavior differences help to determine how these variables may affect us in the perceptual and cognitive processing task.

6.References

Allen, P. A., Wallace, B., & Weber, T. A. (1995). Influence of Case Type, Word-Frequency, and Exposure Duration on Visual Word Recognition. *Journal of Experimental Psychology-Human Perception and Performance, 21*(4), 914-934.

Astur, R. S., Ortiz, M. L., & Sutherland, R. J. (1998). A characterization of performance by men and women in a virtual Morris water task: A large and reliable sex difference. *Behavioural Brain Research, 93*(1-2), 185-190.

Banks, M. S., Geisler, W. S., & Bennett, P. J. (1987). The Physical Limits of Grating Visibility. *Vision Research, 27*(11), 1915-1924.

Barlow, H. B., Blakemore, C., & Pettigrew, J. D. (1967). The neural mechanism of binocular depth discrimination. *Journal of physiology, 193*(2), 327-342.

Bertelson, P., & Morais, J. (1983). A Ponzo-Like Illusion Left and Right of Fixation - a Failed Prediction. *Neuropsychologia, 21*(1), 105-109.

Breitmeyer, B., Julesz, B., & Kropfl, W. (1975). Dynamic Random-Dot Stereograms Reveal up-down Anisotropy and Left-Right Isotropy between Cortical Hemifields. *Science, 187*(4173), 269-270.

Bryden, M. P. (1982). *Laterality: Functional asymmetry in the intact brain*. New York: Academic Press.

Bryden, M. P., & Underwood, G. (1990). Twisting the World by 90-Degrees. *Behavioral and Brain Sciences, 13*(3), 547-547.

Buggery, A. W. H., & Gray, J. A. (1972). sex differences in the development of spatial and linguistic skills. In C. Ounsted & D. C. Taylor (Eds.), *Gender Differences: Their ontogeny and Significance*: Churchill Livingstone, Edinburgh.

Cameron, E. L., Tai, J. C., Eckstein, M. P., & Carrasco, M. (2004). Signal detection theory applied to three visual search tasks - identification, yes/no detection and localization.

Spatial Vision, 17(4-5), 295-325.

Carrasco, M., & Frieder, K. S. (1997). Cortical magnification neutralizes the eccentricity effect in visual search. *Vision Research, 37*(1), 63-82.

Carrasco, M., Giordano, A. M., & McElree, B. (2004). Temporal performance fields: visual and attentional factors. *Vision Research, 44*(12), 1351-1365.

Choi, J., & Silverman, I. (2003). Processes underlying sex differences in route-learning strategies in children and adolescents. *Personality and Individual Differences, 34*(7), 1153-1166.

Christman, S. D. (1993). Local-Global Processing in the Upper Versus Lower Visual-Fields. *Bulletin of the Psychonomic Society, 31*(4), 275-278.

Cumming, B. G., & Parker, A. J. (1997). Responses of primary visual cortical neurons to binocular disparity without depth perception. *Nature, 389*(6648), 280-283.

Curcio, C. A., & Allen, K. A. (1990). Topography of Ganglion-Cells in Human Retina. *Journal of Comparative Neurology, 300*(1), 5-25.

Danckert, J., & Goodale, M. A. (2001). Superior performance for visually guided pointing in the lower visual field. *Experimental Brain Research, 137*(3-4), 303-308.

Davidson, H., Cave, K. R., & Sellner, D. (2000). Differences in visual attention and task interference between males and females reflect differences in brain laterality. *Neuropsychologia, 38*(4), 508-519.

DeAngelis, G. C. (2000). Seeing in three dimensions: the neurophysiology of stereopsis. *Trends in Cognitive Sciences, 4*(3), 80-90.

Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J. F., Poline, J. B., et al. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience, 4*(7), 752-758.

Dewar, R. E. (1967). Stimulus determinants of the magnitude of the Mueller-Lyer illusion. *Perceptual and Motor Skills, 24,* 708-710.

Emmert, E. (1881). Grossenverhaltnisse der Nachbilder. *Klinische Monatsblatter fur Augenheilkunde, 19,* 443-450.

Gaulin, S. J. C., & Fitzgerald, R. W. (1989). Sexual Selection for Spatial-Learning Ability. *Animal Behaviour, 37,* 322-331.

Goldstein, B. (2009). *Sensation and Perception* (8th ed.). CA: Wadsworth-Thomson Learning.

Goldstein, A., & Babkoff, H. (2001). A comparison of upper vs. lower and right vs. left visual fields using lexical decision. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology, 54*(4), 1239-1259.

Grabowska, A., Szymanska, O., Nowicka, A., & Kwiecien, M. (1992). The Effect of Unilateral Brain-Lesions on Perception of Visual Illusions. *Behavioural Brain Research, 47*(2), 191-197.

Gregory, R. L. (1966). *Eye and brain. The psychology of seeing.* London: Weidenfeld and Nicholson.

Hagenbeek, R. F., & Van Strien, J. W. (2002). Left-right and upper-lower visual field asymmetries for face matching, letter naming, and lexical decision. *Brain and Cognition, 49*(1), 34-44.

Halpern, D. F. (1986). *Sex differences in cognitive abilities*. Hilsdale: Lawrence Erlbaum Associates.

Harris, J. P., & Fahle, M. (1996). Differences between fovea and periphery in the detection and discrimination of spatial offsets. *Vision Research, 36*(21), 3469-3477.

Held, R., Birch, E., & Gwiazda, J. (1980). Stereoacuity of Human Infants. *Proceedings of the National Academy of Sciences of the United States of America-Biological Sciences, 77*(9), 5572-5574.

Hershenson, M. H. (1999). *Visual space perception: a primer.* London: MIT Press.

Holway, A. H., & Boring, E. G. (1941). Determinants of apparent visual size with distance variant. *American Journal of Psychology, 54*, 21-37.

Houlard, N., Fraisse, P., & Hecaen, H. (1976). Effects of unilateral hemispheric lesions on two types of optico-geometric illusions. *Cortex, 12*(3), 232-242.

Howard, I. P., & Rogers, B. (1995). *Binocular vision and stereopsis.* New York: Oxford. University Press.

Hung, G. K., Zhu, H. M., & Ciuffreda, K. J. (1997). Convergence and divergence exhibit different response characteristics to symmetric stimuli. *Vision Research, 37*(9), 1197-1205.

Iaccino, J. F. (1993). *Left brain--right brain differences: Inquiries, evidence, and new approaches*. Hillsdale, N. J.

Jameson, D., & Hurvich, L. M. (1959). Note on Factors Influencing the Relation between Stereoscopic Acuity and Observation Distance. *Journal of the Optical Society of America, 49*(6), 639-639.

Jenkins, T. C. A., Pickwell, L. D., & Abd-Manan (1992). Effect of induced fixation disparity on binocular visual acuity. *Ophthal Physiol Opt 12*, 299-301.

Jordan, T. R., Patching, G. R., & Milner, A. D. (1998). Central fixations are inadequately controlled by instructions alone: Implications for studying cerebral asymmetry. *Quarterly Journal of Experimental Psychology,51A*, 371–391.

Jordan, T. R., Patching, G. R., & Milner, A. D. (2000). Lateralized word recognition: Assessing the role of hemispheric specialization, modes of lexical access, and perceptual asymmetry. *Journal of Experimental Psychology-Human Perception and Performance, 26*(3), 1192-1208.

Kimura, D. (1992). Sex-Differences in the Brain. *Scientific American, 267*(3), 119-125.

Krishnan, V. V., Farazian, F., & Stark, L. (1973). Analysis of Latencies and Prediction in Fusional Vergence System. *American Journal of Optometry and Physiological Optics, 50*(12), 933-939.

Lavidor, M., Alexander, T., & McGraw, P. V. (2009). Word recognition processes modulate the naso-temporal asymmetry of the human visual field. *Perception, 38*(10), 1536-1541.

Levine, M. W., & McAnany, J. J. (2005). The relative capabilities of the upper and lower visual hemifields. *Vision Research, 45*(21), 2820-2830.

Levy, J. (1976). Cerebral Lateralization and Spatial Ability. *Behavior Genetics, 6*(2), 171-188.

Lewis, T. L., & Maurer, D. (1992). The Development of the Temporal and Nasal Visual-Fields during Infancy. *Vision Research, 32*(5), 903-911.

Marr, D. (1985). *Vision*. New York: Freeman.

Mays, L. E. (1984). Neural Control of Vergence Eye-Movements - Convergence and Divergence Neurons in Midbrain. *Journal of Neurophysiology, 51*(5), 1091-1108.

Mcglone, J. (1977). Sex-Differences in Cerebral Organization of Verbal Functions in Patients with Unilateral Brain Lesions. *Brain, 100*, 775-793.

Miller, R. J. (2001). Gender differences in illusion response: The influence of spatial strategy and sex ratio. *Sex Roles, 44*(3-4), 209-225.

Mishkin, M., & Forgays, D. G. (1952). Word Recognition as a Function of Retinal Locus. *Journal of Experimental Psychology, 43*(1), 43-48.

Moffat, S. D., Hampson, E., & Hatzipantelis, M. (1998). Navigation in a "virtual" maze: Sex differences and correlation with psychometric measures of spatial ability in humans. *Evolution and Human Behavior, 19*(2), 73-87.

Murray, S. O., Boyaci, H., & Kersten, D. (2006). The representation of perceived angular size in human primary visual cortex. *Nature Neuroscience, 9*(3), 429-434.

Pflugshaupt, T., von Wartburg, R., Wurtz, P., Chaves, S., Deruaz, A., Nyffeler, T., et al. (2009). Linking physiology with behaviour: Functional specialisation of the visual field is reflected in gaze patterns during visual search. *Vision Research, 49*(2), 237-248.

Poggio, G. F., Gonzalez, F., & Krause, F. (1988). Stereoscopic Mechanisms in Monkey Visual-Cortex - Binocular Correlation and Disparity Selectivity. *Journal of*

Neuroscience, 8(12), 4531-4550.

Porac, C., Coren, S., Girgus, J. S., & Verde, M. (1979). Visual-Geometric Illusions - Unisex Phenomena. *Perception, 8*(4), 401-412.

Previc, F. H. (1990). Functional Specialization in the Lower and Upper Visual-Fields in Humans - Its Ecological Origins and Neurophysiological Implications. *Behavioral and Brain Sciences, 13*(3), 519-541.

Rahman, Q., Andersson, D., & Govier, E. (2005). A specific sexual orientation-related difference in navigation strategy. *Behavioral Neuroscience, 119*(1), 311-316.

Rasmjou, S., Hausmann, M., & Gunturkun, O. (1999). Hemispheric dominance and gender in the perception of an illusion. *Neuropsychologia, 37*(9), 1041-1047.

Schindel, R., & Arnold, D. H. (2010). Visual Sensitivity Can Scale with Illusory Size Changes. *Current Biology, 20*(9), 841-844.

Semmlow, J., & Wetzel, P. (1979). Dynamic Contributions of the Components of Binocular Vergence. *Journal of the Optical Society of America, 69*(5), 639-645.

Sereno, M. I., Dale, A. M., Reppas, J. B., Kwong, K. K., Belliveau, J. W., Brady, T. J., et al. (1995). Borders of Multiple Visual Areas in Humans Revealed by Functional Magnetic-Resonance-Imaging. *Science, 268*(5212), 889-893.

Sherry, D. F., & Hampson, E. (1997). Evolution and the hormonal control of sexually-dimorphic spatial abilities in humans. *Trends in Cognitive Sciences, 1*(2), 50-56.

Sperandio, I., Savazzi, S., & Marzi, C. A. (2010). Is simple reaction time affected by visual illusions? *Experimental Brain Research, 201*(2), 345-350.

Talgar, C. P., & Carrasco, M. (2002). Vertical meridian asymmetry in spatial resolution: Visual and attentional factors. *Psychonomic Bulletin & Review, 9*(4), 714-722.

Thomas, O. M., Cumming, B. G., & Parker, A. J. (2002). A specialization for relative disparity in V2. *Nature Neuroscience, 5*(5), 472-478.

Trotter, Y., Celebrini, S., Stricanne, B., Thorpe, S., & Imbert, M. (1992). Modulation of Neural Stereoscopic Processing in Primate Area-V1 by the Viewing Distance. *Science, 257*(5074), 1279-1281.

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (549-586). Cambridge, MA: MIT Press.

Wheatstone C, (1838). Contribution to the physiology of vision-Part the first. On some remarkable, and hitherto unobserved, phenomena of the binocular vision. *Philosophical Transactions of the Royal Society of London, 128,* 371- 394.

Yang, Q., Bucci, M. P., & Kapoula, Z. (2002). The latency of saccades, vergence, and combined eye movements in children and in adults. *Investigative Ophthalmology & Visual Science, 43*(9), 2939-2949.

Young, A. W., & Ellis, A. W. (1985). Different Methods of Lexical Access for Words Presented in the Left and Right Visual Hemifields. *Brain and Language, 24*(2), 326-358.

Zaroff, C. M., Knutelska, M., Frumkes, T. E. (2003). Variation in stereoacuity: Normative description, fixation disparity, and the roles of aging and gender. *Investigative Ophthalmology and Visual Science, 44*(2), 891-990.