EVALUATION OF STEREOPSIS AND FUSION IN PATIENTS WITH VESTIBULAR VERTIGO

DR NOR HASNIDA AB GANI

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DISCLAIMER

I hereby certify that the work in this dissertation is my own except for the quotations and summaries which had been duly acknowledged. I declare that I have no financial interest in the instruments and the computer software used in this study.

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In the Name of Allah, the Most Beneficent, the Most Merciful

They (angels) said: *Glory be to You, we have no knowledge except what You have taught us. Verify, it is You, the All Knower, the All Wise* (2:32)

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ABSTRAK

Pengenalan:

Lakuran dan stereopsis adalah komponen penglihatan binokular di mana stereopsis adalah gred yang tertinggi. Beberapa kajian terdahulu menunjukkan bahawa gangguan penglihatan binokular adalah salah satu penyebab yang menyumbang kepada kesulitan dalam proses penyembuhan vertigo vestibular. Ini disebabkan kerana adanya perbezaan fiksasi dan penurunan stereopsis. Penglihatan binokular yang normal sangat penting dalam menentukan kestabilan postur tubuh kerana ianya diperlukan untuk mengekalkan imej visual pada retina semasa refleks vestibulo-okular. Oleh itu, kajian ini telah dilakukan untuk menilai penglihatan binokular pada pesakit vertigo vestibular.

Objektif:

Untuk membandingkan min stereopsis dan min amplitud vergens lakuran antara pesakit vertigo vestibular dan kumpulan kawalan.

Kaedah:

Kajian keratan rentas perbandingan dilakukan di Klinik Oftalmologi, Hospital Universiti Sains Malaysia, Kelantan dari Januari 2019 hingga Februari 2021 di kalangan pesakit vertigo vestibular dan kumpulan kawalan. Lima puluh tujuh pesakit dibandingkan dengan 57 kawalan dalam lingkungan usia yang sama antara 30 hingga 60 tahun. Kedua-dua kumpulan ini yang memenuhi kriteria yang diperlukan akan dinilai stereopsis dan amplitud vergens lakuran. Stereopsis jauh diuji menggunakan M&S Smart System II PC-Plus dan

stereopsis dekat diuji menggunakan Titmus Test. Amplitud vergens lakuran diukur menggunakan kanta prisma.

Keputusan:

Analisis parametrik stereopsis menunjukkan perbezaan min stereopsis dekat yang signifikan secara statistik ($p<0,05$) dan perbezaan yang tidak signifikan pada min stereopsis jauh ($p>0,05$) antara vertigo vestibular dan kumpulan kawalan. Ujian *Independent t* menunjukkan pengukuran amplitud vergens lakuran yang terdiri daripada positif dan negatif vergens lakuran untuk jarak rehat dan jauh pada titik pecah dan pemulihan adalah signifikan secara statistik dalam perbezaan min antara kedua kumpulan tersebut ($p<0.05$).

Kesimpulan:

Terdapat perbezaan yang signifikan secara statistik pada stereopsis dekat dan amplitud vergens lakuran antara pesakit vertigo vestibular dan kumpulan kawalan. Walau bagaimanapun, tidak ada perbezaan yang signifikan pada stereopsis jauh.

ABSTRACT

Introduction:

Fusion and stereopsis are components of binocular vision in which the stereopsis is the highest grade. Various studies showed that binocular vision dysfunction is one of the causes that contribute to refractory vestibular vertigo due to the presence of fixation disparity and reduced stereopsis. Binocular vision is an important factor for postural stability. Normal binocular vision is required to retain stable visual image on retina during vestibulo-ocular reflex. Thus the presence of binocular vision dysfunction in vertigo warrants an evaluation.

Objective:

To compare the means of stereopsis and fusional vergence between the patients with vestibular vertigo and control subjects.

Methodology:

A comparative cross-sectional study was conducted in the Ophthalmology Clinic, Hospital Universiti Sains Malaysia, Kelantan from January 2019 till February 2021 among patients with vestibular vertigo patients and the control group. 57 patients included in this study with 57 controls who are in the same age range of 30 to 60 years old. Both groups were evaluated for stereopsis and fusion vergence amplitude once fulfilled the required criteria. The far and near stereopsis were tested using M&S Smart System II PC-Plus and Titmus Test respectively. Fusional vergence was measured using a prism bar.

Results:

Parametric analysis of stereopsis revealed a statistically significant difference of mean stereopsis at near ($p<0.05$) and an insignificant difference in mean stereopsis at far ($p>0.05$) between vestibular vertigo patients and the control group. Independent *t* test showed statistically significant difference of mean fusional vergence measurement ($p<0.05$) between these two groups which consists of near and far of negative and positive fusional vergence for break and recovery point.

Conclusion:

There was statistically significant difference in mean near stereopsis and fusional vergence between patients with vestibular vertigo and the control group. However, there was no significant difference in mean for far stereopsis.

Chapter 1

INTRODUCTION

1. INTRODUCTION

1.1 STUDY INTRODUCTION

The prevalence of binocular vision dysfunction in various population has a wide range of discrepancies (Cacho-Martínez *et al.*, 2010). Majority of the studies were done in paediatric population compared to adults (Radakovic *et al.*, 2012; Jang & Park, 2015; Yekta *et al.*, 2015). The prevalence rate that is available in literatures only estimate the occurrence of binocular vision dysfunction in selected population (Cacho-Martínez *et al.*, 2010). There are various types of binocular vision abnormality including convergence insufficiency, convergence excess, divergence insufficiency, divergence excess, heterophoria and fusional vergence dysfunction. The prevalence range is wide. In normal adult population, the prevalence of binocular vision abnormality ranged from 13.5% to 40.0% in many studies (Cacho-Martínez *et al.,* 2010; García-Muñoz *et al.*,2016; Ma *et al.,* 2019). It becomes higher in older adult population once they reach their sixth decade of life (Leat *et al.*, 2013).

Binocular vision consists of three grades namely simultaneous perception, fusion and stereopsis. Problems with either one of this components causes binocular vision dysfunction. The binocular vision dysfunction can be accessed by examining the accommodative excess, accommodative insufficiency, accommodative infacility, convergence insufficiency, convergence excess, divergence excess, divergence insufficiency, basic esophoria, basic exophoria, fusional vergence dysfunction and vertical deviation (Cacho-Martínez *et al.*, 2010). Fusional vergence dysfunction occurs around 0.4-1.5% in normal population (Cacho-Martínez *et al.*, 2010).

Stereopsis and fusion are two parameters that are frequently being used for binocular vision assessment. The stereopsis depends on equal normal visual acuity and normal alignment of the eyes. They could be analysed through stereoacuity, sensory and motor fusion (Heron & Lages, 2012; Bohr & Read, 2013; Lança & Rowe, 2016). Any abnormality of stereoacuity or fusional vergence measurement means there is presence of binocular vision dysfunction (Iwata *et al.*, 2016; Lança & Rowe, 2016).

Various studies on binocular vision dysfunction used fusional vergence and stereoacuity to measure the binocular vision dysfunction (Wright *et al*., 2015, Nabie *et al.*, 2016;). Garcia-munoz *et al*. (2016) analysed the prevalence of accommodative and binocular dysfunction between university students by using several binocular vision tests which included fusional vergence and stereopsis.

The term of vestibulo-ocular reflex was coined by Róbert Bárány more than a century ago, vertigo commonly has been associated as a symptom of vestibular in origin (Chin, 2018). However it also could be a symptom of other etiology that disturbs the body's highly coordinated balance and equilibrium system. Vertigo might be central in origin, a part of systemic diseases, or ophthalmological in etiologies (Bronstein *et al.,* 2010; Armstrong *et al.*, 2016; Rainer *et al*., 2017).

A retrospective study in a Neuro-Otology Clinic in West Malaysia showed that 66% of the causes for vertigo in patients who attended their clinic were vestibular in origin (Philip & Prepageran, 2009). It occurs mostly among 40 to 60 year old (Philip & Prepageran, 2009). Only 3% were central causes while remaining 27% was classified as idiopathic (Philip & Prepageran, 2009). The possibility of ophthalmological causes as the etiologies for this idiopathic group might be a subject of interest for ophthalmologists to explore.

Even though the peripheral causes for vertigo are mainly vestibular in origin, eye problem is still a potential cause. As we know, the vestibulo-ocular reflex is a reflex that link between the vestibular organ and eyes through a very complex nervous system. Hence anything that disturbs the pathway of this reflex could initiate vertigo. A systematic review by Armstrong *et al.* (2016) concluded that there was a link between vertigo and vision problem. Recent evidence has shown that vertigo is also associated with the error in oculomotor functions, abnormal binocular vision, such as in the case of visual vertigo and vertical phoria, defect in visual fields, visual acuity disorders, anisometropia and certain form of cataract (Jackson & Bedell, 2012; Cohen, 2013; Rainer *et al.*, 2017; Chin, 2018).

Most of the time, vertigo is an underrated symptom of ocular problem. In vertical heterophoria or motion sickness, patients complained of diplopia, drowsiness, fatigue, vertigo, nausea and vomiting (Jackson & Bedell, 2012). Meanwhile, patients with binocular vision dysfunction have symptoms of asthenopia, blurring of vision, intermittent diplopia, headache and dizziness (Hamed *et al.*, 2012; Delfosse *et al.*, 2018).

In cases with refractory vestibular symptoms, binocular vision dysfunction may affect the recovery, render the patient to be in a state of chronic dizziness (Bronstein *et al.*, 2010; Pavlou *et al.*, 2015). The delay in recovery also may be explained by the presence of impaired body balance and poor postural control in patients with binocular vision dysfunction (Przekoracka-Krawczyk *et al.*, 2014). Dynamic body balance requires a good binocular vision (Delfosse *et al.*, 2018).

Przekoracka-Krawczyk *et al.*(2014) evaluated the impaired body balance control in adults with strabismus and binocular vision dysfunction. The binocular vision tests used were cover test, alternating cover test with prism bar, fusional vergence, Worth 4 Dot test , near point of convergence and Titmus stereo test. From this study, imbalance of body control could be due to binocular vision dysfunction indirectly and poor oculomotor control.

Leat *et al*. (2013) determine the prevalence of binocular vision dysfunction and eye movement disorders in a clinic population of older adults. Stereopsis and fusion were used as parameters to measure the presence of binocular vision dysfunction in older age. They concluded that poor stereopsis in older age is a risk factor of fall and hip fracture. It showed that good postural balance is needed for good binocular vision.

Pavlou *et al.* (2015) reported in their study involving 34 subjects with refractory peripheral vestibular symptoms, 23.5% of them had binocular vision dysfunction, including impaired stereopsis, heterophoria and higher degree of astigmatism. There was significant different in term of recovery after vestibular rehabilitation when they compared between the group with binocular vision dysfunction and without it. Faster recovery was also observed in the group without problem.

Winkler and Ciuffreda (2009) observed that patients with vestibular dysfunction and visual vertigo would most likely experience fusional vergence as compared to the control groups. There was significant difference when they compared both group to the control groups in term of stereopsis and near point convergence.

Jackson and Bedell (2012) performed an experiment of 43 non-clinical subjects and revealed that there was an association between vertical phoria and motion sickness. Vertical phoria occurs once fusional vergence is interrupted and unable to maintain single vision. There were able to reduce the motion sickness in 50% of the cases through introduction of prism to correct the phoria.

Cohen (2013) reviewed the importance of vision and visual processing in maintaining a sense of balance and equilibrium and the role of the neuro-optometrist in the overall rehabilitation of patients with balance disorders. He assessed the level of sensory motor processing by measuring the visual acuity, ocular alignment, fusional vergence, near point of convergence and stereopsis. The study concluded that vestibular function is a prerequisite for balance and stable visual environment. The combination of balance and neuro-optometric rehabilitative therapy can effectively treat vertigo symptoms.

Rainer *et al*. (2017) discussed one of isolated causes of dizziness was ophthalmology aetiologies such as reduced visual acuity, visual field defect, binocular vision dysfunction, anisometropia, metamophopsia and cataract.

Even though the ocular problem is not the common causes of vertigo, the role of ophthalmologist in assessing the ocular motility perhaps can be one of the diagnostic test carried out for the evaluation of vertigo. Analysis of specific visual functions may have a significant role in searching for the aetiologies of vertigo in times to come (Franco Zietz & Hegemann, 2013).

1.2 BACKGROUND

1.2.1 Binocular Vision

Romano defined binocular vision as a state of simultaneous vision with two seeing eyes that occurs when an individual fixes his visual attention on an object (Morya *et al.,* 2019). Through a well coordinated organisation of motor and sensory process, binocular vision is achieved. These include central fixation with normal visual acuity in both eyes, precise oculomotor control for bifoveal fixation, normal retinal correspondence of visual directions, production of single vision by sensory mechanisms and depth perception by neural mechanisms. Failure of any component in this organisation might compromise binocular vision and stereopsis (Ronald & Clifton, 2011).

By having two eyes, the binocular field of view is larger. Any pathology or refractive problem that causes distortion of image or blind spot in one eye, could be compensated by the other normal eye in retaining the functional vision. Normal binocular vision makes the functional vision better by binocular summation and stereopsis. Stereopsis improves in depth perception that occurs with binocular viewing (Ronald & Clifton, 2011).

The retinal images of the two eyes that share a common visual direction is termed as retinal correspondence. Normal retinal correspondence takes place when both fovea bear identical visual direction which are the retinal elements nasal to the fovea in one eye corresponds to the retinal elements temporal to the fovea in the other eye. Abnormal retinal correspondence is when the fovea of one eye has a common visual direction with an extrafoveal area in the other eye. In this condition, diplopia will be present if corresponding points are not on the horopter curve. Horopter can be defined as all points in a physical space that stimulate corresponding retinal element and thus are seen singly. There is also Panum's area which is an area in front and behind the horopter curve, in which the expected diplopia does not occur (Leuder *et al.*, 2014).

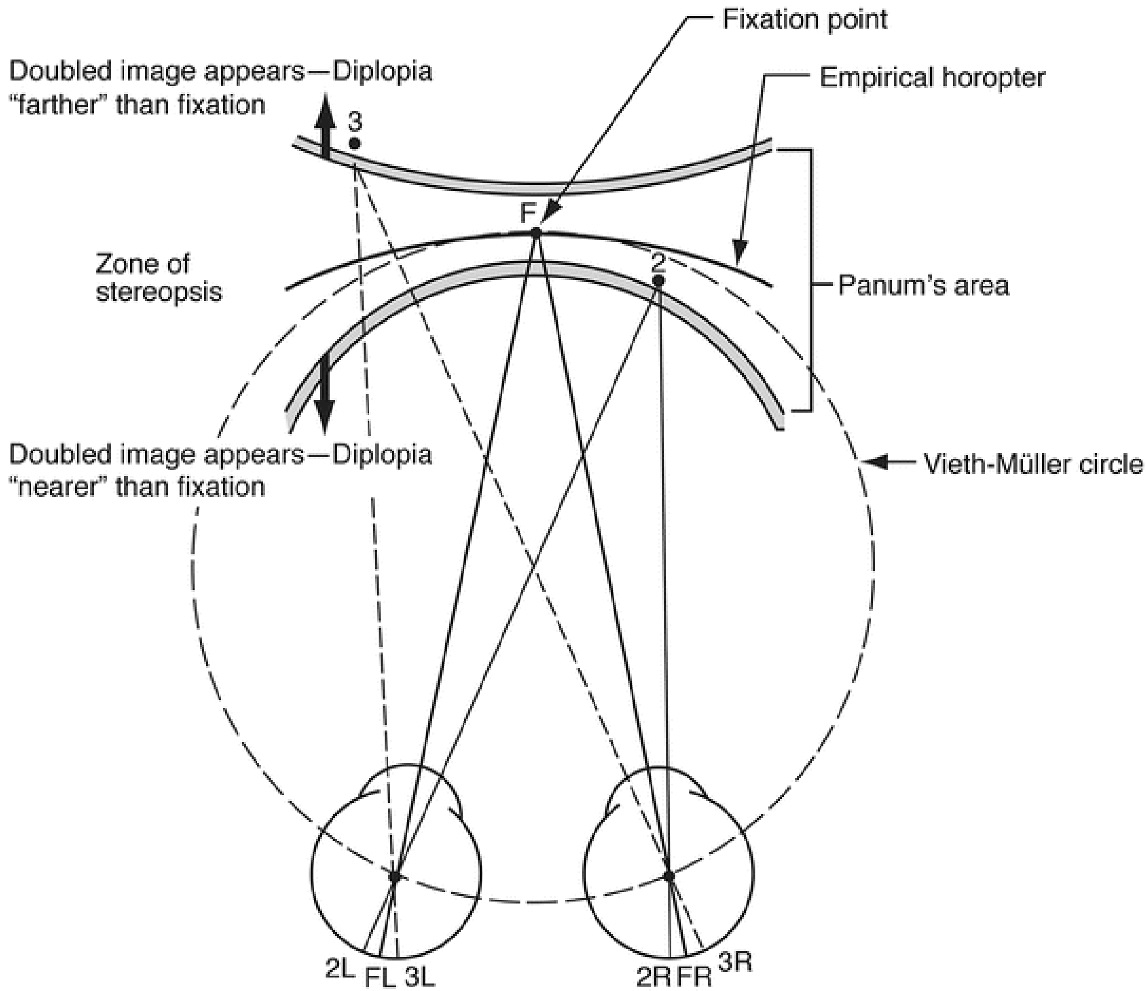

Figure 1.1: Horopter and panum area (Adapted from Allison, (2016). *Practical Management of Pediatric Ocular Disorder and Strabismus: A Case Based Approach*)

Binocular vision consists of three grades as suggested by Claud Worth (Morya *et al.,* 2019). The most basic is simultaneous perception, followed by stereopsis and fusion. Grade one, simultaneous perception is the ability to appreciate two slightly dissimilar objects simultaneously which the image of the object must fall on the fovea, the most sensitive visual area. Simultaneous perception can be measured with synoptophore.

Grade two binocular vision is fusion. Fusion is defined as the ability of both eyes to fuse the dissimilarity images which is incomplete in small detail as a composite image. Fusion can be divided into sensory and motor fusion. Sensory and motor fusion are central processes and happened in visual cortex. Sensory fusion is the ability of the two eyes to perceive two similar images, where each one them formed on each retina and interpreted as a single image (Morya *et al.,* 2019). For sensory fusion to fused, the images must be similar up to 14 minutes of arc and located on the corresponding retinal areas to permit sensory. The Worth 4 Dot test is often considered as a test for sensory fusion.

Motor fusion is a vergence movement of the eye which maintains the sensory fusion onto corresponding retinal area. This movement is called fusional vergence. Several methods can be used to measure fusional vergence using either major amblyoscope, a rotary prism, or a bar prism whereby the prism power is increased gradually until diplopia occur. The normal fusional vergence is shown in the table below (Leuder *et al.*, 2014).

Table 1.1: Average normal fusional vergence in prism diopters (Δ)

Testing Distance	**Convergence**	**Divergence**	**Vertical**
6 metre	14	6	2.5
25 centimetre	38	16	2.6

Taken from BCSC 2014-2015 series: Section 6 – Pediatric Ophthalmology and Strabismus.

Stereopsis is the highest binocular function in the hierarchy (Iwata *et al*., 2016). It is the ability of the eyes to appreciate the subtle binocular disparities and use the information to perceive depth and three-dimensional shape of objects (Morya *et al.,* 2019). Stereopsis is measured in seconds of arc where 1^o is equal to 60 minutes of arc and 1 minute of arc equal to 60 seconds of arc (Bowling, 2016). The lower the of arc value the better stereopsis is. Normal visual acuity is 1 minute of arc while normal stereopsis is 60 seconds of arc which is equal to visual acuity. However, seconds of arc is commonly used for stereopsis.

There are various stereopsis tests that are uses different medium of testing. Contour stereopsis test involves horizontal separation of physical contours presented in each eye with polarized or red-green glasses, such as Titmus stereo test. TNO and Frisby test is random dot stereopsis test that provide the most definitive evidence of high grade binocular vision (Bowling, 2016).

Titmus stereo test, is able to detect the superimposed image of the fly's wings on the plane card which indicates stereopsis. The fly is a test of gross stereopsis which is interpreted in 3000 seconds, the animal component which consist of three rows of stylized animals as 400-100 seconds and the series of circles measuring 800–40 seconds of stereopsis (Bowling, 2016).

The binocular vision dysfunction includes heterophoria, heterotropia, accommodation dysfunction, vergence dysfunction, suppression, amblyopia, central fixation and anomalous retinal correspondence (KKM, 2009). The instability of binocular vision also can cause symptoms of disequilibrium and balance problems which is a symptom of vertigo (Cohen, 2013).

1.2.2 Vertigo

Vertigo is defined as the sense of self-motion when no motion is occurring or the sensation of distorted self-motion during an otherwise normal head movement (Cherian, 2013). American Academy of Otolaryngology – Head and Neck Surgery (AAO-HNS) describes vertigo as the sensation of the room or the world moving, usually a spinning sensation (Malekzadeh, 2015). Any illusion of self motion or object motion, dizziness precipitated by head movement, recurrent dizziness with nausea, or imbalance would qualify as vertigo (Neuhauser, 2016).

Vertigo occurs when there is a mismatch of information that the brain receives from its primary input system, mainly vestibular system, visual and proprioception, or disturbances in its pathway. Vestibular apparatus is a part of inner ear contains sensory organ that detect spatial orientation of the head and initiate postural reflexes through vestibulospinal reflex to maintain the balance of the body (Malekzadeh, 2015). Visual information from the eye provides estimation of position of the eye relative to the surrounding. Through vestibulo-ocular reflex, the gaze is maintained during head movement in order to make sure the image always fall on the fovea (Bronstein, 2018). Disturbance of vestibulo-ocular reflex will be presented as nystagmus.

Balance is the ability to maintain body's centre of gravity over its support base. Our body's equilibrium is maintained by a highly complex integrated sensory motor control system, that requires input from vestibular and visual system also proprioception in addition to the command from higher centre through motor output to all of these systems (Sealy, 2014). When vestibular systems have a problem, our body depends on visual cues and proprioception in order to maintain body posture and balance, while at the same time, central compensation occurs at the higher centre (Bronstein, 2018). Patients with impaired vestibular function mainly depend on their vision to maintain the balance (Winkler & Ciuffreda, 2009).

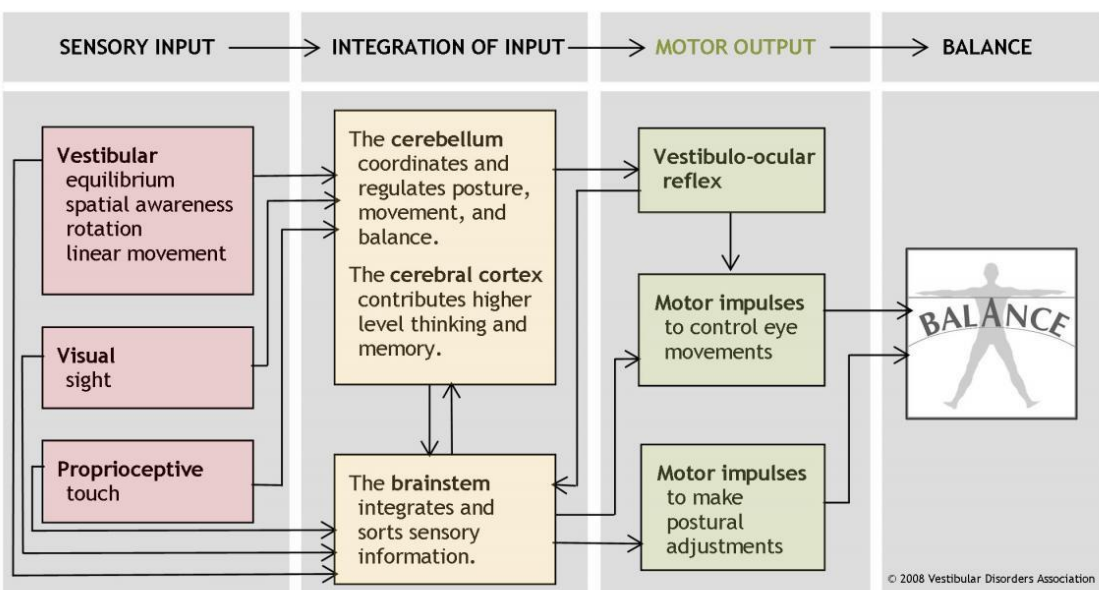

Figure 1.2: The complex balance control system. (Adapted from Vestibular Disorder Association (www.vestibular.org)

The most common cause for vertigo is peripheral and vestibular in origin. However it could also be triggered by central causes, cardiovascular, endocrine/metabolic diseases, neurological, drugs or psychiatric problem (Philip & Prepageran, 2011). The summary of the causes is shown in Table 1.2.

Table 1.2: Causes of vertigo

Causes of vertigo	Examples
Vestibular causes	Benign paroxysmal positional vertigo Vestibular hypofunction Vestibular neuritis Labyrinthitis Meniere's disease Perilymph fistula Superior semicircular canal dehiscence Vestibular migraine
Central causes	Acoustic neuroma Cerebrovascular accident Space occupying lesion Head trauma
Systemic causes	Drugs – eg: aminoglycosides, antimalarial agent, chemotherapy agents Multiple sclerosis Cardiovascular disease Vertebrobasillar insufficiency
Psychological causes	Anxiety Mood disorder Hyperventilation

Patients with vertigo can be examined by performing complete ear, nose and throat examination, cranial nerve, oculomotor tests, vestibulo-ocular reflex test, vestibulospinal tract test, cerebellar test and positional maneuvers (Philip & Prepageran, 2011). In majority of the cases, the diagnosis can be made from a proper history and clinical examination only. Several investigations can be done to help arrive at the diagnosis, such as caloric tests, video nystagmography, vestibular-evoked myogenic potentials and posturography (Bronstein, 2018).

1.3 Rationale of Study

Majority of vertigo patients' eyes and vision are not thoroughly assessed. They may have undiagnosed ocular problems, which may induce vertigo, causing a delay in their definite diagnosis or their recovery from vertigo. Previous studies showed that fixation disparity and reduced stereopsis are among the causes that contribute to refractory vestibular vertigo. Binocular vision is one of the important element for postural stability. Normal binocular vision is required to retain stable visual image on retina during vestibulo-ocular reflex. By conducting this study, the analysed data for stereopsis and fusion could be a strong evidence for compulsory eye examination and binocular vision assessment in patients who are diagnosed to have vestibular vertigo. Thus, early treatment can be given. Ophthalmologists and optometrists undoubtedly will have a very important role in treating the vertigo patients together with neuro-otologist and neurologist. We hope with the completion of this research, a positive and significant finding of this study may sprovide for a more holistic and multidisciplinary approach in treating vertigo patients in the future.

The data also can be used as a reference for the other studies generally in binocular vision research, and particularly in stereopsis and fusion which are still lacking in Malaysia.

Chapter 2

OBJECTIVES AND HYPOTHESIS

2. OBJECTIVES AND HYPOTHESIS

2.1 GENERAL OBJECTIVE

To evaluate the stereopsis and fusion in patients with vestibular vertigo.

2.2 SPECIFIC OBJECTIVES

2.2.1 To compare the mean of stereopsis between patients with vestibular vertigo and control group.

2.2.2 To compare the mean fusional vergence between patients with vestibular vertigo patients and control group.

2.3 HYPOTHESIS

2.3.1 STUDY QUESTIONS

1. Is there any significant difference in the mean of stereopsis between patients with vestibular vertigo and control subjects?

2. Is there any significant difference in the mean fusional vergence between patients with vestibular vertigo and control subjects?

2.3.2 STUDY HYPOTHESIS

1. There is significant difference in the mean of stereopsis between patients with vestibular vertigo and control subjects.

2. There is significant difference in the mean fusional vergence between patients with vestibular vertigo and control subjects.

Chapter 3

MATERIAL AND METHODOLOGY

3. STUDY METHODOLOGY

3.1 Study Design

Type of study: Comparative Cross-Sectional Study.

3.2 Population, Setting And Time

Study Population : All patients with vestibular vertigo in Kelantan.

Source Population : All patients with vestibular vertigo who attended Otorhinolaryngology, Head and Neck Surgery Clinic, Hospital Universiti Sains Malaysia during study duration.

Sampling Frame : All patients with vestibular vertigo age 30–60 years old, attended Otorhinolaryngology, Head and Neck Surgery Clinic, Hospital Universiti Sains Malaysia during study duration.

Place of study : Ophthalmology and Otorhinolaryngology, Head and Neck Surgery Clinic, Hospital Universiti Sains Malaysia.

Study Duration : January 2019–February 2021.

3.3 Sample Saiz and Sampling Method

3.3.1 Sampling Method

Purposive sampling method was used. Patients with vestibular vertigo who attended the Vertigo Clinic, Otorhinolaryngology, Head and Neck Surgery Hospital Universiti Sains Malaysia from January 2019 – February 2021 that fulfilled the inclusion and exclusion criteria and consented for the study were recruited in this study. The selected patients were explained regarding the study purposes and study processes before obtaining their consent.

3.3.2 Sample size

Sample size was calculated using SPSS software 26.0 based on previous study by Nabie *et al*. (2016) and Sharma *et al*. (2008).

3.3.3 Sample Size Calculation

Objective 1

To compare the mean of stereopsis between patient with vestibular vertigo and control subjects.

Based on Nabie *et al.* (2016), the sample size was calculated using two mean formula,

$$n = \frac{2\sigma^2}{\Delta^2} (Z_\alpha + Z_\beta)^2$$

σ =standard deviation of either group

Δ =expected detectable difference between two groups

Z_α =1.96 for α =0.05 (two tailed)

Z_β =0.84 for 80% power

$$n = \frac{2\,(2.17)^2}{2.19^2} (1.96 + 0.84)^2$$

$$n = 15$$

To consider 10% drop out,

n = **17** in each group

Objective 2

To compare the mean of fusional vergence between patient with vestibular vertigo and control subjects. Based on *far negative fusional vergence for break point* measurement in Sharma *et al*. (2008), the sample size was calculated using two mean formula,

$$n = \frac{2\sigma^2}{\Delta^2} \quad (Z_\alpha + Z_\beta)^2$$

σ =standard deviation of either group

Δ =expected detectable difference between two groups

Z_α =1.96 for α =0.05 (two tailed)

Z_β =0.84 for 80% power

$$n = \frac{2\ (1.7)^2}{1.1^2} \quad (1.96 + 0.84)^2$$

$$n = 37$$

To consider 10% drop out,

n = **40** in each group