THE PROFILES OF MALAY MUSLIMS WITH VESTIBULAR DISORDERS AND THE OUTCOME OF VESTIBULAR REHABILITATION

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by

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Nurul Syarida

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LIST OF SYMBOLS

°	Degree
%	Percent
n	Number of subjects
μV	Microvolt

LIST OF ABBREVIATION

ABEVR	Automated Balance Evaluation Vestibular Rehabilitation
ABR	Auditory Brainstem Response
AC	Air conduction
ASCC/SSCC	Anterior or superior SCC
BF_{10}	Bayes factor
BPPV	Benign paroxysmal positioning vertigo
CCR	Cervicocollic reflex
CNS	Central nervous system
Cohen's d	Effect size
COR	Cervico-ocular reflex
CPA	Cerebellopontine angle
CSR	Cervicospinal reflex
CSVR	Culturally Specific Virtual Rehabilitation
cVEMP	Cervical vestibular evoked myogenic potential
DHI	Dizziness Handicap Inventory
DVN	Descending (or spinal) vestibular nucleus
HIT	Head Impulse Test
Hospital USM	Hospital Universiti Sains Malaysia
IAC	Internal auditory canal
ICF	International Classification of Functioning, Disability and Health
ICF for Vertigo	International Classification of Functioning, Disability and Health core set for patients with vertigo, dizziness and balance disorders
ICVD	International Classification of Vestibular Disorder
IIUM	International Islamic University Malaysia

IIUM Hearing and Speech Clinic	International Islamic University Malaysia Hearing and Speech Clinic
IIUMMC	International Islamic University Malaysia Medical Centre
IPA	Interpretive phenomenological analysis
LA	Left anterior
LARP	Left Anterior Right Posterior
LARP	Left Anterior and Right Posterior
LL	Left lateral
LP	Left posterior
LSCC/HSCC	Lateral or horizontal SCC
LVN	Lateral vestibular nucleus
MD	Meniere's disease
MDD	Mal de debarquement
MRI	Magnetic Resonance Imaging
ms	Milisecond
MVN	Medial vestibular nucleus
My-VRBQ	Vestibular Rehabilitation Benefit Questionnaire – Malay version
OCR	Ocular-counter-rolling
ORL-HNS clinic	Otorhinolaryngology, Head & Neck Surgery Clinic
OTR	Ocular tilt reaction
PPPD	Persistent perceptual postural dizziness
PSCC/ISCC	Posterior or inferior SCC
RA	Right anterior
RALP	Right Anterior Left Posterior
RALP	Right Anterior and Left Posterior

RL	Right lateral
RM ANOVA	Repeated measure ANOVA
RP	Right posterior
SCC	Semicircular canals
SCM muscle	Sternocleidomastoid muscle
SD	Standard deviation
SPEV	slow-phase eye velocity
SVN	Superior vestibular nucleus
TV	Television
URTI	Upper Respiratory Tract Infection
USM	Universiti Sains Malaysia
VAS	Visual Analog Score
VCR	Vestibular colic reflex
VHIT	Video Head Impulse Test
VN	Vestibular nuclei
VOR	Vestibulo-ocular reflex
VRBQ	Vestibular Rehabilitation Benefit Questionnaire
VSR	Vestibular spinal reflex
WHO	World Health Organisation

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PROFIL MELAYU MUSLIM BERMASALAH VESTIBULAR DAN KESAN REHABILITASI VESTIBULAR

ABSTRAK

Mereka yang didiagnosis dengan masalah vestibular kronik dijangka mengalami gejala vestibular yang mengganggu ketika menjalani aktiviti kehidupan seharian. Dalam kajian ini, adalah penting untuk mengetahui masalah khusus yang dihadapi oleh umat Islam ketika menjalankan tugas harian mereka (termasuk solat) dan jika pemulihan vestibular konvensional berkesan untuk mengurangkan gejala. Kajian ini mempunyai reka bentuk campuran dengan tiga fasa berturut. Pada fasa pertama, faktor pencetus dan/atau penambah teruk gejala vestibular ditentukan. Pada fasa berikutnya, reka bentuk kajian campuran-konvergen digunakan, iaitu kaedah kuantitatif (VHIT, cVEMP dan MyVRBQ) dan kualitatif (temu ramah mendalam). Daripada 91 responden, 68% melaporkan bahawa gejala mereka dicetuskan oleh pergerakan badan dan kepala. Hampir separuh daripada mereka melaporkan sekurang-kurangnya satu gerakan solat mencetuskan dan/atau memburukkan lagi gejala mereka. Pada fasa kedua kajian, walaupun ujian VHIT dan cVEMP menunjukkan dapatan yang normal (kecuali latensi P13 dan N23), MyVRBQ menunjukkan bahawa para peserta terjejas oleh gejala tersebut. Analisis kandungan menemukan lima kandungan utama: 1) Gejala biasa, 2) Kesan pada aktiviti umum, 3) Kesan menunaikan solat, 4) Keadaan yang boleh memperburuk dan/atau memprovokasi gejala vestibular, 5) Strategi untuk mengatasi dan/atau menghalang daripada mengalami simptom. Selepas rehabilitasi vestibular, penurunan skor MyVRBQ yang ketara dapat dilihat di semua kategori (seawal dua minggu). Dua kandungan utama ditemui: 1)

Peningkatan dalam aktiviti umum, dan 2) Peningkatan dalam solat. Walaupun penilaian objektif (VHIT dan cVEMP) tidak sensitif, kesan gejala dan manfaat selepas pemulihan ditunjukkan dengan jelas oleh MyVRBQ. Analisis kandungan dapat menemui aspek-aspek penting lain yang tidak dapat ditemui daripada penilaian kuantitatif (termasuk kemampuan menunaikan solat sebelum dan selepas pemulihan). Hasil kajian ini akan memanfaatkan profesional untuk memberikan perkhidmatan yang optimum kepada pesakit Muslim yang bermasalah vestibular kronik.

THE PROFILES OF MALAY MUSLIMS WITH VESTIBULAR DISORDERS AND THE OUTCOME OF VESTIBULAR REHABILITATION

ABSTRACT

Those who are diagnosed with chronic vestibular disorders are anticipated to experience disturbing vestibular symptoms when pursuing their daily life activities. In the present study, it was of interest to know the specific difficulties faced by Muslims when performing their daily tasks (including solat) and whether the conventional vestibular rehabilitation would be effective in reducing the symptoms. This is a mixed-design study with three consecutive phases. In the first phase, triggering and/or worsening factors to vestibular symptoms were determined. In the subsequent phases, a mixed-convergent study design was employed, i.e., quantitative (VHIT, cVEMP and MyVRBQ) and qualitative (in-depth interview) methods. Of 91 respondents, 68% reported that their symptoms were triggered by body and head movements. Nearly half of them reported at least one prayer movement triggered and/or worsened their symptoms. In the second phase of the study, despite normal findings from VHIT and cVEMP (except for P13 and N23 latencies), MyVRBQ showed that the participants were affected by the symptoms. Content analysis unveiled five content areas: 1) Common symptoms, 2) Effects on general activities, 3) Effects on performing solat, 4) Conditions that may exacerbate and/or provoke vestibular symptoms, 5) Compensatory strategies to overcome and/or hinder from having the symptoms. Following rehabilitation, significant reductions in MyVRBQ scores were seen in all categories (as early as two weeks). Two content areas were discovered: 1) Improvements in general activities, and 2) Improvements in solat. While

the objective assessments (VHIT and cVEMP) were insensitive, the occurrence of the symptoms and the benefit of the rehabilitation were clearly shown by MyVRBQ. The content analysis was able to discover other important aspects missed to be covered by the quantitative assessments (including the ability to perform solat before and after the rehabilitation). The study findings would be useful to clinicians in providing optimum services to Muslim patients with chronic vestibular disorders.

CHAPTER 1

INTRODUCTION

1.1. Research background

The ability to perform daily life activities that involve navigation and body postures are made possible with an intact balance system. Balance system is a sensory integration between vestibular, visual and proprioceptive systems (Bronstein, 2016). When the vestibular system is insulted, four main symptoms may be present which are vertigo, dizziness, vestibulovisual symptoms and postural imbalance (Bisdorff et al., 2015). In particular, vertigo is spinning sensation when one is in static position, while dizziness is spatial disorientation without false sensation motion, vestibulovisual symptoms is the visual disturbances resulted from lesion in vestibular system and postural imbalance is the sensation of unsteadiness even when in an upright position.

After the vigorous symptoms, the condition may be followed with persistent sensations of floating, dizziness, imbalance and blurry of images during static or in motions (Bronstein and Lempert, 2010). Not later after several days, the balance system is able to adapt to the disruptions which the disabling symptoms would cease or lessen as the balance system recovers spontaneously. In this respect, vestibular compensation process may have occurred (Manzari et al., 2013). Vestibular compensation is a neurologic phenomenon that occurred at the central nervous system contributing to functional recovery (Deveze et al., 2014).

Nevertheless, the symptoms could remain for months or years in cases where the compensation has not occurred or incomplete. As such, the affected individuals would experience the horrendous symptoms persistently and possibly avoid their routine activities to prevent from experiencing the symptoms (Lacour et al., 2016). Those who have been living with vestibular symptoms for more than three months are considered to have chronic vestibular disorders (Kerber, 2016). In cases of incomplete compensation or uncompensated vestibular system, vestibular rehabilitation would be advised to facilitate and accelerate vestibular compensation (Bronstein and Lempert, 2010). The basis of vestibular rehabilitation is for the brain and vestibular system to recognise the altered signals and fine-tune the balance system through the adaptation, substitution and habituation exercises. A general approach of vestibular rehabilitation is to involve head and body movements, and should target movements that are provoking risks for the patients (Hall et al., 2016).

For Muslims diagnosed with vestibular pathologies, the effects of the disorders may not be limited to routine activities. The ability to establish prayer (solat) may be affected as well. Solat in Islam consists of slow and repeatedly head and body movements, and there are five times solat that Muslims are obliged to perform. In this regard, little is known on the specific difficulties faced by Muslims with chronic vestibular disorders in performing their daily life activities (including the ability to perform solat). In addition, to the best of my knowledge in the vestibular rehabilitation field, there are no published studies investigating improvements in the ability to perform solat following vestibular rehabilitation among those with chronic vestibular disorders.

In clinical settings, specific objective and subjective vestibular assessments are performed among patients with vestibular disorders. Videonytagmography (VNG), video head impulse test (VHIT), cervical vestibular evoked myogenic potential (cVEMP), ocular vestibular evoked myogenic potential (oVEMP), posturography and others are examples of objective vestibular assessments (Katz et al., 2015). To document the effects of vestibular symptoms on daily life activities, subjective self-report questionnaires such as dizziness handicap inventory (DHI), vertigo symptom scale (VSS), activities and balance confidence scale (ABC) and others are typically administered (Katz et al., 2015). To determine the improvement following vestibular rehabilitation, a subjective questionnaire such as vestibular rehabilitation benefit questionnaire (VRBQ) is carried out (Alghwiri et al., 2011).

To further explore on the important issues that Muslims have to encounter due to the vestibular symptoms and their experience following vestibular rehabilitation, a mixed-study design is considered appropriate to be employed. This study design utilizes both quantitative and qualitative study methods concurrently to obtain complete understanding of a phenomenon from different perspectives (Creswell and Clark, 2018). In the phase I of the present study, semi-structured interview was employed to discover quantitatively the commonalities in activities that Muslims may experience that initiated or exacerbated their vestibular symptoms. In the phase II and III of the present study, objective assessments such as cVEMP and VHIT were performed to determine the status of the vestibular organ prior to and following vestibular rehabilitation. The patients' subjective perception towards the severity of the symptoms and the effects on quality of life was measured using self-report questionnaire (vestibular rehabilitation benefit questionnaire-Malay version, MyVRBQ). The approach for the qualitative study design included an in-depth interview to analyse and understand the experience living with vestibular symptoms at personal level.

1.2. Problem statement

Individuals who are diagnosed with chronic vestibular disorders would typically report of limited movements and restrictions in the daily activities as maladaptive strategies towards the symptoms. The vestibular rehabilitation aims to improve the functionality of the patients. The exercises in vestibular rehabilitation are encouraged to be individually oriented. Hence, it is deemed essential to discover the common activities that trigger and/or worsen the vestibular symptoms among Muslims (particularly those who lived in east coast of Malaysia) diagnosed with chronic vestibular disorders.

Furthermore, studies on the impacts of vestibular symptoms and improvements after undergoing the vestibular rehabilitations have mostly utilized objective vestibular assessments. As such, not many studies have explored in-depth the effects of living with chronic vestibular disorders from the patients' perspectives. Notably, the implications of the religious practice of patients with chronic vestibular disorders have not been explored as well. To the best of our knowledge, no studies have been published on the implications of living with vestibular disorders from these two perspectives (the combination of quantitative and qualitative approaches). The improvements following the vestibular rehabilitation sessions are frequently reported from objective vestibular measurements and self-rated questionnaires. Thus, a mixed-study design is crucial to unveil resourceful information regarding the changes experienced by those with vestibular disorders after the sessions of rehabilitation have been completed.

1.3. Objective of the study

1.3.1. General objective

To explore the profiles of Malay Muslims with chronic vestibular disorders before and after following vestibular rehabilitation using quantitative and qualitative methods.

1.3.2. Specific objectives

1. To determine the activities that trigger and/or worsen vestibular symptoms amongst the chronic vestibular disordered patients.
2. To determine the objective and subjective vestibular assessments amongst Malay Muslims with chronic vestibular disorders before and after vestibular rehabilitation.
3. To explore in-depth qualitatively the difficulties/issues (including when performing solat) experienced by Malay Muslims with chronic vestibular disorders before and after vestibular rehabilitation.
4. To compare the findings between pre- and post-rehabilitation sessions amongst Malay Muslims with chronic vestibular disorders.

1.4. Research questions

Based on the objectives, the present study aimed to answer the following research questions:

1. What are the common activities that trigger and/or worsen the dizziness and/or vertigo amongst the vestibular/balance disordered patients?

2. Which vestibular assessments (objective or subjective) are better in identifying chronic vestibular disorders amongst Malay Muslims?
3. What is the additional information provided by the qualitative analysis regarding the difficulties/issues (including when performing solat) experienced by Malay Muslims with chronic vestibular disorders?
4. Are the findings of the vestibular assessments statistically different between pre- and post-rehabilitation sessions amongst Malay Muslims with chronic vestibular disorders?
5. What are the improvements experienced by Malay Muslims with chronic vestibular disorders after vestibular rehabilitation from the qualitative perspective?

1.5. Null hypothesis

1. There are no significant differences in cVEMP, VHIT and MyVRBQ between pre-rehabilitation and post-rehabilitation sessions.

1.6 Significance of the study

The findings from the present study offer several benefits. Firstly, through structured phone-interview, the common activities triggering and/or worsening the balance/vestibular symptoms Malaysians (particularly in the east coast of Malaysia) including the religious activity such as performing prayer could be determined. Secondly, from the information, exercises for the rehabilitation could be designed to tailor the needs of the population. The vestibular rehabilitation regime is more effective when it considers the needs of the individuals.

Thirdly, from objective and subjective vestibular assessments, information regarding the status of vestibular organ and self-perception on the implication of the vestibular disorders amongst those with chronic vestibular disorders may be discovered. A detailed exploration of the effects of vestibular rehabilitation on the daily life of Malay Muslims could complement the profiles of those with chronic vestibular disorders. The fourth benefit is to provide evidence whether the dedicated vestibular rehabilitation is beneficial to improve the ability of Malay Muslims to perform their religious responsibility. Putting a stop, the findings from the present study could become the reference to the audiological professionals to include the need for spiritual health in the assessments and the exercises for rehabilitation (fifth benefit).

CHAPTER 2

LITERATURE REVIEW

2.1. The balance system

The balance system is an intricate and integrated system that controls human balance function that involves coordination of three different systems which are vestibular, visual and proprioception (Bronstein, 2016). These three systems are working in tandem to ensure the head and body is stable and to preserve a clear visual image both in static and dynamic conditions. The system is also essential to maintain a consistent internal-external spatial representation as to prevent any mismatch of inputs and preserve a steady body posture in an environment.

The balance system receives the inputs not only from the vestibular sensory organs, but also from the neck muscles, spinal cord, visual system, autonomic function, reticular formation and cerebellum (MacDougall and Curthoys, 2012). Upon receiving the afferent nerves from the various systems, the inputs are processed and delivered to the targeted efferent systems, such as the eye muscles and other muscular system to control for the eye movements and postural stability, as well as the autonomic responses and sensations (MacDougall and Curthoys, 2012) through the integrations of the inputs at the central processor of the balance system, which are the cerebellum, cerebral cortex and brainstem. Figure 2.1 shows the general overview of the human balance system.

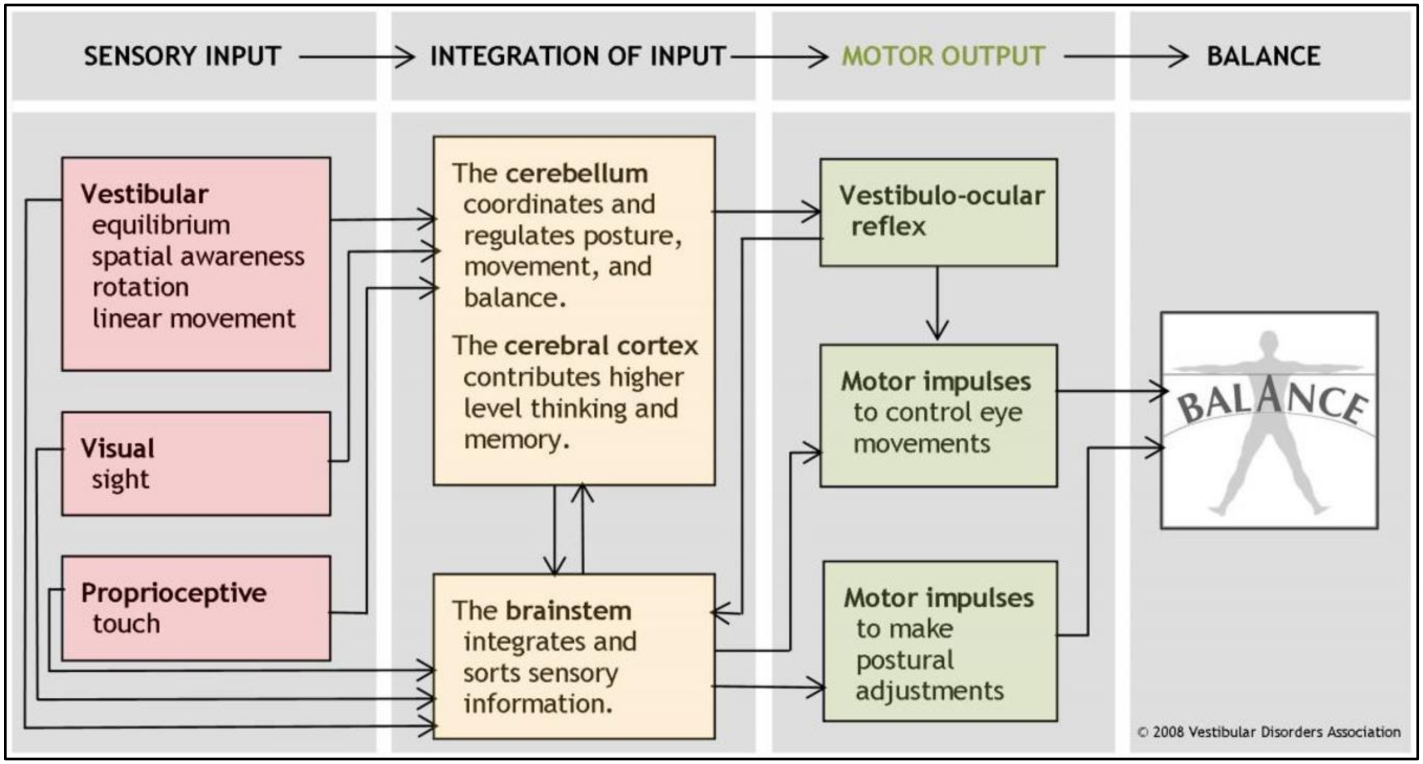

Figure 2.1 This is the illustration of the systems that responsible for human balance system. Adapted from Watson and Black (2008).

2.1.1. Vestibular sensory organs

The vestibular system is part of the inner ear, which is posterior to the cochlea. Each side of the ear has a set of five vestibular sensory organs which are three semicircular canals (SCC) and two otolithic organs. Figure 2.2 illustrates the five vestibular sensory organs and the vestibular nerve. The three semicircular canals consist of one horizontal plane canal known as lateral or horizontal SCC (LSCC/HSCC), and two vertical canals, which are anterior or superior SCC (ASCC/SSCC) and posterior or inferior SCC (PSCC/ISCC). The three canals are position approximately orthogonal to each other which the LSCC is not exactly in the horizontal plane, but it is 30° from the horizontal plane (Kingma and Van de Berg, 2016). The SCCs are responsible for angular movements (Kingma and Van de Berg, 2016).

The two otolithic organs are utricle and saccule. The arrangement of the saccule and utricle is also perpendicular to each other on the vestibule. Saccule is in the vertical direction, while the utricle is in the horizontal direction (Katz et al., 2015). The position of the utricle is above the saccule on the vestibule and approximates the plane of the LSCC. Utricle and saccule are both responsible for linear acceleration and deacceleration. In particular, saccule is responsive to the vertical direction (i.e., up and down) movements and utricle is sensitive towards tilts and the horizontal plane movements (i.e., side to side or front/back) (Katz et al., 2015). The arrangement of all the five sensory organs enables the system to respond to any positions of the head and body regardless of the angle of movements (Fetter, 2016).

The SCC of the right ear is a mirror image to the SCC of the left ear. Thus, the canals on both sides are conjugate pair appearing as one connected circle (Kingma and Van de Berg, 2016). For instance, the HSCC of the right side interlinks to the HSCC of the left-side, the ASCC of the right-side pairs to the PSCC of the left ear, or vice versa. This complimentary conjugate pairing prepares the system readily for a relative change of information between the two sides of the ears. The relative difference of information between the left and right sensory organs is used to determine the direction, velocity, and acceleration of movements. Such an arrangement also prepares the system for redundancy of information. Via the redundancy of the information, the system differentiates if the signal is the results of movements or is it a physiological body reaction that is not related to movements (Khan and Chang, 2013). For example, if there are relative differences between the ears, as in turning the head to one side, the system would initiate appropriate responses to the responsible muscles. If the change occurs equally in both sides of the ears such as in the elevation of body temperature, the system would disregard this as a movement.

The redundancy of input also increases the reliability of the vestibular system. If one of the organs is disturbed medically or pathologically, other sensory organs and the central nervous system (CNS) would still be able to receive the inputs from different routes that are not disrupted (Kingma and Van de Berg, 2016). The ability of the CNS to be able to receive stimuli from other vestibular parts, despite the hypofunction of one of the vestibular organs, facilitates compensation (Khan and Chang, 2013). The mechanism of compensation is further detailed in Section 2.7.

2.1.2. Vestibular nerve

The vestibular nerve is a subdivision of the vestibulocochlear nerve (VIII cranial nerve). It is an afferent projection from the bipolar neurons of Scarpa's (vestibular) ganglion. The vestibular nerve has two branches, which are the superior vestibular nerve (which innervates the lateral and anterior SCC as well as the utricle) and inferior vestibular nerve (for posterior SCC and saccule organs innervations) (Strupp and Brandt, 2013). The illustration of the vestibular nerve innervating the vestibular sensory organ is shown in Figure 2.2. The vestibular nerve relays afferent signals from the labyrinths through the internal auditory canal (IAC) to the vestibular nuclei in the brainstem and the cerebellum for processing.

The vestibular nerve has both regular and irregular firing pattern (Herdman and Clendaniel, 2014). The regular firing pattern of the nerve has a tonic rate of about 90 spikes per second and small variability in interspike intervals. The irregular firing pattern is when the nerve has no firing at rest but develops highly variable interspike intervals when there is head movement. The regular pattern of firing is most important for the vestibular-ocular reflex (VOR). On the other hand, the irregular firing pattern is vital for the vestibular spinal reflex (VSR) and coordinating responses between the otoliths and canals. The regular firing of the vestibular nerve is sensitive to as small as 0.5 spikes per degree per second of head velocity. With the efficiency of the nerve, humans can easily move their heads beyond 300 degrees per second (deg/sec) of velocity.

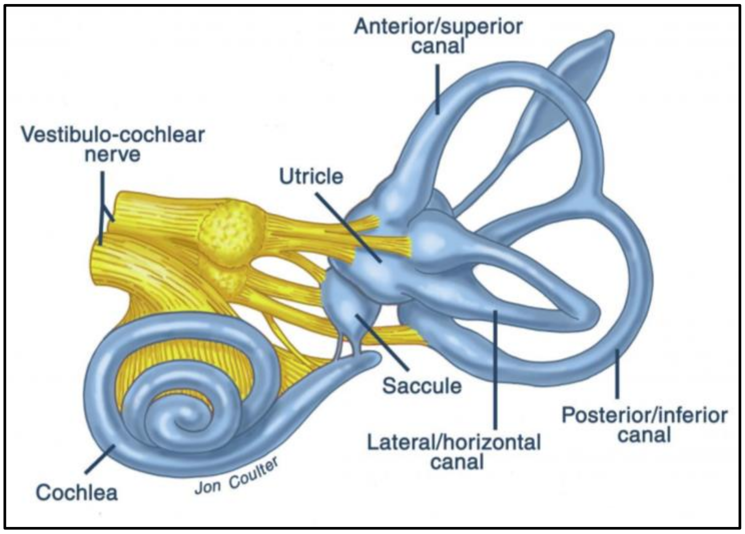

Figure 2.2 . Illustration of the five organs of the vestibular system and vestibulo-cochlear nerve. Picture was adapted from the website of Northwest Florida Ear Nose and Throat (http://www.nwfent.com/our-services/vertigo-and-balance-evaluation/vestibular-system/)

2.1.3. Vestibular nuclei (VN)

Inputs from the vestibular sensory organs are transmitted to two main processors, which are vestibular nuclei (VN, also known as vestibular nuclear complex) and cerebellum. VN is positioned particularly within the pons and extends caudally into the medulla (Fetter, 2016). VN is the primary processor of vestibular input. It has fast connections from the afferent nerve towards the efferent neurons. Apart from the vestibular inputs, it also receives various afferent nerves including cerebellum, reticular formation, spinal cord, visual system, auditory system, tactile and their counterparts on the other side of the brainstem.

Four major divisions of VN including medial vestibular nucleus (MVN), descending (or spinal) vestibular nucleus (DVN), lateral vestibular nucleus (LVN), and superior vestibular nucleus (SVN). SVN and MVN are the primary relays for VOR (Fetter, 2016). Even though MVN is the main relay for VOR, it is also involved in relaying the VSR input and coordinates simultaneous movements of head and eyes. LVN is mainly for the VSR. DVN owns no primary relay but it connects to all the other nuclei and cerebellum. Besides the four primary divisions, VN has at least seven "minor" nuclei. The left and right vestibular nuclei on the brainstem communicate through a commissures system. The commissures system allows sharing of information and holds the responsibility for the push-pull mechanism of the conjugate paired canals (allowing for the occurrence of the VOR) (Fetter, 2016). Figure 2.3 illustrates the vestibular nuclei and central vestibular pathway.

2.1.4. Cerebellum

Cerebellum, located at the posterior cranial fossa, monitors performance of the vestibular system and readjusts the central vestibular processing if necessary (also known as an adaptive processor) (Khan and Chang, 2013). It receives inputs not only from the vestibular system but it also processes the afferent information from the somatosensory, visual and autonomic nervous system. It is at the cerebellar vermis; the midline part of the cerebellum, that responds to vestibular stimulation. The cerebellum is not involved directly in vestibular reflexes but in the absence of this structure, the reflexes become uncalibrated and ineffective. As such, it has an inhibitory influence on the vestibular nuclei.

There are three parts of the cerebellum that influence vestibular reflexes, which are cerebellar flocculus, cerebellar nodulus and anterior-superior vermis of the cerebellum. The cerebellar flocculus is responsible for adjusting and maintaining the VOR gain (Khan and Chang, 2013). In animal studies, lesions to this part decreased the adaptation ability in animals, resulting in asymmetrical gain of the VOR (Herdman and Clendaniel, 2014; Strupp and Brandt, 2009). Typically, individuals with cerebellar degenerations or the Arnold-Chiari malformation have floccular disorders (Herdman and Clendaniel, 2014).

The cerebellar nodulus is essential to adjust the duration of VOR and deals with input from the otolith organs as well. Lesions to this part, for instance, in medulloblastoma cases, patients would have gait ataxia and nystagmus (Herdman and Clendaniel, 2014). The anterior-superior vermis of the cerebellum has a role in VSR. Excessive alcohol intake and thiamine deficiency could compromise this region, which would result in profound gait ataxia and instability body posture (Herdman and Clendaniel, 2014). This could happen because the sensory inputs from the lower extremities are unavailable to stabilise the posture.

2.1.5. Ascending and descending pathway of the VN

The vestibular system is a complex and sophisticated network system. It has descending and ascending pathways from its main relay processor (Dieterich and Brandt, 2015). The ascending pathway is involved in transferring of the input within the brainstem, to the thalamus and the cortex, as well as the cerebellum.

The descending pathways relay the inputs from the VN to the spinal cord, as well as to the autonomic nervous system. Thus, the outputs are not only the evoked skeletal and ocular muscle reflexes, but also the autonomic reflexes. Changes in blood flow, respiration and heart rate are regulated by the vestibulo-sympathetic reflexes. Any injury to this part would influence blood pressure, heart rate and respiration of the affected individuals (Holstein et al., 2014).

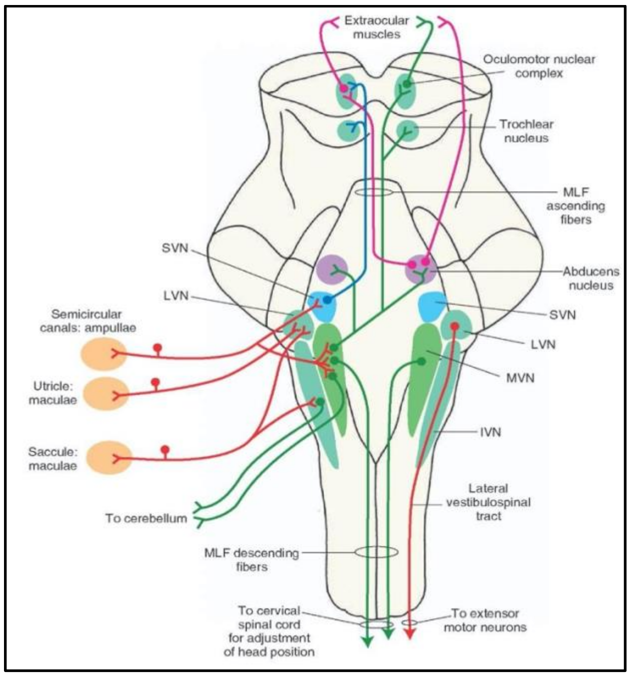

Figure 2.3 Illustration of vestibular nuclei and the central vestibular pathways. Picture was adapted from what-when-how.com.

2.1.6. Higher level processing

In a sustained head movement, SCC would reach a constant velocity. In lapse of time, the neural firing of the SCC decays exponentially. Time constant, or the time taken for the firing rate of the SCC to reduce 32% from its initial rate is approximately 7s. Nevertheless, CNS perseveres the response to a longer duration, which is up to 20s. The prolongation of the time constant in the brainstem is known as the velocity storage mechanism (Cullen, 2016). The velocity storage mechanism works as the depository site, i.e., it stores information about head velocity from all the related motion sensors.

In the light time (i.e., daylight), retinal slips supply inputs to the velocity storage mechanism. Retinal slips are the slippage of images across the retina during head movements. This slippage of images, recognised as error signals by the VOR, drives the velocity storage system and retains the vestibular-related responses when the vestibular afferent inputs begin to decay (Whitney and Sparto, 2011). Other than the retinal slips, somatosensory and otolithic information also drive the velocity storage mechanism.

2.2. Reflexes in the vestibular systems

The inputs processed from the vestibular nuclei and cerebellum are transmitted to efferent pathways. The efferent outputs control muscles of the eyes, neck and spinal cords as reflex systems. The integrated reflex systems are vestibular ocular reflex (VOR), vestibular spinal reflex (VSR), vestibular colic reflex (VCR). All the reflexes systems are monitored by the central nervous system, cerebellum, and higher cortical processes (Writer and Arora, 2012).

2.2.1. Vestibular ocular reflex (VOR)

The vestibular-ocular reflex (VOR) is the reflex system that controls the ocular muscles (Katz et al., 2015). VOR detects head movements and generates compensatory eye movements. The compensatory eye movements are known as nystagmus. VOR is essential to maintain a stable and precise image on the retina during head and body movements. VOR works best with quick head movements and very poor with slow accelerations. There are two components of VOR, which are angular VOR and translational VOR (Herdman and Clendaniel, 2014). The angular VOR is mediated by the SCCs and important for gaze stabilisation. The otoliths control the translational VOR. The translational VOR is when the head is moved at high frequency while initially viewing a near target image.

2.2.2. Vestibular spinal reflex (VSR)

The vestibular spinal reflex (VSR) is the reflex response from the vestibular system to the spinal cord (Katz et al., 2015). It receives the combination of inputs from touch sensory on the skin and proprioceptors on the feet, the hands, joints, and trunk to determine the position of the body in the environment. It is thus responsible for initiating compensatory body movements to stabilise head and body posture. This reflex is important to prevent one from falling.

2.2.3. Vestibular colic reflex (VCR)

Vestibular colic reflex (VCR) has the cardinal role to stabilise the head, particularly during ambulation through relaxation and contraction of the neck muscle (Cullen, 2016). VCR also has contribution in gaze stabilisation. As such, it stabilises visual images on the fovea of the retina by acting on the neck muscles.

2.2.4. Other reflexes

2.2.4(a) Cervical sensory reflexes

Cervical sensory reflexes consist of cervico-ocular reflex (COR), cervicospinal reflex (CSR) and cervicocollic reflex (CCR) (Herdman and Clendaniel, 2014). The neck proprioceptor supplies the afferent input to these cervical sensory reflexes. As in COR, the receptors around the neck stimulate the eye reflex movements. In certain conditions, COR supplements the VOR. COR also assists the VOR when the vestibular system is compromised (Herdman and Clendaniel, 2014). The neck proprioceptor also drives CSR to adjust the position of the limb to maintain body posture. CSR compliments the VSR by modifying muscles activity of the trunk and limb. CCR is responsible to stabilise head position on the body. Even though the contribution of the CCR in human is still ambiguous, there is likelihood that CCR has a leading role in maintaining the head movement, particularly in the vertical plane (Herdman and Clendaniel, 2014). CCR may also contribute to the function of VCR when there is injury to the vestibular organs.

2.2.4(b) Visual reflexes

The vestibular reflexes are very efficient for movements at high frequencies (more than 0.5Hz) but are inadequate for low frequency movements. This limitation, nevertheless, is complemented by visual reflexes. These reflexes also have contributions to the vestibular central system and are responsible for the basic eye movements (e.g., smooth pursuit and saccade) and postural stability (Herdman and Clendaniel, 2014). Even though the visual reflexes are efficient only for low frequency movements, they are also beneficial in situations where the vestibular system is insulted.

2.2.4(c) Somatosensory reflexes

Somatosensory reflexes are involved in the steadiness of posture. This reflex is used to a greater extent in those with bilateral vestibular loss compared to healthy individuals with well-functioning vestibular system (Herdman and Clendaniel, 2014).

2.3. Vestibular pathology

The vestibular pathology is one of the causes of dizziness and balance disturbance. A study by Neuhauser et al. (2005) found that a tierce of those who had consulted for medical treatment for their dizziness was related to the vestibular disorders. In several epidemiology studies of vestibular pathology, it was found that the prevalence of vestibular disorders amongst those with complaint of dizziness and/or vertigo to be in the range of 35% to 40% (Abdul Wahat et al., 2013; Agrawal et al., 2009). The studies also found that the prevalence was proportional to the increase in age. The growth was expected as the life expectancy was expanded and that would include the prevalence of balance dysfunction (Dillon et al., 2010).

The vestibular pathology could be classified into peripheral and central lesions. The peripheral vestibular lesion is the pathology involving the peripheral organs of the vestibular system, which include SCC, otolith organs and vestibular nerves. The most common types of peripheral vestibular disorders are benign paroxysmal positional vertigo (BPPV), Meniere's disease (MD), vestibular neuritis, vestibulopathy, vestibular paroxysmia, and superior canal dehiscence syndrome (Abdul Wahat et al., 2013; Bisdorff et al., 2013; Strupp and Brandt, 2013). The central cause of vestibular pathology is the lesion affecting the central controller of the balance system such as the cerebellum, brainstem and central vestibular pathway (Brandt and DIeterich, 2017). The typical central vestibular pathologies are vestibular migraine, vertebrobasilar circulation, multiple sclerosis, tumours of the posterior fossa, neurodegenerative diseases, and vestibulotoxicity (Sanders and Gillig, 2010). It is also not uncommon for individuals to have both types of pathologies.

2.4. Sign and symptoms of vestibular pathology

Dizziness is the most common symptom reported. However, it is too general in descriptions. The dizziness reported could be either vertigo, presyncope, disequilibrium, or light-headedness (Muncie et al., 2017). Each of the symptoms carry different information and meaning. Thus, it is very important to further detail the exact descriptions of the dizziness reported by the patients. Vertigo is the perception of rotational sensation in the absence of any motions. Presyncope is the feeling of unconsciousness, disequilibrium is the loss of balance without any head sensations, and light-headedness is a vague symptom that may be described as the feeling of disconnected from the environment.

The symptoms reported could help clinicians to prioritise the assessments to the patients, diagnose the related pathology more accurately and much importantly, to appropriately manage the patients. The symptoms may also contribute to the type of pathology associated with the patients. For instance, those who reported vertigo were most likely related to vestibular disorders (Dommaraju and Perera, 2016). Other symptoms such as presyncope or light-headedness may present due to other systemic diseases such as cardiovascular, neurologic, metabolic, and psychiatric problems. Thus, clear descriptions of the symptoms reported by the patients are very critical.

As an effort to guide clinicians, the Committee for Classification of Vestibular Disorders of the Bárány Society has published the International Classification of Vestibular Disorder (ICVD). ICVD has grouped four main categories of presenting symptoms of vestibular disorders, which are vertigo, dizziness, vestibulovisual symptoms, and postural symptoms. Definition for each symptom according to Bisdorff et al. (2009) is shown in Table 2.1.

Table 2.1 Definition for each of the vestibular symptom according to the International Classification of Vestibular Disorder (ICVD) by Bisdorff et al. (2009)

Symptoms	**:**	**Definitions**
Vertigo	:	The sensation of self-motion when no self-motion is occurring or the sensation of distorted self-motion during an otherwise normal head movement.
Dizziness	:	The sensation of disturbed or impaired spatial orientation without a false or distorted sense of motion.
Vestibulovisual symptoms	:	Visual symptoms that usually result from vestibular pathology or the interplay between visual and vestibular systems. These include false sensations of motion or tilting of the visual surround and visual distortion (blur) linked to vestibular (rather than optical) failure.
Postural symptoms	:	Balance symptoms related to maintenance of postural stability, occurring only while upright (seated, standing, or walking).

The effects of lesion on the vestibular system can also be categorised into static and dynamic deficits. Static deficits refer to symptoms that are present in a stationary position, while dynamic deficits are presenting symptoms that occur during movements (Herdman and Clendaniel, 2014).

2.4.1. Static deficits

After an acute unilateral vestibular hypofunction, there are notable signs and symptoms of static and dynamic deficits (Herdman and Clendaniel, 2014). The static deficit is the presentation of the signs and symptoms in a static condition; for example, the presence of spontaneous nystagmus even without head movements. The spontaneous nystagmus is the rhythmic jerking eye movements following peripheral vestibular lesion mainly observed in the horizontal plane. The fast phase of the rhythmic rapid eye movements is typically directed away from the lesion side. The vertical components of the nystagmus are typically small or absent, presumably due to the opposite directions of eye movements from anterior and posterior canals. The anterior canal causes upward eye movements, while the posterior canal produces downward eye movements. The opposite directions of the eye movements would result in net cancellation of the vertical nystagmus. The static imbalance is related to the asymmetrical tonic discharge within the vestibular nuclei (Herdman and Clendaniel, 2014).

Other presentations of static deficit are ocular tilt reaction and lateropulsion. The ocular tilt reaction (OTR) is the by-product of otolith pathway hypofunction (Huh and Kim, 2013). The components of OTR include tilting of the head to the lesioned side, skew deviation of the ipsilesional eye lower than the contralateral side and the contralateral eye rolled upward to the lesioned side. Figure 2.4 shows the example of OTR in a patient. Lateropulsion is the unsteadiness of the postural control towards the side with lesion, particularly during the acute stage of vestibular hypofunction (Herdman and Clendaniel, 2014).

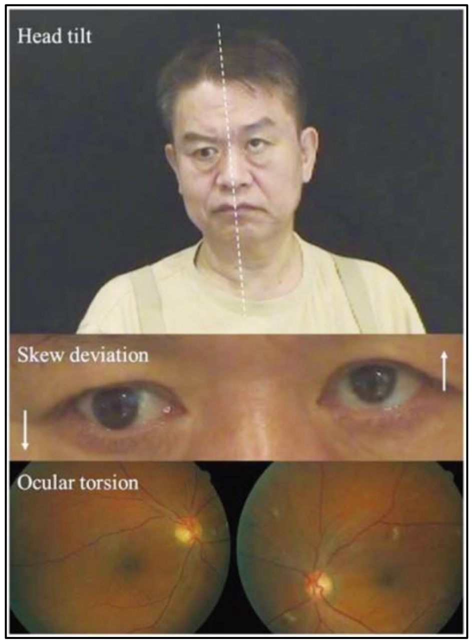

Figure 2.4 Example of the Ocular Tilt Reaction. Picture was adapted from Huh and Kim (2013).

2.4.2. Dynamic deficits

Dynamic symptoms are accentuated with head and body movements. Dynamic deficits are typically associated with asymmetrical and/or diminished VOR, resulting in blurry of images when individuals with the vestibular disorder are in motion (Herdman and Clendaniel, 2014). The dynamic deficits also include instability of body posture and unsteadiness in ambulation. Typically, patients with these symptoms would adopt an adaptive mechanism to minimise the associated dynamic problems and tendency of falling. There are also deficits in otolithic dynamic responses following unilateral vestibular lesion (Herdman and Clendaniel, 2014). The ocular counter-rolling (OCR) response is asymmetrical with a smaller OCR for roll-tilts of the head towards the affected