CHARLES UNIVERSITY

FACULTY OF PHYSICAL EDUCATION AND SPORT

DEPARTMENT OF PHYSIOTHERAPY

APPLICATION OF VIRTUAL REALITY ON DYNAMIC POSTURAL STABILITY

Master's Thesis

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Abstrakt:

Název

PŮSOBENÍ VIRTUÁLNÍ REALITY NA DYNAMICKOU POSTURÁLNÍ STABILITU

Cíl

Cílem studie je zjistit, zda aplikace 3D VR má u zdravých dospělých osob významný vliv na dynamickou posturální stabilitu.

Metodika

Do studie bylo zařazeno 11 zdravých dospělých osob (n = 11; 7 mužů, 4 ženy) průměrného věku 27 let. Při postupech před testem a po něm byly použity systémy NeuroCom, Smart Balance Master System, Sensory Organization Test SOT (Composite Equilibrium, Sensory Analysis of Somatosensory SOM, Visual VIS, Vestibular VEST, and Preference PREF) a Motor Control Test MCT (Weight Symmetry). Aplikace 3D virtuální reality byla provedena pomocí Samsung Gear Goggles, doba působení byla 5 minut.

Výsledky

Mezi výsledky před testováním a po testování s VR pomocí systémů SOT Composite Equilibrium, Sensory Analysis of Somatosensory SOM, Visual VIS, Vestibular VEST a MCT Weight Symmetry nebyly zjištěny žádné významné rozdíly ($p > 0.05$).

Závěr

Podle výsledků z jednoho testování nevede aplikace VR u zdravých dospělých osob k významným rozdílům v dynamické posturální stabilitě. K objasnění efektivity virtuální reality u zdravých osob je zapotřebí dalších studií.

Klíčová slova

posturální stabilita, dynamická posturální stabilita, rovnováha, výpočetní dynamická posturografie, CDP, silová plošina, NeuroCom, virtuální realita, virtuální prostředí, VR

Abstract

Objective

The aim of this study was to identify if there is any significant difference in dynamic postural stability after 3D Virtual Reality VR application on healthy adults.

Methodology

There were 11 healthy adults participants (n=11 , 7 males, 4 females), with age average of 27 years. Pre-test and post-test procedures were performed by using NeuroCom, Smart Balance Master System, Sensory Organization Test SOT (Composite Equilibrium, Sensory Analysis of Somatosensory SOM, Visual VIS, Vestibular VEST, and Preference PREF) and Motor Control Test MCT (Weight Symmetry). Application of 3D Virtual Reality was provided by using Samsung Gear Goggles, with 5 minutes duration.

Results

There were no significant statistical differences in SOT Composite Equilibrium, Sensory Analysis of Somatosensory SOM, Visual VIS, Vestibular VEST, Preference PREF, and MCT Weight Symmetry results ($p > 0.05$) after the Virtual Reality application.

Conclusion

The application of Virtual Reality has no significant difference on dynamic postural stability in healthy adults from one session exposure. Further investigation and trials are needed to clarify the Virtual Reality effectiveness on dynamic postural stability of healthy adults.

Keywords

Postural Stability, Dynamic Postural stability, Balance, Computerized Dynamic Posturography, CDP, Force Platform, NeuroCom, Virtual Reality, Virtual Environment, VR

Declarations

I declare that this work of this thesis entitled "Application of Virtual Reality on Dynamic Postural Stability" is my own work (except where acknowledgements indicate otherwise), under supervision of MUDr. David Pánek, Ph.D.

I declare that this thesis work has not been, or being submitted for any degree in this or other university.

Acknowledgements

I would like to express my appreciation and thanks to my supervisor MUDr. David Pánek, Ph.D. for his helpful guidance, encouragement and kindness through working on this thesis. I would also like to express my gratitude to Doc. Paed Dr. Dagmar Pavlů, Csc who helped me a lot since my bachelor degree study until now. I would also like to extend my grateful thanks to all of my teachers during my bachelor and master studies in this faculty.

Dedications

I would like to dedicate this thesis to my family, my father, mother, sisters and brothers who have given me all support and encourage to be here and obtain this degree in my study.

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List of Abbreviations

AR: Augmented Reality

BBS: Berg Balance Scale

BESS: Balance Error Scoring System

CDP: Computerized Dynamic Posturography

COP: Center of Pressure

CTSIB: Clinical Test for Sensory Integration in Balance

DGI: Dynamic Gait Index

DPSI: Dynamic Postural Stability Index

FRT: Functional Reach Test

HMD: Head Mounted Display

MCT: Motor Control Test

mCTSIB: Modified Clinical Test for Sensory Integration in Balance

PREF: Preference

PST: Postural Stress Test

PT: Pull Test

SBMS: Smart Balance Master System

SEBT: Star Excursion Balance Test

SLS: Single Leg Stance

SOM: Somatosensory

SOT: Sensory Organization Test

TTS: Time to Stabilization Test

TUG: Timed Up and Go Test

VE: Virtual Environment

VEST: Vestibular

VIS: Visual

VR: Virtual Reality

VRE: Virtual Reality Exposure

VRET: Virtual Reality Exposure Therapy

1. Introduction

Postural stability is considered as major function of balance system in humans, which is could be divided due body state to static and dynamic, whereas the static postural stability manifested by quiet standing, and the dynamic postural stability which is the control or and maintaining of posture and balance while performing dynamic or and movement tasks or when transitioning from dynamic to static state, an example of dynamic postural stability is maintaining of stability while gait and executing movements during activities of daily living. To achieve the postural stability in both of its state the static and dynamic, the central nervous system (CNS) works with afferent sensory information from different sensory systems, which include visual system, somatosensory system and vestibular system and analyze their input information and integrate them in process known as sensory organization, which rely or sensory reweight the sensory inputs through theses sensory systems depending on body situation and environment or circumstance that human is actually presenting in. Then, the central nervous system CNS send motor commands to be executed by body segments to keep the postural stability and react with sensory inputs and surrounding. The postural stability has various methods for its measuring which vary from clinical to laboratory measuring methods, which include Computerized Dynamic Posturography (CDP), which we are going to use in our study.

Vision is one of the five senses humans have. Visual sensory system and its information is considered as one of the main sources for controlling of posture and balance, when this visual system is affected that would result in postural instability and decreasing of balance. Based on importance and essential role of vision and visual sensory information in maintaining of postural stability, utilization of virtual reality (VR) technology is emerged with more developed systems in recent decades in research field about its role or effect and influence on postural stability in healthy people or patients with different types of diseases which include neurological, vestibular and motor dysfunctions and others. In addition, the virtual reality is used in many fields such as medical, education, training, treatment and rehabilitation and of course entertainment, which is being the most common purpose of using this technology, that technology which is rapidly developing and commercially available with low cost devices and systems like

Head Mounted Display (HMD) which we are going to use in our study, further, there are different virtual reality displays which vary among aural, haptic, vestibular and visual which is most common in use with different applications and systems. (Akizuki et al., 2005: Booth, Masud, Connell, & Bath-Hextall, 2014; Gatica-Rojas, & Méndez-Rebolledo, 2014; Horlings et al., 2009; Mao, Chen, Li & Huang, 2014; Nishiike et al., 2013; Virk, & McConville, 2006).

Theoretical Part: Literature Review

2. Background

2.1. Anatomy and Physiology of The Vestibular System

The peripheral vestibular system is situated in the inner ear (Figure.1), it comprises of the bony labyrinth and the membranous vestibular labyrinth, which is located in the petrous portion of the temporal bone. Cochlear and vestibule make up the bony labyrinth, whereas posterior vestibule part is composed of utricle and saccule and anterior cochlear part is helix shaped involving spiral organ which is responsible for hearing function. (Goldberg, Wilson, Angelaki, & Cullen, 2012; Marieb & Hoehn, 2007; Khan & Chang, 2013).

Perilymph or perilymphatic extracellular fluid, connective tissues and blood vessels are filling the area within and around the vestibular bony and membranous labyrinth, which is analogous to cerebrospinal fluid. Whilst, endolymphatic or endolymph fluid is filling structures of the membranous labyrinth which is like to intracellular fluid. (Goldberg, Wilson, Angelaki, & Cullen, 2012; Marieb & Hoehn, 2007; Khan & Chang, 2013).

The vestibular apparatus is comprised of the otolith organs and semicircular ducts. The otolith organs are composed of the utricle and the saccule, they are sensory structures of head orientation in space, which deal with linear acceleration, gravity force and head tilt movement. Both of the saccule and the utricle involve sensory neuroepithelium or so called macula, which is placed in anterior wall of the utricle and in ventro-lateral wall of the saccule. The utricular macula detect motion in horizontal plane, whereas saccular macula detect vertical plane motion. (Khan & Chang, 2013; Highstein, Fay, & Popper, 2004; Baloh & Honrubia, 2001; Cullen, 2012; Goldberg, Wilson, Angelaki, & Cullen, 2012).

The macula is covered by gelatinous material involved of calcium carbonate particles known as otoconia or otoliths, whereas hair cells emerge on it. The otoconia is thicker than the endolymph and rise gravity on the endolymph which let the otolith respond to linear acceleration. (. (Khan & Chang, 2013; Highstein, Fay, & Popper, 2004; Baloh & Honrubia, 2001).

The semicircular canals are curved structures, which get into the utricle at the end of each of the canals, whereas these ends dilate to form ampulla. The ampulla encompasses the sensory neuroepithelium or crista ampullaris, which covers by cupula that composed of gelatinous material involved the hair cells. The crista ampullaris is like to the macula. The semicircular canals are situated in planes which are orthogonal to each other. The semicircular canals consist of one horizontal canal and two vertical anterior and posterior canals. These canals respond to angular acceleration and rotation head motion. They work in functional pairing, while the horizontal canals on both side paired together, the two anterior canals on each side paired with contralateral posterior canals on other side. In the lateral ducts, the kinocilia of the hair cells are oriented to the utricle while, the hair cells of superior and posterior ducts orientation are to the duct. The cupula is displaced due to endolymph movement while rotational acceleration, which moves the hair cells into reverse rotation direction. (Khan & Chang, 2013; Highstein, Fay, & Popper, 2004; Baloh & Honrubia, 2001; Honrubia & Hoffman, 1997; Kesser & Gleason, 2011; Marieb & Hoehn, 2007; Jacobson & Shepard, 2014; Naunton, 1975; Goldberg, Wilson, Angelaki, & Cullen, 2012).

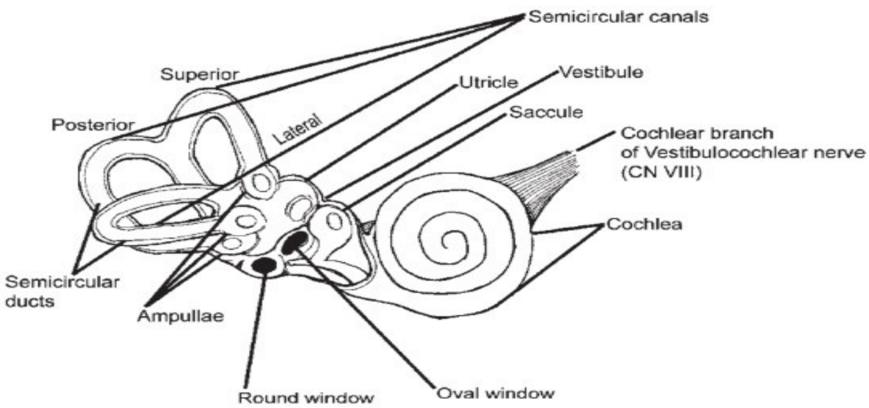

Figure 1. The Vestibular System. (Khan & Chang, 2013)

2.1.1. The Vestibulocochlear Cranial Nerve (VIII)

The vestibulocochlear nerve (8th cranial nerve) consists of two nerves the cochlear and the vestibular (Figure. 2), whereas the cochlear responsible for sound and hearing function and the vestibular is responsible for balance and equilibrium. In pontomedullary junction of the brainstem the vestibular split from the cochlear nerve. Most of vestibular fibers merge to the cerebellum.

The vestibular nerve is composed of superior and inferior parts of vestibular ganglion or Scarpa's ganglion. (Benoudiba, Toulgoat, & Sarrazin, 2013; Khan & Chang, 2013; Honrubia & Hoffman, 1997; Marieb & Hoehn, 2007; Spickler & Govila, 2002; Naunton, 1975; Goldberg, Wilson, Angelaki, & Cullen, 2012).

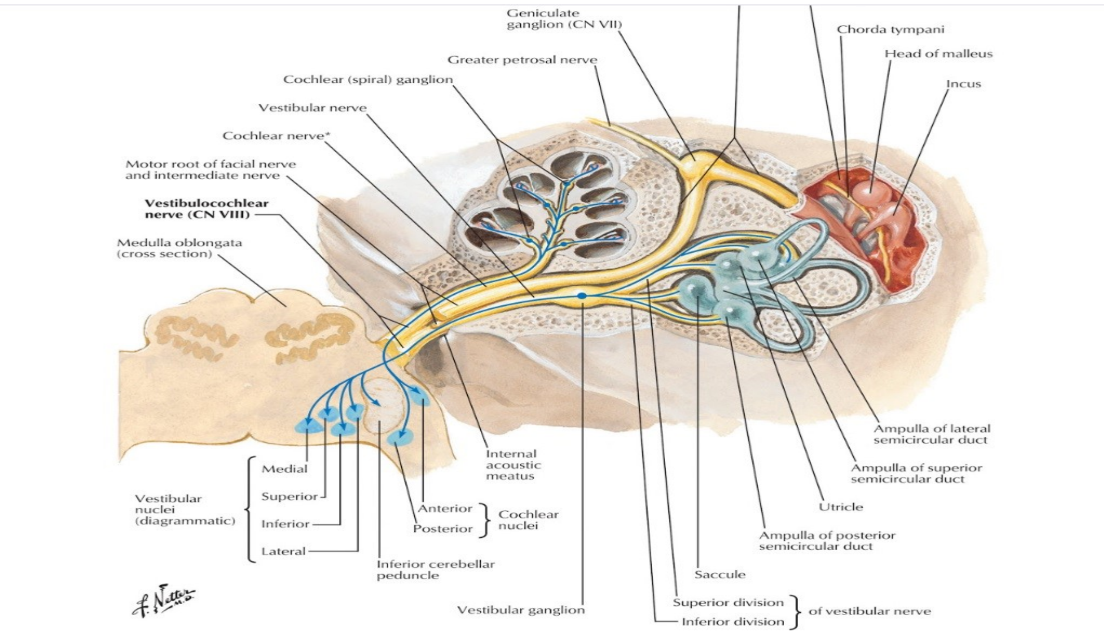

Figure 2. Vestibulocochlear Nerve. (Netter, 2017)

2.1.2. Vestibular Reflexes

The vestibular reflexes are comprised of the hair cells and a three neuron arc co ntains afferen neuron, vestibular neuclei and motor neuron of abducens and oculomotor nuclei. The vestibular reflexes are functionally involved in keeping stability, generatin g muscle activity to perserve the equlibrium and eye stability while body movement an d participating in keeping muscle tone. The vestibular reflexes contain the vestibuloocu lar reflex and the vestibulospinal reflex. (Honrubia & Hoffman, 1997; Khan & Chang, 2013; Highstein, Fay, & Popper, 2004; Jacobson, & Shepard, 2014; Cullen & Roy, 2004).

The Vestibular Reflex (VOR) works to stabilize images on fovea of retina in ey e while head motion and reflexively move the eyes toward reverse side. Moving the hea d to one side makes the endolymph fluid move in the semicircular ducts, which depolar izes the hair cells in the same side of head movement and polarizes them on other side of movement, resulted in increment of afferent neurons activity that that transmit to the vestibular nuclei and cerebellum, which resulted into eye muscles contraction that mov e the eye to the opposite side. (Honrubia & Hoffman, 1997; Khan & Chang, 2013; Goldberg, Wilson, Angelaki, & Cullen, 2012; Jacobson & Shepard, 2014; Baloh & Honrubia, 2001; Cullen & Roy, 2004).

The Vestibulospinal Reflex (VSR) is reflexively react to head acceleration by e xtending limbs muscles of the same side of the head acceleration, while the other side li mbs muscles contracted. The VSR is more complex than the VOR and merging signals from vestibule, vision and motor system through brainstem and cerebellum to keep bod y posture and balance, by preserving body center of mass over individual base of suppo rt. The VSR is comprised of lateral vestibular spinal and medial vestibular spinal tracts and reticular spinal tract.

The lateral vestibular tract which arises from the lateral vestibular necleus, effer ent vestibular fibers transmitted caudally through the spinal cord on the same side wher eas their neurons supply all spinal cord sections in cervical, thoracic and lumbar, which make trunk and limb extension on the same side while inhibit the extension of opposite side.

The medial vestibular tract of the vestibular spinal reflex is araised from medial vestibular nucleus, where the angular head acceleration signals send to. The medial vest ibular tract goes down to the middle of thoracic spinal cord. It participates in neck and head movement and coordination. (Honrubia & Hoffman, 1997; Khan & Chang, 2013; Goldberg, Wilson, Angelaki, & Cullen, 2012; Naunton, 1975; Jacobson & Shepard, 2014; Cullen & Roy, 2004; Goebel, 2008; Baloh & Honrubia, 2001).

Relatively to the vestibular spinal reflex there is vestibulocollic reflex, which pa rticipate in activation of neck muscles and maintain head position alignment and its orie ntation in space relative to gravitational force independently of movement of trunk, it w orks as righting reflex. (Jacobson & Shephard, 2014; Khan & Chang, 2013; Baloh & Honrubia, 2001).

2.2. Postural Stability

Postural stability could be defined as the ability to maintain the body in equilibrium state and achieving that by keeping center of body mass within base of support limits, whereas static postural stability is keeping steadiness on stable or fixed state of support base, in other words it is maintain posture in quite standing, while dynamic postural stability is the ability of person to keep his or her balance and body posture when there is changing or transitioning of body state and equilibrium like from dynamic to static state, in other words it is maintaining balance while providing moving tasks. Both of static and dynamic postural stability are working depending on the central nervous systems and peripheral nervous system, these systems are working together in controlling of body posture, balance and center of gravity over support base, to achieve upright standing, whereas the central nervous system integrates the peripheral nervous system sensory systems through visual, vestibular and somatosensory inputs, and it responds with motor actions to control and maintain body posture alignment and position over support base by exerting muscle activation and contraction. (Alexandrov, Frolov, Horak, Carlson-Kuhta, & Park, 2005; Aydog, Aydog, Cakci, & Doral, 2006; Aydog, Bal, Aydog, & Cakci, 2006; Cote, Brunet, Gansneder, & Shultz, 2005; Diniz-Filho et al., 2015; Gago et al., 2015; Guskiewicz, 2001; Heebner, Akins, Lephart, & Sell, 2015; Karimi, & Solomonidis, 2011; Mao, Chen, & Huang, 2014; McCollum, Shupert, & Nashner, 1996; Payne, 2006; Peterka, 2002; Peterka, & Loughlin, 2004; Razavi, 2017; Redfern, Jennings, Martin, & Furman, 2001; Sell, 2012; Tiron, Berteanu, Cretu, Anton, & Gagea, 2009; Wikstrom, Arrigenna, Tillman, & Borsa, 2006; Wikstrom, Tillman, Chmielewski, Cauraugh, & Borsa, 2007; Wikstrom, Tillman, Smith, & Borsa, 2005; Goldberg, Wilson, Angelaki, & Cullen, 2012).

2.2.1. The Vestibular System

The peripheral vestibular system, which is situated in the temporal bone, that consists of the three semicircular canals, which work with angular acceleration, while the two otolith organs work with linear acceleration. The lateral vestibular nucleus, which innervated by the vestibular-cochlear nerve, that has a role in the stability of the posture and the vestibulospinal reflexes, it responds to the information from the vestibular system in order to keep body posture in alignment. If the vestibular system will be affected on one side or both side then, there will be changing in the control of the posture and balance resulted in reduced of the stability. (Horak, 2006; Laurens et al., 2010)

2.2.2. The Somatosensory System

Utilization of the somatosensory information, which is considered as one of the sensory systems that work in integration through the central nervous system to keep postural stability in static and dynamic states. These inputs information offered by the somatosensory through proprioception and tactile touch, whereas the proprioception information senses and works with position and movement of the body through joints and muscles with respect to feet, and tactile senses light touch, vibration, pressure, temperature and flutter, while the touch is contacting to the skin, and pressure is manifested by big force applied on skin and underlying tissues which is existed for example with the postural stability in plantar aspect of feet while standing position. (Peterka & Loughlin, 2004; Kalajainen, 2015)

2.2.3. The Visual System

When we talk about the visual system, eye is first and main thing to focus on (Figure. 3), the eye is composed of many portions, for each of them its own properties and purposes. The front side of the eye is the cornea, that works with light focusing and transmitting to the eye, while the lens is at the back of the cornea and focuses light toward the retina. Another eye part is the iris which appears with color differs individually, which regulates entering of light quantity or magnitude to the eye. Whereas the dark dot or pupil, which is the center of the eye, that becomes wider or smaller to control the light intensity that enters to the eye. In addition, there is the retina, which is comprised of layer of nerves located at back of each eye, it receives and transmits the light information to the optic nerve, that works on connection between the brain and the eyes. The visual information is important in keeping the postural stability in humans, if there will be any deficit impairing partially or total loss of the vision, that will result in postural instability more in in dynamic state and conditions. (Hunter & Hoffman, 2001; Kalajainen, 2015; Laurens et al., 2010; Marieb & Hoehn, 2007).

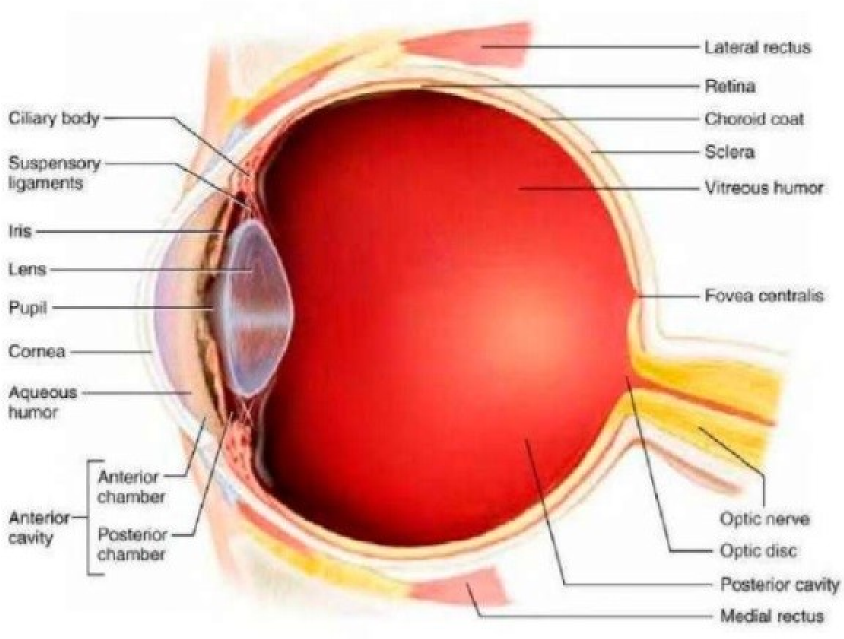

Figure 3. Anatomy of Human Eye. (Shier, Butler, & Lewis, 2001)

2.2.4. The Integration of Sensory Systems

Through sensory organization, which is the sensory systems integration and contributing by the central nervous systems to keep the postural stability of human. The visual, vestibular and somatosensory systems which have an important role in body postural control, however, their information and inputs are not sufficient if each sensory system works alone without the role of the central nervous system or if there are disorders affecting these sensory systems themselves. (Horak, 2006; Laurens et al., 2010; Kalajainen, 2015; Peterka & Loughlin, 2004).

2.3. Spatial Orientation

Spatial orientation is the ability of humans to orient their selves in environment or surrounding in relation to the gravitational force, it is considered as one of main balance system functions. To obtain this awareness of body in space, there are sensory inputs and signals required which include proprioceptors, graviceptors, vestibular inputs and others, moreover, senses of hearing and vision are needed for better spatial orientation, these senses and inputs are related and interacted, however, if there will be any dysfunction interruption or loss of them that may lead to reduction in spatial orientation and its functionality. The vestibular system which works in relation with gravity force through the maculae and semicircular canals, which sense the head orientation and acceleration, further, the vestibular system gives information with respect to gravitational force about movement speed and altering in direction, which enable the body to keep its posture and balance, and make or perform different movements. (Brandt, Wist, & Dichgans, 1975; Coluccia & Louse, 2004; Goldberg, Wilson, Angelaki, & Cullen, 2012; Horak, 2006; Keshner & Kenyon, 2009; Kozhevnikov & Hegarty, 2001; Payne, 2006)

2.4. Computerized Dynamic Posturography (CDP)

Back to the history, the development of balance control evaluation was based on two approaches. The first one which started in the 19th century by Romberg, by comparing body sway in both eyes open and closed conditions to evaluate proprioception system. Romberg interpreted the execution of the balance test that in case of a person standing on stable surface the proprioception system should be dominant in balance function, and when there is disruption of proprioception information the visual system will be main source of sensory information to maintain balance. The utilizing of static posturography brought further developing and expanding of Romberg's work by acquiring quantitative measures and analysis of body sway. The second approach, utilized in postural stability evaluation containing brief and spontaneous balance disturbing to figure out postural responses characteristics. (Jacobson & Shepard, 2014; Payne, 2006).

Computerized Dynamic Posturography (CDP) was founded in 1970's by Lewis Nashner. The development of CDP was financially supported by NASA, which was utilized for assessing vestibular system functionality and postural stability in astronauts after space flight. Then The National Institute of Health funded the further developing of CDP, to evaluate effects of some diseases on balance control. (Jacobson & Shepard, 2014; Payne, 2006; Vaudrey, 2006; Bernstein & Burkard, 2009).

The first description of clinically use of CDP in assessing sensory and motor parts of postural stability was provided by Lewis Nashner in 1982. Commercially, there are The Balance Quest (Micro Medical Technologies), and The Equitest (NeuroCom International, Inc.), which is shown in methodology section, which was produced in 1986. (Payne, 2006; Vaudrey, 2006; Bernstein & Burkard, 2009; Ionescu, Morlet, Froehlich, & Ferber-Viart, 2006; Shepard & Janky, 2010).

CDP is not considered as diagnostic tool but as objective tool to evaluate balance function, which detect sensory dysfunction of visual, somatosensory and vestibular systems that are participating in balance control. It gives information about dependency on each of the sensory systems individually in maintaining balance, and in case of a sensory system abnormality showed the reliance on other intact sensory systems, and clarify the postural stability strategy that a person used. It can identify the presence of imbalance and if it is due to sensory, motor or central integration, or involving of these factors together. (Payne, 2006; Vaudrey, 2006; Bernstein & Burkard, 2009).

By utilizing CDP, it is possible to identify vestibular system using in normal state or if it is present with impairment. It could help in rehabilitation plan setting or to quantify effects of different disorders on balance control. However, CDP doesn't give information about location of lesion or etiological cause. (Payne, 2006; Vaudrey, 2006; Bernstein & Burkard, 2009; Black, 2001; Goebel, 2008).

Priority of making a treatment decision is due to results of CDP, which is in addition to history taken of a person, results of clinical examination and findings of diagnostic tests, which are working in coupling. In case of incompatible findings of a person history or physical examinations, CDP is playing a role helping an examiner to unveil pathologies that are not suspected, unconscious person state and intended provocation of symptoms. (Vaudrey, 2006; Black, 2001).

CDP challenging conditions through providing the two main types Motor Control Test (MCT) and Sensory Organization Test (SOT), which are simulation to conditions that a person face in normal life environment. CDP is working with isolation of these sensory and motor components, which collaborate to achieve postural stability and balance. (Vaudrey, 2006; Bernstein & Burkard, 2009; Goebel, 2008; Shepard & Janky, 2010; Daube, 2002)

2.5. Postural Stability Testing Methods

In the past, assessment of postural stability was done by observation without using of technology or quantitative methods. Later on, with evolution of technology and existence of computers, postural stability evaluation mechanisms got improved and varied. Postural stability assessment nowadays could be divided into clinical and laboratory tests or measures. Common clinical postural control tests comprise of Balance Error Scoring System (BESS), The Star Excursion Balance Test (SEBT), Romberg sign, Functional Reach Test (FRT) and Dynamic gait index. Laboratory postural control tests include Computerized Dynamic Posturography (CDP) which contains force platform testing, using Biodex, NeuroCom Equitest and Balance Quest. (Cote, Brunet, Gansneder, & Shultz, 2005; Wikstrom, Tillman, Smith, &Borsa, 2005; Horak, 1997; Ross & Guskiewicz, 2004).

In general, postural stability evaluation is considered to be subjective or objective, in subjective method testing examiner involved in assessment of balance performance based on qualitative standards, whereas objectively testing collect, analyze and compute quantitative data through the computer system of the device. In spite of that laboratory postural stability tests provide better accuracy and ability to reveal impairments of the balance function, the clinical balance tests have positive features include simplicity of providing, inexpensive cost and have more direct interpretation of their results (Berg, Maki, Williams, Holliday, & Wood-Dauphinee, 1992; Riemann, Guskiewicz, & Shields, 1999; Kalajainen, 2015; Maranhão-Filho, Maranhão, Silva, & Lima, 2011A; Maranhão-Filho, Maranhão, Lima, & Silva, 2011B)

2.5.1. Clinical Measures

Clinically, there are many tests for assessing postural stability, they vary due to the purpose and state of postural stability if it is either static or dynamic. Previously, the balance evaluation was by triggering reflexive responses and by assessing sway of the body posture in standing position. Later, postural control was recognized as complex of motor and sensory components, which needs more investigations and examinations. The clinical postural balance testing is varied and there is no one unique test that could assess comprehensively the postural balance control or stability. However, due to the objective of the clinical balance evaluation and the balance problem, the examiner can set the clinical assessment of balance whereas this assessment varies to several ways, functional, systemic and quantitative posturography. The functional and posturography are utilized in identification of balance deficits to expect risks which a person may face, while the systems and posturography are utilized to unveil the underlying reason of the balance deficits or lesions so that they could be treated. (Horak, 1997; Mancini & Horak, 2010; Riemann, Guskiewicz, & Shields, 1999).

2.5.1.1. Static Measures

There are many static postural stability tests, which include Romberg's Sign is one of the first clinical static postural stability tests, which was developed by Moritz Heinrich Romberg in 1853, it is subjective assessment of somatosensation system by absence of visual feedback to rely on proprioception and vestibular systems. The test provides while person is in standing position, putting feet together, start with open eyes condition for thirty seconds and then in closed eyes condition for thirty seconds, the examiner assess the person ability in maintaining balance by observation if there is presenting of any sway to the sides or loosing balance and feet contact to the floor. Romberg tandem or sharpened, is similar to The Romberg Test except the feet position, which placed in heel to toe position. (Goebel, 2008; Riemann, Guskiewicz, & Shields, 1999; Lanska, 2002; Lanska & Goetz, 2000; Maranhão-Filho, Maranhão, Silva, & Lima, 2011A).

In 1986, Shumway-Cook, Nashner and Horak described Clinical Test for Sensory Integration in Balance (CTSIB) to evaluate the balance maintaining through utilizing sensory systems, the CTSIB is consisted of six conditions include two conditions of visual conflict, which were eliminated in modified CTSIB. The Modified CTSIB has four conditions in standing position as follows the first and second while standing with feet together on firm surface in eyes open and eyes closed conditions, respectively, and the third and fourth conditions are performed on foam surface in open eyes and closed eyes, respectively, each condition is repeated three times. The modified CTSIB showed high agreement by 90% with Sensory Organization Test (SOT). It is considered as clinical form of SOT, however, it is utilized in static balance control. (Boulgarides, McGinty, Willett, & Barnes, 2003; Maranhão-Filho, Maranhão, Silva, & Lima, 2011A; Wrisley & Whitney, 2004; Whitney, Wrisley, & Furman, 2003).

Functional Reach Test (FRT) was introduced in 1990 by Duncan, Weiner, Chandler and Studenski. It evaluates voluntary stability limits anteriorly, while a person in standing position provide maximal forward bending to reach maximum point by arm while keeping feet position and measure the distance according to yardstick fixed on a wall at the level of the person's shoulder. (Maranhão-Filho, Maranhão, Silva, & Lima, 2011A; Jonsson, Henriksson, & Hirschfeld, 2003; Sousa & Sampaio, 2005; Bennie et al., 2003; Mancini & Horak, 2010; Pieber et al., 2016).

Single Leg Stance (SLS) or One Leg Standing Test, is provided by individual standing barefoot with arms folded in front of upper trunk and focus eyes on a point with distance by one meter away, using one foot each time, in both open and closed eyes conditions, respectively, within thirty seconds. The SLS is one of the Berg Balance Scale (BBS) items. (Maranhão-Filho, Maranhão, Silva, & Lima, 2011A; Hertel, Gay, & Denegar, 2002; Flansbjer, Blom, & Brogårdh, 2012; Ross & Guskiewicz, 2004; Cote, Brunet, Gansneder, & Shultz, 2005; Mancini & Horak, 2010).

Pull Test (PT) or Postural Stress Test (PST), is presented while the examiner standing behind the individual, the examiner provides posteriorly pulling of the individual shoulder to disturb the balance. (Maranhão-Filho, Maranhão, Silva, & Lima, 2011A).

Balance Error Scoring System (BESS) is low cost clinical evaluation of balance control, commonly utilized in persons with concussion, mild head injury. The BESS is performed while the individual is closing eyes, with hands over hips, the test is performed in three positions in single leg stance with nondominant leg, double leg stance and tandem stance with nondominant leg behind the dominant one. The standing is provided over two different kinds of surfaces firm and foam. Each trial is lasting twenty seconds and errors are counted through the trials. The BESS has good validity and reliability of postural stability evaluation. There is significant correlation of The BESS error scores and Equitest. There is similarity of BESS scores and SOT composite scores in mild head injury in athletes individuals. (Bell, Guskiewicz, Clark, & Padua, 2011; Finnoff, Peterson, Hollman, & Smith, 2009; Broglio, Zhu, Sopiarz, & Park, 2009; Onate, Beck, & Van Lunen, 2007; Wilkins, McLeod, Perrin, & Gansneder, 2004; Docherty, McLeod, & Shultz, 2006; Kalajainen, 2015).

2.5.1.2. Dynamic Measures

In dynamic control of posture, there are functional tasks need to be provided. Evaluation of dynamic postural control needs participation of somatosensory, physiological movements and muscle strength in addition to maintain upright balance. There are a lot of dynamic postural control tests for children an elderly people, however, there are less proper tests among healthy or sport populations functional balance abilities. (Gribble & Hertel, 2003**)**.

The dynamic postural stability tests, include Timed Up and Go Test (TUG), is simple clinical test, performed by standing up from a chair walking three meters, turn around and walk back to the chair and sit down. Time is measure in seconds using stopwatch, time below 10 seconds is normal. It could indicate fall risks of old individuals. In addition, there are modifications of TUG test, TUG cognitive is performed as the TUG with adding task of counting backward from any number between 20 and 100, whereas TUG manual is provided as TUG test while the individual holding a full cup or glass of water. (Boulgarides, McGinty, Willett, & Barnes, 2003; Bennie et al., 2003; Mancini & Horak, 2010; Sousa & Sampaio, 2005; Maranhão-Filho, Maranhão, Lima, & Silva, 2011B)

The Star Excursion Balance Test (SEBT) is easy and low cost dynamic balance test that performed in standing position on one leg while second leg is trying to maximum reach directions which already made on floor, these directions are anterior, posterior, lateral, medial, anterio-medial, anterio-lateral, posterio-medial and posterio-lateral. The individual provides maximal reach with most distal part of his foot, which is marked and measured in centimeters using measure tape. Each leg provided furthest reach in each direction while keeping balance. The SEBT has good reliability and used as functional test for lower limbs. (Kinzey & Armstrong, 1998; Cote, Brunet, Gansneder, & Shultz, 2005; Olmsted, Carcia, Hertel, & Shultz, 2002; Delahunt, McGrath, Doran, & Coughlan, 2010).

The dynamic gait index (DGI) is devised by Shumway-Cook and Woollacott, it assesses individual functional stability while walking and to assess elderly fall risks. The DGI consists of eight items, each item scaled of 0 to 3 scores whereas 0 indicates no ability and 3 indicates normal gait of the individual. These items comprised of free gait, gait at different levels of speed, different positions of head, gait turn to 180 degrees, stairs climbing and gait around and over objects. (Jonsdottir & Cattaneo, 2007; Whitney, Wrisley, & Furman, 2003; Whitney, Hudak, & Marchetti, 2000; Maranhão-Filho, Maranhão, Lima, & Silva, 2011B).

Time to Stabilization test (TTS) evaluates postural stability in combination with jump landing task. It calculates time of individual to stabilize on after jump landing. The TTS test is based on somatosensory feedback, pre-programmed muscle patterns and both muscle responses reflexively and voluntary. The TTS has latent imperfections which includes evaluation of postural stability in isolation of each force vertical, anterio-posterior and medio-lateral directions and calculation flaws which were corrected and Dynamic Postural Stability Index (DPSI) was introduced to overcome the TTS inherent imperfections, furthermore, it is more reliable and precise. (Wikstrom, Tillman, Smith, & Borsa, 2005; Wikstrom et al., 2007; Ross & Guskiewicz, 2003).

2.5.2. Laboratory or Tools Measures

There are several devices used in evaluation of balance functions and postural stability. The Balance Quest which is produced by (Micro Medical Technologies) presented in (Figure.4), which comprised of two testing parts Sensory Organization Test

(SOT) and Limits of Stability (LOS), (Ionescu, Morlet, Froehlich, & Ferber-Viart, 2006; Payne, 2006).

Figure 4. The balance Quest System. (Ionescu, Morlet, Froehlich, & Ferber-Viart, 2006)

The Biodex Balance System (BBS) (Figure. 5), is utilized in testing of postural stability and body sway, by moving force plate in anterior posterior and medial lateral directions at the same time. In BBS it is possible to move with foot and force plate to twenty degrees. It computes Overall Stability Index OSI which indicates the average body position from the middle, Medial Lateral Stability Index MLSI and Anterior Posterior Stability Index APSI which indicate the average body position in these directions. BBS uses 4 conditions in measuring postural control, stable surface with open eyes, stable platform with closed eyes, moving platform with eyes open and moving platform with eyes closed. (Kalajainen, 2015; Cachupe, Shifflett, Kahanov, & Wughalter, 2001; Sherafat et al., 2013; Ibrahim, Mattar, & Elhafez, 2016).

Figure 5. The Biodex Balance System. (Sohn, Jee, Hwang, Jeon, & Lee, 2015)

Smart Balance Master System (Natus Medical Incorporated, Clackamas, Oregon USA) has a dynamic platform which can move up and down in SOT or into forward or backward translation movements in MCT according to chosen protocol by an examiner. It has different protocols as follows Sensory Organization Test (SOT), Motor Control Test (MCT), Adaptation Test (ADT), Limits of Stability (LOS), Rhythmic Weight Shift (RWS), Sequence Training, Weight Bearing Training and Custom Training. It quantifies and measures balance control in a person by calculating body sway during challenging conditions of moving platform or surrounded walls, by collecting signals through four sensors localized in each force plate corner, two at the top and two at the bottom of the force plate. It has computer that is processing the software to use the system and other components as shown in Figure (6). (Lee, 2014; Balance and Mobility Academy, 2017; Goebel, 2008).

Smart Balance System is an assessment and training tool that deal with vestibular, visual and somatosensation systems in standing position, and due to this standing position during testing procedure and to ensure safety, there is a safety harness a person must wear it to prevent falls in case of losing balance, the safety harness is attached to metal bar at the top of The Smart Balance System. As shown in Figure (7). (Vaudrey, 2005; Payne, 2006; Lee, 2014: Goebel, 2008).

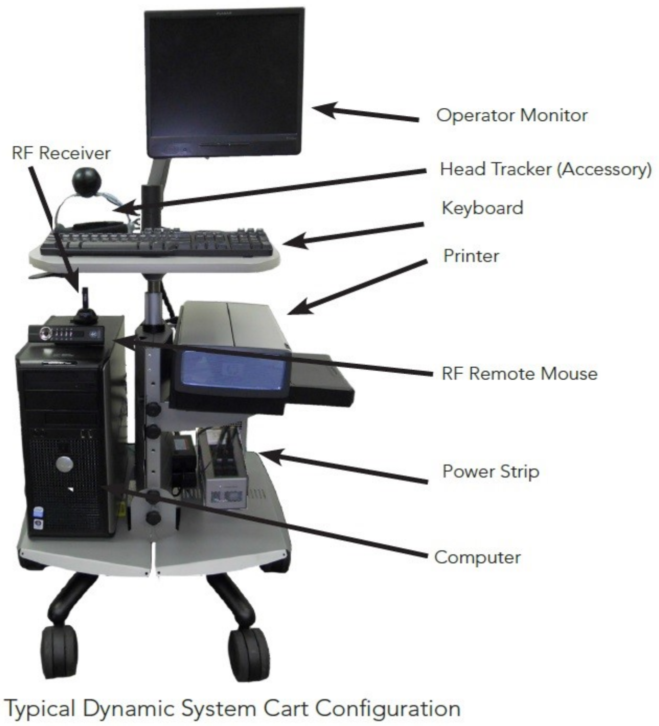

Figure 6. Computer and Components of The Smart Balance Master System. (Balance and Mobility Academy, 2017)

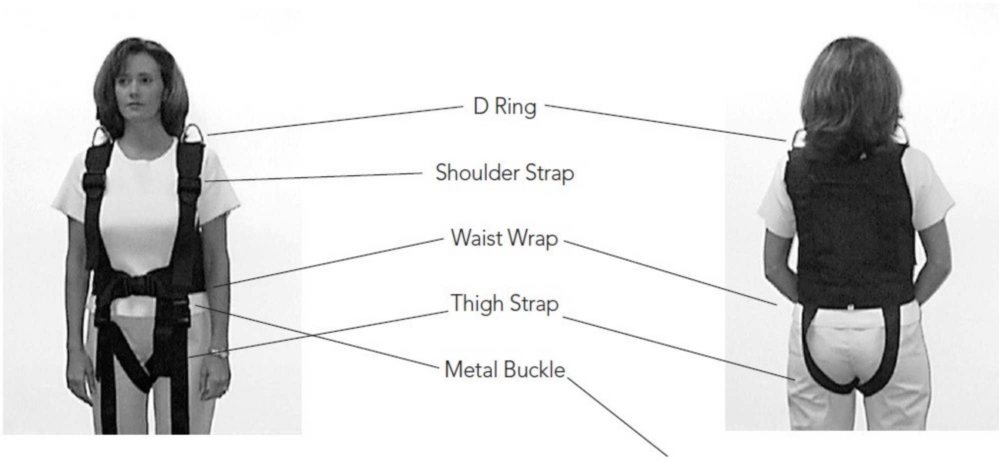

Figure 7. Safety Harness in The Smart Balance Master System. (Balance and Mobility Academy, 2017).

Sensory Organization Test SOT

The Sensory Organization Test (SOT) is considered as functional balance evaluation. The SOT evaluates equilibrium in each condition of the test and overall equilibrium conditions, it assesses the three sensory systems visual, vestibular and somatosensory or proprioception that used in maintaining a person balance in stance position. The SOT comprised of six conditions, that are progressively increased in difficulty by systematically interrupted the sensory systems of vision and proprioception to rely control of balance more on the vestibular system. The six conditions of the SOT contain of different visual conditions that include open eyes, closed eyes and moveable visual surrounds, the visual surrounds comprise of three walls one in front and two to the sides. Moreover, the force platform conditions vary from being fixed with no movement to moving alone or moving in proportion to visual surrounds movement.

The six SOT conditions are going on as follows, started simply with first condition while open eyes there is no movement of the visual surrounds or the force platform, second condition with closed eyes and fixed surroundings and force plate, while eyes open in condition three there is only visual sway of the surrounds with fixed support, in forth condition eyes must be open and the support will move only while the walls fixed, sway referenced of the support with closed eyes is the fifth condition, and the last sixth condition ends up with open eyes and sway of both the visual surrounds and platform, as shown in the Figure (8). Each condition of the six SOT conditions has three times trials sequentially. (Vaudrey, 2005; Payne, 2006 Lee, 2014; Bernstein & Burkard, 2009; NeuroCom® Balance Manager, 2016A; Oda & Ganança, 2015; Vanicek, King, Gohil, Chetter, & Coughlin, 2013).

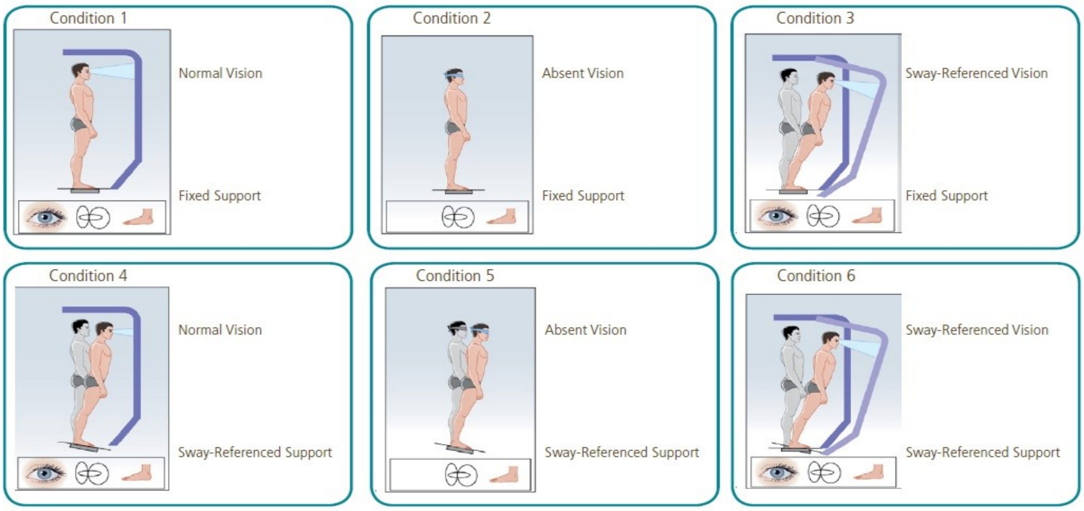

Figure 8. The SOT Conditions in The Smart Balance Master System. (NeuroCom® Balance Manager, 2016A)

Motor Control Test MCT

In Motor Control Test MCT, which evaluates a person balance function, by translation movements of the force plate into forward and backward directions, these movements are repeated three times in sequence for each translation amplitude which varies from small, medium to large. These platform displacements evaluate automatically motor response as result to the perturbation state initiated. MCT resulted in different outcome measures include weight symmetry, which indicates to the weight distribution under both legs prior to the translation movements, latency is another measures which is involved with time between the force platform displacement and a person automatic motor response, and lastly the amplitude scaling, that determine the strength of both legs response and the translation displacement magnitudes. (Vaudrey, 2006; Payne, 2006; NeuroCom® Balance Manager, 2016B; Vanicek, King, Gohil, Chetter, & Coughlin, 2013; Oda & Ganança, 2015).

The Wii Balance Board (WBB; Nintendo, Kyoto, Japan) (Figure. 9), with 23×43 cm plate that transmits vertical force under each corner as a subject stands or moves on its surface, it is utilized in entertainment, games based therapy in rehabilitation and training of different cases included balance disorders. In addition, recently it is being utilized in evaluation of standing balance as low cost device which is commercially available, its advantages are small size that doesn't need large space and portability, which is in contrast of the CDP that highly costed and occupy large space. However, the CDP is considered as gold standard in evaluation of postural stability or and balance, the WBB is showed to be valid and reliable. (Bartlett, Ting, & Bingham, 2014; Chang, Chang, Lee, & Feng, 2013).

In several studies (Chang, Chang, Lee, & Feng, 2013; Holmes, Jenkins, Johnson, Hunt, & Clark, 2012; Park & Lee, 2014) reported that the WBB has high validity and good reliability in evaluation of standing balance and it could be used alternative to gold standard posturography as clinically balance assessment among young healthy, older adults and patients with Parkinson's disease. Additionally, in a study by (Clark et al., 2010) about reliability and validity of utilizing the WBB in evaluation of standing balance, compared of with posturography force plate on thirty young participants, resulted in high reliability of the two evaluation tools in center of pressure (COP) path length outcome measure. (Gil-Gómez, Lloréns, Alcañiz, & Colomer, 2011; Rendon, 2011). Moreover, in a study on thirty seven old adults, perform balance tests in different conditions include Modified Clinical Test of Sensory Integration for Balance (mCTSIB) in four conditions of eyes open and closed, and open and closed eyes in standing on soft surface, and tandem stance test on force platform and the WBB, to determine the validity and reliability of utilizing the WBB in measuring of COP, resulted in high validity and reliability of utilizing the WBB in COP displacement outcome measure while providing the mentioned balance tests by the older adults. (Scaglioni-Solano & Aragon-Vargas, 2014). However, in a study by (Rendon, 2011) reported that center of balance of Smart Balance Master and mean center of gravity of WBB in young and older adults showed no significant correlation, but there was significant correlation in older adults among mean sway in Smart Balance Master and mean stability by WBB, and concluded that the WBB is valid in evaluation of unilateral leg stance.

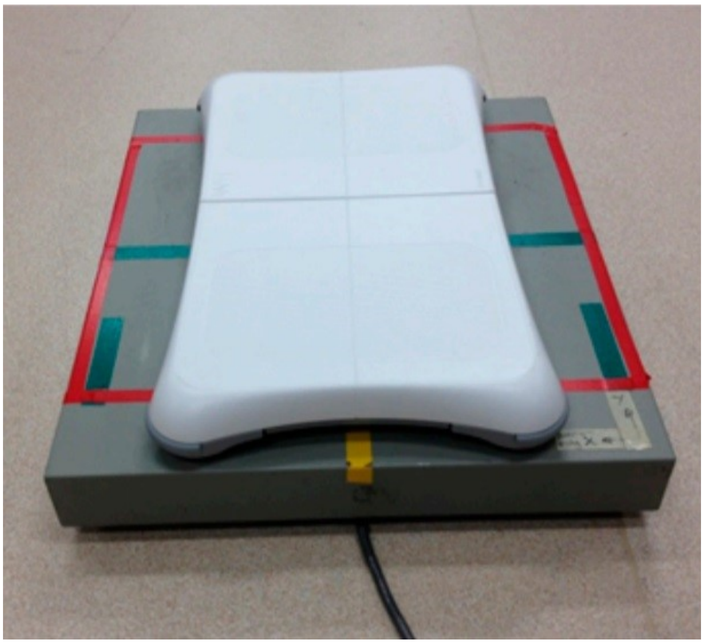

Figure 9. The Wii Balance Board. (Leach, Mancini, Peterka, Hayes, & Horak, 2014).

2.6. Virtual Reality

2.6.1. History

Back to the history of virtual reality, briefly we will go through the development of the virtual reality. In 1916 Albert Pratt patented for first Head Mounted Display HMD, Edward developed indoor flight simulator for training of flying and navigation in 1929. In 1946 ENIAC produced first digital computer to the American Army. In 1965 Morton Heiling developed multisensory virtual reality system using prerecorded film with experience of vision, vibration, sound, smell and wind, which provides virtual non-interactive reality. (Mazuryk & Gervautz, 1996; Sherman & Craig, 2002). Morton Heiling continued to 1960 with patented for developing Stereoscopic-TV Apparatus for personal usage, which was like the HMD developed later in nineties, which was providing display with sight, sound and smell. In 1961 Philco and Bryan developed HMD for using with head motion follow remote video camera. In 1963 Ivan Sutheland developed application that utilized light pen for interactional selecting and drawing, and input keyboard, which introduced interaction using computer graphics. In 1968 Ivan Sutherland paper work "A Head-mounted Three-Dimensional Display" mentioned his developed tracked stereoscopic HMD, while this HMD utilized tubes like that utilized in TV pictures, with providing two lenses providing two pictures for each eye, and ultrasonic and mechanical tracking. Back again to flight simulator which was developed by Evans and Sutherland in 1973, by using computer system that generate visual images, this system had offered night view only and limited in the display view. (Sherman & Craig, 2002). Videoplace is a virtual reality utilized cameras placed on screen and other inputs, enabling users interaction due to detecting them in two dimensional view, this system was developed by Myron Krueger in 1975. (Mazuryk & Gervautz, 1996; Sherman & Craig, 2002). In 1977, The Sayre Glove introduced, which worked for providing information about hand, by lightning relative to finger motion into flexion direction. In 1979 Eric Howlett created Large Expanse Enhance Perspective system that could make large view through lenses from small display, which was used subsequent by NASA in producing HMDs and then commercially produced by different companies. (Sherman & Craig, 2002). Visually Coupled Airborne Systems Simulator VCASS introduced by Thomas Furness in 1982, this system is developed flight simulator, used by wearing HMD for augmented reality. (Mazuryk & Gervautz, 1996). At NASA in 1984, Virtual Visual Environment Display VIVED built with HMD. In 1985 DataGlove produced by VPL. First commercial virtual reality device produced was Eyephone HMD in 1988, which contains two paired LCD screens display. (Mazuryk & Gervautz,1996; Sherman, & Craig, 2002). In 1989 full virtual reality system introduced by VPL company, in the same year and month of June, Autodesk. Inc. produced three dimensional world making program that could be used in personal computer belonged to Cybespace project. (Sherman & Craig, 2002). In 1989-1990 BOOM was commercially available, which is a box with 2 CRT monitors, a person could see through holes by holding it and placing it to his or her eyes, while mechanical arm evaluates the box position, it considered as head based display. CAVE (CAVE Automatic Virtual Environment) introduced in 1992, it is virtual reality and visualization system, it works by projecting pictures on room walls, used while putting on LCD glasses. Compared to HMD, the CAVE provided higher images quality and resolution, and larger view. (Mazuryk & Gervautz, 1996; Sherman & Craig, 2002). The virtual reality development continued among the nineties, in 1997, Cyber-Grasp introduced, that stimulate touch and grasping in the VR. In 2000 first 6 sided CAVE inaugurated in the US. (Sherman & Craig, 2002)

Since late twentieth century computer graphics were utilized in lots of disciplines such as designing, engineering, architecture and other fields. Due to developing of technology and new computers which resulted in spreading of using computers and computer graphics not only for professional users but for normal persons as well. Gaming using computers was one of the first usage of this computer graphics. Development of the computer graphics was not for 2D, however, it reached to 3D, 4D, 180 view and 360 view, which allows persons or users interaction and manipulation and being known currently as virtual reality. In the middle of the sixties of the 20th century, Ivan Sutherland gave his definition of the virtual reality as making the virtual reality feel, look and sound like real, and react as real to the user action. (Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003)

2.6.2. Definition

Virtual Reality VR has many definitions and other terms similar in some points and different in others. One definition of the virtual reality is that computer graphics images being generated to output VR device for participating and interaction in a simulated reality. (Schroeder, 2008). Another definition is that computer hardware and software designed for creation of virtual environment that enable user to be in. (Persky & McBride, 2009). Greenbaum, 1992 defined the VR as alternate environment full of images being generated using computers, these generated images react to person motion, the person engaged in this environment by using goggles and gloves. While Coates, 1992 defined it as the VR is electronic simulators presented simulation environment by using HMD goggles and wired clothes that allow persons to being interacted in 3D world. (Steuer, 1992)

According to (Sherman & Craig, 2002), the virtual reality has four keys components which are virtual world or environment, immersion, interaction and feedback of sensory systems. The virtual world is content that being played in the virtual reality system and description of the virtual reality components and their relations to each other. Immersion, is feeling or sensation of a person that he or she is engaged into an environment. Interaction, or interactivity is a major component in the VR, the VR looks like real by reacting and responding to person actions and motions to be interactive. Sensory feedback, is considered as a major component of the VR, while the VR gives feedback to sensory systems or senses like vision in visual input, touch, hearing and others. The definition of the virtual reality after presenting the mentioned components is, the VR is a medium using computer simulator that enables users to interact with, the simulator recognizes users actions and positions then, it responds by changing or augmenting the feedback to one of sensory inputs or more, which results in feeling of immersion in that reality. (Sherman & Craig, 2002)

2.6.3. Terms Related to Virtual Reality

Virtual Environment (VE)

Virtual Environment (VE) is a term that sometimes mean virtual reality or virtual world, although the virtual environment was known before the term virtual reality. Therefore, the virtual environment is synonym for the virtual world, and it is also mean the virtual world played in the virtual reality system. (Mazuryk, & Gervautz, 1996; Sherman & Craig, 2002)

Augmented Reality (AR)

Augmented Reality (AR) is composed of both real and virtual realities, by emerging and overlying of the virtual reality on the real world to enhance visual input and deliver more information about the real world to a person. Usually users are wearing HMD for this application, however, it is possible to be displayed on palm based display, these devices are suitable for moving through the real world. The augment reality could be utilized in different cases for practice and education and others. (Keshner & Kenyon, 2009; Mazuryk & Gervautz, 1996; Sherman & Craig, 2002; Riva & Wiederhold, 2015: Riva, 2009)

Artificial Reality

Artificial Reality is one of the terms that gives description of artificial environments that a person can interact with. Myron Krueger definition of the artificial reality is a reality that react to user actions which enables user feel realistic of that reality. (Sherman & Craig, 2002)

Presence

Presence could have the definition that, it is feeling or sensation of existing and being in a world or environment. (Hettinger, & Haas, 2003; Steuer, J.,1992)

Telepresence

Telepresence is interaction in remote real world that is viewed using mediators or means which could be cameras and microphones to share that world's images and sounds for example. (Mazuryk & Gervautz, 1996; Sherman & Craig, 2002; Steuer, 1992; Riva, 2009)

Teleoperation

Teleoperation is opposite to the telepresence, it is utilizing remote devices to have the possibility of interaction to the environment, a person watches that environment from outside, in contrast to the telepresence where the environment viewed from inside to outside. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996)

Cyberspace

Cyberspace is a location or space existed for example in computer networks and internet that make communication and interaction possible between people far away to each other. As described by William Gibson in 1984. (Mazuryk & Gervautz, 1996; Persky & McBride, 2009; Sherman & Craig, 2002; Hettinger & Haas, 2003)

2.6.4. Levels of Immersion

Immersion can be defined as perception of being involved in the virtual reality. There are two types of immersion, physical or sensory immersion and mental immersion, the *physical immersion* is when a person being involved in the through the application of the virtual reality, however, he is no full immersion of all sensory inputs or the whole body, whereas the *mental immersion* is occurred when a person is fully immersed and engaged in the virtual environment**.** However, there is no full understanding of these two types of immersion, or their relationship to each other, or how could we differentiate them. (Sherman & Craig, 2002)

Levels of immersion are determined by kind and quality of the virtual reality system that a user participate in and interact with. As ideal model of the virtual reality immersion, there should be inputs or information to all sensory systems of user, high quality and resolution of the VR and to be synchronized as well. (Mazuryk & Gervautz, 1996). In spite of absence of standards or parameters to evaluate the immersion levels, there are ranges of the virtual reality involvement as follows: *None*, whereas a person perceives or feels that he or she tethered to electronic system. *Minor*, when a person feels the virtual environment and moving of its objects, but not engaged yet. *Engaged*, when a person feels of participation and interaction in the virtual reality, however, the person still distinguish between virtual and real environments. *Full mental immersion*, a fully participating and have feeling of being immersed in the virtual reality maybe to the level that users don't feel they're connected to the virtual reality system. (Sherman & Craig, 2002)

2.6.5. Virtual Reality Inputs

Interaction with the virtual reality will not be achieved if there are no inputs to the virtual reality system by a user. Thus, the virtual reality inputs collect user actions, command and tracking his or her body segments to computer system, which immerse that user in the virtual reality. In user monitoring, which contains both active and passive methods of input information to computer, in active method, a user can utilize auditory commands, or selecting and entering information via different ways such as joystick, keyboard, platform and others, while the passive way provides information to the system about user location and looking direction. These both ways of information inputs, provide tracking of use body segments and position tracking that offers orientation and location of user to the system. These tracking methods categorized to electromagnetic, optical, ultrasonic, mechanical, inertial, videometric and neural. On other hand, there is world monitoring, which collect information and data from physical reality that is not necessary link with user to the virtual reality. This monitoring could be for physical reality or the virtual reality. Information from physical reality could be used as part of the virtual reality like in augmented reality. (Burdea & Coiffet, 2003: Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003; Riva, 2009)

2.6.6. Virtual Reality Outputs

The sensation of person in the virtual reality comes from what it displays to him, this sensation through vision, hearing, touch or tactile feeling, which are the senses that the virtual reality systems working with. The virtual reality application with more senses participation lead to more immersion level of the person being in that virtual reality application. Output displays devices are categorized into visual, haptic or tactile and aural or auditory, they look similar in some areas and different in others. These displays devices are divided into stationary or fixed displays, head based displays and hand based displays. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996**;** Burdea & Coiffet, 2003**;** Riva, 2009)

The visual display, the most common type of the visual displays is the head mounted display HMD. The application of the virtual reality determines what to choose from these visual displays. We can divide the visual displays devices according to the basic division of all displays types as follows, in stationary or fixed, fishtank and projection, in head based, Head Mounted Display HMD, and hand based, palm virtual reality. The visual display devices or systems differ in their properties in visual output demonstration in color, resolution, field of view and others, and on logistic level in tracking system, environmental demands, safety cautions, prices and others. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003; Riva, 2009)

The *fishtank,* or monitor based virtual reality is the simplest type of the visual displays , which uses computer monitor. Persons can look to three dimensional virtual reality, looking into, around and in all directions of that monitor screen. The fishtank virtual reality is considered as stationary visual display, which needs computer monitor, tracking system and shutter glasses with liquid crystal LCD paired lenses, or utilizing a filter instead of these glasses. The fishtank virtual reality prices in compare to other VR devices is not high cost, however, it is not offering good level of immersion to users due to small field of view and restriction of user movements in case of filter using over the monitor screen, but the fishtank resolution is better than low prices head mounted display. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003; Riva, 2009)

The projection based visual displays, is fixed visual display with large screen and large field of view of users, which enable them to immerse more in the virtual reality. The projection based visual display can be made up by numbers of CRT monitors next to each other, with no frame between them for better watching. Rear projection virtual reality is common used. There are single screen projected and surrounded projected visual displays. In the projection based VR, the tracking system is different than that used in fishtanks. Users can wear polarized glasses or shutter glasses in the projection based display, whereas the polarized glasses are used with special single projection system or with two projection system with polarized filter. The application of the virtual reality determines the number of screens used in the projection based displays from to six screen around, top, bottom and all walls. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003)

The head based visual displays, is the most common used in the virtual reality. It is not fixed like previous mentioned visual displays types, but it is moving with head movement. The head based virtual reality displays could be the HMD, counterweighted displays like BOOM, small screens like Private Eye, and others. The head based displays screens are small in size and light in weight due to its purpose by wearing or holding them by the users. In the head based VR displays, there are many possibilities of choosing tracking methods. The advantage of this type of the visual displays is the range of person motion during application, however, that would be limited in use of sitting in cockpit for example. On the other hand, the disadvantage could be because of tracking lag, which may resulted in confused vision, head oscillation and simulation symptoms sickness.

(Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003; Riva, 2009)

See through head based visual displays, is the type of visual display that works with augmented reality, by mixing both the real world and the virtual reality. Applying this based on two ways video and optics, the video way by utilization both a video of physical reality and computer images generation, and the optical way done by utilizing mirrors or lenses to overlay computer generated images. Furthermore, annotation is could be presented by providing information or explanations for the physical reality with augmented reality that could help in training, learning, tasks performing or others.
Hand held display, is considered as virtual reality and augmented reality visual displays, it is small size screen that could be held by hand. It still need more developing to be used out of experimental and research fields. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003)

Aural or Auditory Displays, are divided to two basic divisions, fixed displays and moving or head based displays, whereas headphones are similar to the HMD. The headphones can work with isolation of real world sounds or interfere it with virtual reality to a user hearing system, while speakers enable more users to hear the sounds. These two basic aural displays are limited, in contrast to the number of the visual displays. The auditory display have different properties in sound stage, localization, amplification and others, the logistic properties include mobility, noise pollution, environment demands, safety, prices and others. Sound creation is easier than visual graphics, in addition, sound latencies and lags are less concern than in visual displays, in contrast, hearing sense is more sensitive than vision, so it is substantial that the sound be synchronized with visual input information. In the aural displays, it could be that the two basic types working together. Also it could be added to the virtual reality simply with low cost. In fixed auditory displays like speakers that act well with fixed visual displays allowing good mobility of persons using them, and more persons can use them as well, while in headphones, which are head based displays that act well with head based visual displays, with good portability and privacy. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003)

Haptic displays, haptic or somatosensation and touch sensation, this type of displays are not easy to make, because of its relations to touch sensation of persons, which required direct contact to the persons who are affecting these displays, these action and reaction made with the haptic displays make them input and output devices at the same time, however, it is possible to be input or output separately. Utilizing of the haptic displays are not common like visual or aural displays systems in the virtual reality. When it comes to general division of the virtual displays, it is hard to divide the haptic displays into fixed, head based or hand held**,** that is due to the way a person deal with this type of displays, by interacting and contacting usually by hands, arms, feet or legs. There are four divisions of the haptic displays interaction in the virtual reality, first, Tactile displays, which give information about grasp, touch, heat or texture of surfaces. Second, End effector displays, that give simulation to palpate and grasp objects, which provide pressure and resistance. Third, Robots displays, which give information of shape, site or texture by utilizing robots. Forth, Three dimensional hardcopy, considered as output haptic display, that gives information via haptic and visual of objects. The haptic displays systems provide tactile and force stimuli to persons, which work by contacting with these systems. Due to the haptic displays high cost and hard to work with in the virtual reality they are less used. (Sherman & Craig, 2002; Mazuryk & Gervautz, 1996; Burdea & Coiffet, 2003)

Vestibular displays, in this type of displays, which is associated with body motion, that could be offered in motion based systems, that could move a platform a person stand on or whole place the person sits in, an example of body motion system is the floght simulator, whereas the whole system move to induce vestibular inputs in combination with visual information as well, moreover, other examples of this type of system is what already known in entertainment field such as flying and driving systems. In using of the virtual reality, there is working on decreasing gravity level on user body that enables vestibular sensation changing, this could be achieved by some ways like utilization of underwater locations as in astronauts preparation for space flights, other ways are hanging a user in the air or pulling a person in concentric moving ring. (Sherman & Craig, 2002)

2.6.6.1. Low Cost Head Mounted Display HMD

The development of the virtual reality technology and its systems, which reached to production of low cost and small weight Head Mounted Display HMD, which is widely spread for several purposes such as gaming in entertainment field, learning and training in educational field, rehabilitation and treatment in medical and health fields and others. There are different types and products of the HMDs that commercially available like Oculus Rift DK1 HMD (Figure.9), which was available commercially in 2013, advantages of this goggles include high visual field and small weight, while low resolution of lenses considered as negatives of this type of HMD. In addition, another type of HMD is Samsung Gear VR (Figure.10), which produced after Oculus RiftDK1, it was introduced as result of work between Samsung and Oculus. It works with Samsung Galaxy S6 smartphone, by placing the smartphone in the Samsung Gear VR, the Samsung Galaxy S6 is working here as source of power and image, which is directed to eyes of an user. One of negatives of this HMD is in modifying or setting lenses focus, which is sometimes looking blurry in some parts of visual field to the user, however, its lenses resolution is higher than Oculus RiftDK1, further, when main camera in back of the smartphone not covered, it could be utilized in augmented reality. This type of goggles come with control touchpad to the side of it that enables the user to work and control within the VR system. (Buń et al., 2015; Buń et al., 2017; Cochrane, 2018; Diniz-Filho et al., 2015; Gago et al., 2016; Riva & Wiederhold, 2015; Rolland & Hua, 2005; Santos et al., 2009; Sherman & Craig, 2002). Moreover, after the Samsung Gear VR came the newer Samsung Gear Oculus VR, which works with Samsung Galaxy S7, which is the HMD we used in our experiment and described in methodology section. (Mosadeghi, Reid, Martinez, Rosen, & Spiegel, 2016; Tashjian et al., 2017). Additionally, there is Goggle Cardboard, which is designed to be compatible with different mobile phones like android phones, apple iphones, and windows smartphones. It produced in 2014 by Google. (Cochrane, 2018; Riva & Wiederhold, 2015). Moreover, there are also other types and companies that produced HMDs like HTC VIVE (Figure.11), and Sony PlayStation VR (Figure.12). (Buń et al., 2017).

Figure 10. Oculus Rift DK1 HMD. (Buń et al., 2017)

Figure 11. Samsung Gear VR HMD. (Buń et al., 2017)

Figure 12. HTC VIVE HMD. (Buń et al., 2017)

Figure 13. Sony PlayStation HMD. (Buń et al., 2017).

2.6.7. Applications of The Virtual Reality

Since the development of the virtual reality technology, its utilization varies in many fields, starting from research and experimental, to architecture, engineering, medical, therapeutic, rehabilitation, education, pedagogy, training, tourism and entertainment and games. (Sherman & Craig, 2002; Riva & Wiederhold, 2015; Cochrane, 2018; Burdea & Coiffet, 2003; Hettinger & Haas, 2003)

2.6.7.1. The Virtual Reality in Medical and rehabilitation field

Using of the virtual reality in medical area varies, where it could be used in surgical training, planning and augmented, and assessment, treatment and rehabilitation of different cases whether they were motor, neurological, and psychological or others. In the surgery training of surgeons, the virtual reality and augmented reality are used in the small invasive surgeries, where is the incision of operated site is small, and here is the role of the virtual and augmented realities via surgical simulators, which enable the surgeons to have better look or view to the operated site, by entering endoscope inside the incision via tubes, while the surgeon can watch that on monitor or screen, using visual and force feedback. Robotic is also used in surgery such as in surgeries for eyes that could be accurate and safe. The virtual and augmented realities are applied also in computer aid surgery and image based diagnostic. (Satava, 1995; Mazuryk & Gervautz, 1996; Riva, 1997; Riva, 2003; Riva & Wiederhold, 2015; Hettinger & Haas, 2003)

2.6.7.1.1. The Virtual Reality in Vestibular Disorders

Vestibular disorders is one of the fields that could be treated with utilizing the technology of the virtual reality, vestibular rehabilitation is usually provided by using conventional and standard treatment, however**,** with presence of the technology of the virtual reality, which significantly improved patients state and symptoms. In a meta analysis of seven studies on efficacy of using Virtual Reality (VR) for rehabilitation of vestibular system dysfunctions, for 176 patients , age between 18 and 84 years. They had VR based vestibular therapy between six to twelve sessions, with duration of one to eight weeks, a session lasts between twenty four and forty five minutes. Results showed obvious improving after VR vestibular therapy in the studies, average efficient of the studies range between 4.4 to 43.5%, Dizziness Handicap Index (DHI) mean decreased. Efficacy were not directly linked with VR exposure time (p=0.24), or with session number (p= 0.36). Concluded that the virtual reality is potential promising tool for vestibular rehabilitation for peripheral vestibular disorders. (Bergeron, Lortie, & Guitton, 2015). Additonally, in a study on eighty three patients with central, peripheral and mixed vestibular disorders, over 6 weeks course of treatment, in 6 therapy sessions for each group and each session lasts 60 minutes, the groups were customized physiotherapy treatment group and virtual reality based treatment group, the customized physiotherapy comprised of gaze stabilization, static and dynamic balance, eyes and head motion coordination and gait, while the VR based treatment includes virtual reality exposure while walking on treadmill. By measuring self report and performance of functional balance, they concluded that, there were significant differences in most of outcome measures after the treatment in both groups and keeping of these improvement at six month follow up, but there were no significant differences between the two groups. (Alahmari et al, 2014). In addition, In a study (Yeh et al, 2014) on forty nine patients with vestibular dysfunction, using 3D virtual reality system for treatment, which performed in six sessions, in four weeks course, the VR system for treatment composed of four games with exercising tasks like Cawthorne-Cooksey exercises. Resulted in significant difference and improvement of all outcome measures of training scores except one, in balance outcome measure, there were significant improvements in condition before the VR in mean mediolateral direction, and in condition after the VR in maximum mediolateral direction and statokinesigram when compared between before and after the treatment.

However, the virtual reality tool could be used as evaluation tool not only as treatment tool, in a study on 116 healthy participants and 10 patients with total vestibular loss to evaluate balance performance by using Wii Balance Board WBB and virtual reality, in different conditions of visual inputs which were in open and closed eyes conditions, and stable and perturbed visual inputs, these conditions were performed on stable and foam surfaces. Results showed that in healthy participants falls increased proportionally with age and with perturbation amplitude in stable and foam surfaces, in patients with total vestibular loss in conditions of eyes closed and perturbed visual input on foam surface all of theses patients failed, however, there were lesser falls in stable visual input than in closed eyes condition in both healthy and total vestibular loss participants. (Chiarovano et al., 2017).

2.6.7.1.2. The Virtual Reality in Impaired Balance Patient

In a study of using virtual reality based balance training by using Nintendo Wii Fit Plus on twenty six patients with impaired balance, which resulted in high usability and enjoyment levels of using this virtual reality balance training than standard physiotherapy treatment. (Meldrum, Glennon, Herdman, Murray, & McConn-Walsh, 2012).

In a systematic review of 8 randomized control trials about virtual reality efficacy in balance impaired patients, with total number of subjects were 239, these included studies used different virtual reality applications and systems. They concluded that, they could not agree or disagree of utilizing the VR based treatment rather than standard physiotherapy in impaired balance patients. (Booth, Masud, Connell, & Bath-Hextall, 2014).

Studies by Flynn et al., 2007, Cikajlo et al., 2012 and Pluchino et al., 2012 on virtual reality home training showed that it could be effective for balance disorders, but the question will be about what (VR) training program or design to choose, for how long time and frequency, precautions and safety for using it in some diagnosis and states of patients. (Mao, Chen, Li & Huang, 2014).

2.6.7.1.3. The Virtual Reality in Motor Rehabilitation

The environment that patients who need motor rehabilitation involved in, it seemed to be similar if it is real one or virtual one, whereas in a study by Feldman and his colleagues on hemiparesis patients, they compared making of movements in virtual world and real world, while in the virtual reality the patients hands were in glove with force feedback device, and electromagnetic tracking system was used in orient of hand in the virtual reality, resulted in no significant differences in characteristics of the movement in both virtual reality and physical world. Despite usual utilization of the virtual reality was for evaluation of activities of daily living, cognition functions and memory, there were also virtual reality applications that used in evaluation of balance, locomotion, functions of upper and lower limbs. (Merians, Tunik, & Adamovich, 2009; Sveistrup, 2004). In a study (Yin, Hsueh, Yeh, Lo, & 2016) on 10 stroke patients, by utilizing virtual reality cycling training system, that assess force and speed of cycling, and offered feedback to the patients to concentrate cycling training more on affected side. Results showed that there were significant differences in bilateral pedal force and force plate ($p=0.046$, $p=0.031$) respectively, post training in comparing to control group. Using of the virtual reality in field of motor recovery for patients post different types of neurological impairments started with 2D VR in simple design and then it improved and got more complex to 3D VR which may also has tactile inputs more than only visual and aural inputs. Furthermore, there are lab based customized training systems, these systems have higher flexibility, which used more for disable patients. These systems have haptic part, which is beneficial in initiation and making of movement in starting phase of treatment and rehabilitation of these patients. Gaming is also used in rehabilitation of motor deficits, by developing of therapeutic games that use interaction, for example 6 degree of freedom robot arm which could be used by adults and children as well. Moreover, Utilization of robots systems that could work in combination with the virtual reality increased variety of patients that could use this virtual reality technology and games as well in rehabilitation and treatment of motor deficits. (Merians et al, 2014; Merians, Tunik, & Adamovich, 2009). The concepts of adaptation of activities based neuroplasticity, tasks oriented of motor training and demand of repetitive practice with increased doses. These are the motor rehabilitation and treatment bases to use the virtual reality. Repetitive tasks oriented treatment and gradually increased practice are the ways of motor rehabilitation used nowadays which may lead to change neural organization and neuroplasticity in these patients, however, there are difficulties to make motor rehabilitation programs, that involve repetitive task training, one of these difficulties is intensity of these training, for example in stroke patients it is well documented that there is difficulty to provide sufficient treatment volume. It seemed that classical program for motor rehabilitation is not offering adequate repetitive task training to induce neuroplasticity and neural reorganization. (Merians et al, 2014; Merians, Tunik, & Adamovich, 2009).

There are some evidences that people could learn motor skills in the virtual reality and then transfer this motor learning to physical world, and this could be possible also in patients with disability, that enable patients to do tasks in easier way, with better safety, and with more customized to be appropriate to patient state, and simpler to learn due to feedback while practice, and provided more joy and fun. (Holden, 2005; Sveistrup, 2004). This motor learning evidence in some studies done in this field, in a study on healthy subjects, who played table tennis in virtual reality, while virtual teaching gave them augmented feedback, their performance was better than subjects who had real coach teaching. In addition, in a study on healthy subjects who performed task of moving metal ring over metal wire, in both virtual reality and real world, the subjects divided into three groups, the VR group, the real world group and control group with no training of that task. Results showed that there were significant improvements in both groups of the VR and real world task training ($p<0.001$). Additionally, in Webster and colleagues study on evaluation of efficacy of utilizing virtual reality based program for wheelchair training on physical reality wheelchair utilization, the study subjects were patients with unilateral neglect syndrome and stroke as training group and another control group. All patients in both groups had classical training of utilizing the wheelchair, while the VR group had in addition VR training, resulted in significant improvements of the VR group by less errors and falls while using wheelchair in real world when compared to the control group post training. (Holden, 2005). Moreover, in a study on 24 patients with chronic stroke aimed to understand recovery of motor function from neurophysiology point of view, by utilizing robot and virtual reality, whereas the patients divided into robotic in combination of the virtual reality treatment group, and another group had robotic treatment only, both groups had forty sessions, with time duration of forty to forty five minutes for each session, 5 times per week, in the VR robotic group there were two dimensional VR on screen in front of the patients, resulted in improving of Rivermead Mobility Index and knee force in the VR group more than robotic one, while Performance Oriented Mobility Assessment and hip force showed improvement only in the VR robotic group. They concluded that, the combined VR robotic training improve balance and gait in chronic hemiparesis patients and help in activation of motor areas in brain, which involve motor learning and planning, that may lead to increase level of motor performance and function. (Calabro et al, 2017).

2.6.7.1.4. The Virtual Reality Post Stroke

Stroke has been rehabilitated in different ways, using repetitive task training, which is common in use due to its efficacy on gait and functions of upper extremities. However, recently the virtual reality is being used in treatment of patients with stroke, which seems to be effective and showed improvement in balance, gait, physical function, muscles activation and mobility. The virtual reality could work with vision, hearing and tactile sensation, by utilizing motor learning and neural or brain plasticity principles in recovery of these patients. However, some of the virtual reality systems are high cost and not provided in any hospital or clinic, but there are other VR systems that could be offered like low cost HMD, videogames and other low cost and easy to get VR systems. (Cho, Lee, & Song, 2012; Park, Lee, & Lee, 2013; Kim, Park, & Lee, 2015; Park,Yang, Uhm, Heo, & Kim, 2016). In a study of twenty five patients with chronic stroke, divided into two groups Virtual Reality Reflection Therapy (VRRT) and control groups. Both VRRT and control groups had conventional rehabilitation for 30 minutes a day, five times a week for four weeks. VRRT group had in addition to conventional treatment, VRRT program with the same amount and duration as conventional rehabilitation. Results showed significant improvement post rehabilitation in both groups in Berg Balance Scale (BBS) but more significantly improvement in VRRT group ($p<0.05$). Functional Reach Test (FRT), Timed Up and Go test (TUP) and 10 meter walking (10mWV) test showed significant improvement in VRRT group in compare to baseline and compared to control group ($p<0.05$). Static balance ability of the subjects was measured by using zebris force platform, showed significant improvement in all conditions with opened eyes and medial-lateral sway with eyes closed and anterior-posterior sway with opened eyes in compare to control group. (In, Lee & Song, 2016).

Additionally, in (Song & Park, 2015) study on 40 stroke adults patients, who split into two groups, a group with virtual reality using Xbox Kinect and a group train with ergometer bicycling, the duration of the course was for 8 weeks, the training program for both groups were in half hour daily, five times a week, which resulted in significant differences in both groups in weight distribution on the affected side, limits of stability anteriorly and posteriorly, and in Timed Up and Go test and 10 meter walking test ($p<0.05$), whereas the virtual group had more significantly improvement when compared to the second group, which concluded that there is efficacy of utilizing these two methods of training using the virtual reality and the ergometer training in improving stroke patients balance and walking. In addition, in a controlled trial by (Singh, Nordin, Aziz, Lim, & Soh, 2013), on 28 stroke adults patients**,** they were divided into two groups, one control group and one virtual reality based balance training group, both groups went through two hours of treatment, which were twice a week and were for six weeks course duration, the control group had conventional treatment, while the virtual reality based balance training group had the conventional treatment in addition to the virtual reality games balance training using Nintendo® Wii Fit Plus with its Balance Board and Xbox 360 Kinect for half hour. The results showed significant improving of both groups in the Time Up and Go Test and Thirty-second Sit to Stand Test for functional mobility and lower extremities strength, but there were no significant differences between these two groups**.** They concluded that replacing part of the stroke treatment by utilization of the virtual reality offer effective treatment and enable patients to train at home and save time of physiotherapists.

Moreover, in a scoping review by (Darekar, McFadyen, Lamontagne, & Fung, 2015) on the influence of virtual reality based treatment in stroke patients, with using 24 studies. They reported that there were significant improvement in patients balance and gait post the VR based treatment. Furthermore, in a systematic review study (Corbetta, Imeri, & Gatti, 2015), that used fifteen trials with total number of 341 subjects. The included studies had substitution part or whole conventional treatment program with virtual reality based treatment, the studies were varies in treatment course from two to six weeks, in twenty to sixty minutes treatment sessions a day, through two to six days per week. Using outcome measures of balance, gait speed and mobility, they concluded that the virtual reality based treatment when replaced to some or all of the conventional physiotherapy treatment showed significant improvement in the balance, gait speed and mobility. In addition, in (Kim, Choi, Lee, & Song, 2015) study on forty stroke patients to see the effects of virtual reality treadmill training on their gait ability and function, they were divided into virtual reality treadmill training group and control group, the control group had only treadmill training, while the VR training group had the virtual reality of real word recording, both groups had treatment in a course of four weeks, for half hour a day, 3 times a week. The patients results showed significant improvement in the gait function and ability in both groups, more improvement in the VR group, there were also significant differences between the two groups post the training sessions. Moreover, in a study by (Park, Lee, & Lee, 2013) on 16 chronic stroke patients, they were divided into two groups, virtual reality based training group, who had virtual reality based training for half hour a day, 3 times a week, both groups had standard physiotherapy treatment for one hour a day, 5 times a week, the treatment procedure was lasting for 4 weeks. Resulted in significant improvement in the VR group in gait ability when compared to the control group. Further, in a study (Kim, Park, & Lee, 2015) on twenty patients with stroke using virtual reality based treadmill training, which was added to the standard physiotherapy treatment with half hour a day, three times a week, while the control group had only standard physiotherapy with half hour in a session, three times a week, both groups treatment duration lasted four weeks, resulted in significant differences that showed significant improvement of the virtual reality based treadmill training group in balance.

Additionally, in a study on 22 stroke patients (Cho, Lee, & Song, 2012), using virtual reality based balance training using videogames, the patients were divided into two groups, both groups had conventional physiotherapy and occupational treatment, for one hour a day, five times per week, while the virtual reality group had in addition half hour of the virtual reality based training, three times per week, the duration of treatment procedure lasted six weeks. Results showed significant improvement of dynamic balance in the VR group when compared to the control group, and there were no significant differences of static balance in both groups. In addition, in (Lee, Kim, & Lee, 2015) study on 24 patients their diagnosis is stroke, they divided into virtual reality group and task oriented group, all patients had standard physiotherapy for one hour and five times a week, in addition to half hour a day, three times a week for each group with their training programs during six weeks course of treatment. The results from the measurements of static and dynamic balance showed that there were significant differences in both training groups ($p<0.05$) and there were significant differences between the two groups ($p<0.0001$) in dynamic balance using Functional Reach Test. They concluded that utilization of the virtual reality based treatment showed better improving of stroke balance ability in comparing to the task oriented treatment program. Moreover, in a study by (Park, Yang, Uhm, Heo, & Kim, 2016), utilizing VR based eccentric training on 30 stroke patients, they were divided into slow velocity eccentric training group and fast velocity training group. After eight weeks of training, in half hour a day, five times per week, which resulted in significant differences in balance and muscles activation of lower limbs in slow velocity eccentric training group when compared to the fast velocity one.

2.6.7.1.5. The Virtual Reality in Parkinson's Disease Patients

The virtual reality technology could be used for patients with parkinson's disease for gait and balance training (Yen et al., 2011). In a study on 42 parkinson's disease patients, divided into virtual reality based balance training group, standard balance training group and control group, with training duration lasting six weeks. The VR group had virtual reality based balance training in twenty minutes by using balance board and screen, while the standard balance group had twenty minutes of training. Resulted in no significant differences between the VR and standard balance groups, but the VR group significantly increased in equilibrium score of SOT condition six post training ($p<0.001$), but not at follow up, and the standard balance group significantly increased in equilibrium score of SOT condition five ($p<0.001$) post training compared to control group, and in vestibular sensory ratio there was significant increasing in the standard balance training group post treatment and at follow up. In addition, in a study of walking for twenty minutes using HMD, on 33 subjects divided into parkinson's disease patients group, healthy old group and healthy young group. Which resulted in no significant differences of simulation sickness symptoms in all groups post the VR application, there were also no significant differences in static and dynamic balance post the VR immersive walking in all groups, but there were decreasing in level of stress in all groups after the virtual reality exposure, and increasing of arousal level in the group of parkinson's patients post the VR application. (Kim, Darakjian, & Finley, 2017). In another purpose use of the virtual reality in patients with parkinson's disease, a study by (Arias, Robles-García, Sanmartín, Flores, & Cudeiro, 2012) to assess repetitive rhythmic hand movements in healthy older adults and parkinson's disease patients, there were ten Parkinson/s disease patients group, twelve healthy older adults group and twelve young healthy group, they were performing finger tapping in real world and virtual reality using HMD, concluded that the virtual reality is valid and reliable to be utilized in assessing repetitive rhythmic movements of hand.

2.6.7.1.6. The Virtual Reality in Cerebral Palsy

The using of the virtual reality in patients with cerebral palsy showed that it is effective treatment tool in improving balance and motor functions. In a systematic review and meta-analysis study of nineteen randomized control trials, to investigate the efficacy of the virtual reality in improving motor functions of children suffering from cerebral palsy, they reported that, the virtual reality tool is improving cerebral palsy children patients motor functions, and it is effective compared to standard physiotherapy treatment. (Chen, Fanchiang, & Howard, 2017). In addition, in an update evidence based systematic review with thirty one studies included, with 369 total number of subjects, with variation of time duration for each session between twenty to one hundred twenty minutes, in two to ten weekly sessions. They reported that, utilization of the virtual reality showed moderate evidence in improving of children and adolescents cerebral palsy patients balance and motor functions. (Ravi, Kumar, & Singhi, 2017).

2.6.7.1.7. The Virtual Reality in Pain Management

The utilization of the virtual reality in management of pain seemed to be effective in different pain causes of acute pain stage, while chronic pain needs more investigation and researching. In a study for pain management on one hundred hospitalized inpatients with acute pain, using 3D virtual reality using HMD, and 2D video on screen, in both groups the time duration of exposure was fifteen minutes. Results showed that there were significant differences in the 3D VR group in decreasing pain level compared to the 2D video group, with no reporting of motion sickness symptoms of the VR. (Tashjian et al., 2017). In another type of pain which is chronic and by using the virtual reality as home treatment, an exploratory study by (Garrett, Taverner & McDade, 2017) on ten patients with chronic pain, using the virtual reality HMD for half hour a day, three times a week, for one month, resulted in no significant differences of pain scores before and after the treatment, but there was decreasing in pain of some patients during the virtual reality application which is not lasting more, there were also reporting of cybersickness in some patients, but no other side effects were mentioned by the patiens.

2.6.7.1.8. The Virtual Reality in psychology

The utilization of the virtual reality in psychology and psychotherapy started since the beginning of the nineties, its uses were in anxiety disorders, different types of phobias or fears like acrophobia, agoraphobia, fear of spiders, fear of flying, social fear, claustrophobia and others via using virtual reality exposure therapy. In recent years there were developing of virtual reality applications for evaluation, understanding and treatment of psychological problems. After spreading of the virtual reality devices and systems that could be portable with low cost, the using of the virtual reality in treating psychological disorders increased, which one of its benefits is that the brain deal with it as real, and that is helpful in facing what patient fear of with safe environment. (Botella et al., 2004; Bowman & McMahan, 2007; Coelho, Waters, Hine, & Wallis, 2009; Riva, 2005; Riva, 2009; Smith, 2015)

Most common utilizing of the virtual reality is in phobias or fears treatment. Since the beginning of 90s, Hodges and his colleagues reported utilization of virtual reality exposure therapy of patients with fear of heights, which presented a new mean of exposure therapy. (Riva, 2005). Virtual Reality Exposure Therapy (VRE) or (VRET), which has higher level of safety and less cost than real world exposure therapy, where it works by making a patient intentionally faces what he or she fears of, which decreases anxiety. The utilization of the virtual reality exposure therapy has positives that, it could be provided with control of therapist, which enables therapist and patient to work with most fearful parts and repeat it without the need to repeat whole procedure, immersion in VRE enables patient to engage to the virtual world and experience more than real world exposure. (Riva, 2009). In a study by North and North in 1996, using case study design, utilizing the virtual reality in 8 therapeutic sessions, with time duration of fifteen and twenty-eight minutes for each session. There were significant improvements and decreasing of anxiety symptoms and avoidance. (Coelho, Waters, Hine, & Wallis, 2009).

In addition, in (Emmelkamp, Bruynzeel, Drost, & Van Der Mast, 2001) study on ten acrophobic patients, who had the virtual reality exposure therapy at first 2 treatment sessions and then had vivo or real world exposure therapy sessions. Results showed that both of real and VR exposure therapies significantly improve anxiety, while the VRE significantly improve avoidance and attitude as well, which showed that the VRE had effectiveness from first two sessions and they concluded that both exposure therapies had efficacy on acrophobic patients more with the VR. Additionally, in a study on thirty three acrophobic patients, divided into seventeen patients in virtual reality exposure therapy and seventeen patients in real world exposure therapy, they had 3 therapy sessions with 60 minutes for each, resulted in significant differences of both exposure therapies groups in anxiety, avoidance, attitude and in behavioral avoidance test when compared between before and after treatment, but there were no significant differences I comparing between after treatment and 6 months follow up, however, the patients keep their improvement at half year follow up. (Emmelkamp et al., 2002). The virtual reality technology is not used only for acrophobia treatment, but it could be used in its understanding and investigating as well. (Coelho, Waters, Hine, & Wallis, 2009). Furthermore, the virtual reality could be used in psychotherapy field in post traumatic disorders, stress disorders and management, sexual disorders, obesity and eating disorders. (Riva, 2009; Botella et al., 2004).

2.6.7.2. The Virtual Reality in Education and Training

The utilization of the virtual reality in field of training and education started early with flight simulators that were military used and then were used for civil flight training for pilots. There was also the driving simulation system for training on car driving. They used also with astronauts and with medical students to train and learn about surgeries procedures or with learning anatomy by animation and images that designed by using computers as presented in Figures (12&13). In the field of military training, there are applications that are designed to immerse the soldiers in the virtual reality environments with enemies and friends forces that simulate the real world, to train on some tactics and ways used in military aspects. (Bowman & McMahan, 2007; Cochrane, 2018; Mazuryk & Gervautz, 1996; Persky & McBride, 2009; Huang, Liaw, & Lai, 2016; Lee, 2012)

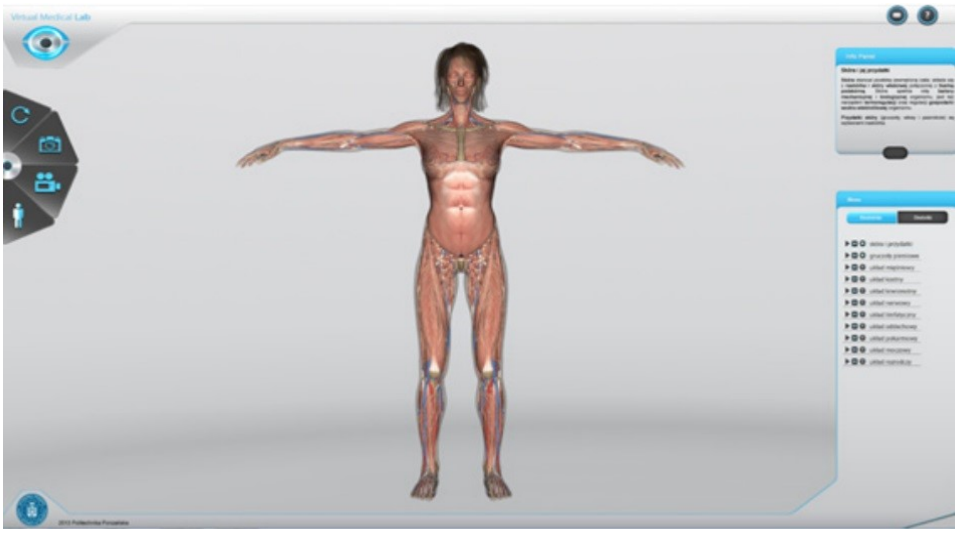

Figure 14. Anatomy learning by using Virtual Reality. (Buń et al., 2015)

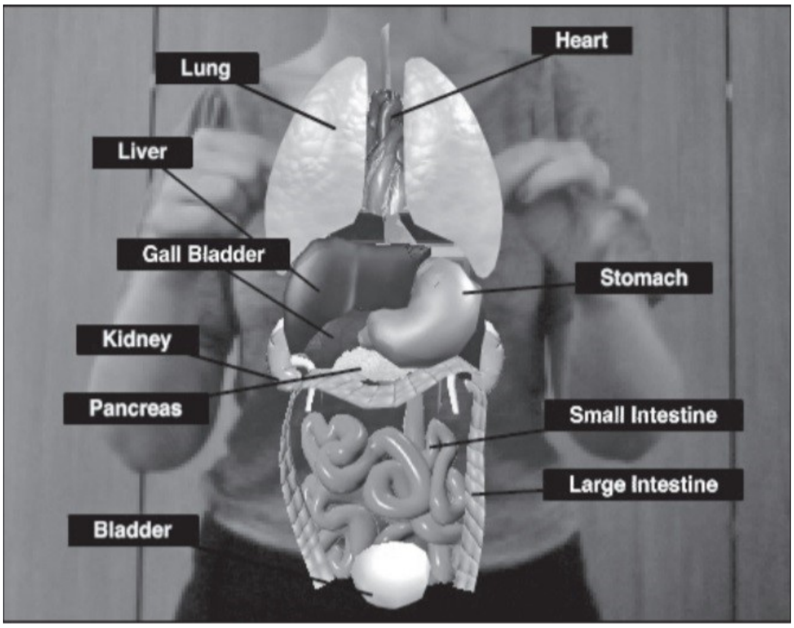

Figure 15. Anatomy leasing by using Augmented Reality. (Lee, 2012)

2.6.7.3. The Virtual Reality in Entertainment

The virtual reality technology was also used in the area of entertainment and gaming, with developing of the technology and decreasing of its cost, which then provide games systems. There are different types of the VR applications in the field of entertainment, personal computer based virtual reality games, games systems like Nintendo, PlayStation, Xbox and others. In addition, the HMD involve in this field by ability to play games using it. (Bowman & McMahan, 2007; Mazuryk & Gervautz, 1996)

2.6.8. Adverse Effects of Using The Virtual Reality

Utilization of the virtual reality may have side effects which manifested within the virtual reality application or post it, these side effects seemed to be like the ones resulted after using of simulators. These side effects could be named as simulator sickness, which have been classified to three main parts. *Oculomotor*, which maybe blurred vision, double vision, eye strain, focus difficulty, fatigue of vision and headache. *Disorientation*, which may present by vertigo, feeling dizzy, unstable posture or decreased in performance. *Nausea*, which may manifest with sweating, feeling sleepy, appetite loss, stomach ache, salivation increment and may reach to vomiting. (Mazuryk & Gervautz, 1996; Riva, 1997; Smith, 2015; Yokota, Aoki, Mizuta, Ito, & Isu, 2005; Ohyama et al., 2007)

Simulator sickness symptoms lasts between several minutes to hours post the virtual reality application. Symptoms of nausea and disorientation in simulation and virtual environments are occurred as result of sensory conflict that happened during the virtual reality exposure, this sensory conflict occurred between different sensory systems such as visual, vestibular and proprioception systems, or by comparing of sensory inputs to individual past experience stored in the brain. The sensory conflict may happen between the visual system and the vestibular system, and within the vestibular system its self between the otoliths and semicircular canals. (Riva, 1997; Ohyama et al., 2007)

2.6.9. The Virtual Reality Future

Although prediction is not easy when it comes to the technology which is very fast developing in last decade. As an example of the development in virtual reality and its applications, in field of psychology treatment which was known in second half of nineties. That what we expect to see in near future, when developers and researchers find new features, applications and uses of the virtual reality in many fields for exploring, treating, training and researching and more. Generally, we expect developing of the hardware of the virtual reality systems in different displays systems as output devices, in haptic displays which needs more working and developing than visual and aural displays. More developing is expecting in mixed displays systems and augmented reality, which will be beneficial in many fields in future as it was previously and is being nowadays. In addition, software is also expected to be developed more, which would enable users to get the virtual reality software by themselves due to their interests, for example as packages that could be customized in designing of these software, which would be fitted and appropriated to different cases and fields for healthy or unhealthy people. (Sherman & Craig, 2002)

Experimental Part

3.Methodology

3.1. Objectives

The aim of this study is to identify the effects of five minutes 3D Virtual Reality application exposure on healthy young adults dynamic postural stability, to determine the dynamic postural stability statistical differences post virtual Reality VR intervention.

3.2. Research question

What is the effect of virtual reality application exposure on dynamic postural stability in healthy young adults?

3.3. Hypothesis

We hypothesize that there will be positive effects of utilizing Virtual Reality VR technology on dynamic postural stability in healthy young adults.

3.4. Methods and Materials

This is pilot experimental study, assessing dynamic postural stability by using Sensory Organization Test (SOT) for visual, vestibular and somatosensory systems. And Motor Control Test (MCT). Theses assessments are provided by using Smart Balance System, NeuroCom (Natus Medical Incorporate, Clackamas, Oregon USA). The experiment procedure was approved by The Ethics Committee of Faculty of Physical Education and Sport, Charles University in Prague. (In Appendix I, The Application of Ethics Committee Approval).

Setting

Participants were tested in Laboratory of Kinesiology of Physiotherapy Department at The Faculty of Physical Education and Sport, Charles University in Prague.

Subjects

There were 11 participants (7 males, 4 females) aged between 21 to 39 years (mean 27 years, SD = 4.6 years). Their height ranged from 160 to 185 cm (mean = 171.5 cm, SD = 6.8 cm). They ranged in weight from 50 kg to 108 kg (mean = 69.3 kg, SD = 18.7 kg). The subjects were chosen from college students at The Faculty of Physical Education and Sport, Charles University in Prague. The subjects signed informed consents forms for the experiment. (Appendix II).

Inclusion Criteria
- Healthy Adults
- Age range between 20 and 40 years
- Male and female

Exclusion Criteria
- Neurological disorders
- Motor disorders
- Head and spinal cord injuries
- Sensory deficits
- Visual deficits
- Vestibular disorders
- Joint instability
- Lower extremity injuries last 6 months
- Taking medications affect balance or postural stability

3.4.1. Instrumentation

Balance Assessment by Using SMART Balance Master System

The SMART Balance Master System (SBMS) (NeuroCom International Inc., Clackamas, OR) was used for this study, as shown in Figure (14). It performs computerized dynamic posturography to assess quantitatively sensory and motor components of postural stability.

SBMS has an 18” x 18” force plate with four transducers, in each corner of the force plate, two anterior and two posterior transducers, these sensors receive signals from applied vertical force of subject on the force plate.

There are three panels around subject, one in front and two on both sides to right and left. The force platform and visual surrounds are fixed or moveable according to conditions of Sensory Organization Test SOT, their movements are in sagittal plane in both anterior and posterior (AP) directions.

SBMS is connected to PC computer to run its software and to make balance assessment by choosing desired test, after entering the data of subjects to software system, and to extract the results post-testing. The data were collected at sampling frequency of 100 Hz.

Figure 16. Smart Balance Equitest System. (Balance and Mobility Academy, 2017)

Samsung Gear VR and Samsung Galaxy S7

We play the virtual reality 3D video, by using Samsung Gear VR (SM-R323), which is compatible with Samsung Galaxy S7 as image source to use and play the videos. We used Samsung galaxy S7 in playing the 3D video on the Samsung gear VR.

3.4.2. Methods

Dynamic balance

Dynamic balance was measured by using Computer Dynamic Posturography (CDP), Master NeuroCom, with using Sensory Organization Test (SOT) and Motor Control Test (MCT).

Sensory Organization Test (SOT)

SOT is testing sensory systems contribute in postural stability, these systems are somatosensory, visual and vestibular systems. SOT is composed of six conditions, each condition has three trials. As follows:

Condition 1: eyes open, fixed visual surround and fixed platform. Condition 2: eyes closed and fixed platform. Condition 3: eyes open, moving visual surround and fixed platform. Condition 4: eyes open, fixed visual surround and mobile platform. Condition 5: eyes closed and mobile platform. Condition 6: eyes open, moving of visual surround and mobile platform. As shown in Table (1). Composed Equilibrium and Preference (PREF) are evaluated by SOT as well.

Table 1. Sensory Organization Test SOT

Condition	Vision	Surroundings	Surface	Sensory System
1	Open eyes	Fixed	Fixed	Somatosensory
2	Closed eyes	Fixed	Fixed	Somatosensory
3	Open eyes	Moving	Fixed	Somatosensory
4	Open eyes	Fixed	Moving	Visual
5	Closed eyes	Fixed	Moving	Vestibular
6	Open eyes	Moving	Moving	Vestibular

Motor Control Test (MCT)

Evaluate automatic stabilizing response to external disturbances. Timing, strength and symmetry of response. MCT comprised of two directions forward and backward translation movements of force platform, in each direction there are three different magnitude of translation movement small, medium and large translation movement, in each magnitude and direction there are three times repetition in sequence, with random delay of 1.5-2.5 seconds, these displacements of force platform in proportion to subject height.

Virtual Reality Application

Virtual Reality (VR) application was provided by using Samsung Gear and Samsung S7. The 3D video colored computer graphic of roller coaster for 5 minutes duration, was used from YouTube, the video name is "VR Avatar 3D VR Roller Coaster 3D SBS for VR BOX 3D not 360 VR", (3D-VR-360 VIDEOS, 2017) as shown in figure (15).

Figure 17. The presented 3D video. (3D-VR-360 VIDEOS, 2017)

3.4.3. Procedure

Prior to the experiment, participants signed an informed consent form (Appendix II) about participating in this study. They were well informed about the experiment procedure and their questions about it were answered.
Demographic data were gathered. The data about subjects age, gender, height, weight and date of birth, and were entered to the NeuroCom system.

Procedure consists of pre-test of dynamic postural stability, included SOT and MCT, application of virtual reality VR and post-test of dynamic postural stability, with SOT and MCT. As shown in diagram of the experimental procedure Figure (16).

Before Starting of dynamic balance assessment, included SOT and MCT, subjects were wearing a safety harness and they were properly fitted to it, which was strapped to overhead bar in NeuroCom for prevention of falling in case of losing balance. Then they were asked to remove shoes and socks and stand on platform barefoot, stand erectly with arms by their sides, looking forward at eyes level to face visual display, which is turned off. Feet were positioned on force platform relatively to person height as described by NeuroCom, whereas lateral calcaneus positioned to S, M or T lines in proportion to their height, whereas S ranged to 140 cm, M 165 cm and L more than 166 cm, medial malleolus were positioned directly over horizontal line on force plate. If subject moves foot from testing position, trial stopped, discarded and repeated after he or she repositioning correctly (Figure 17).

In SOT, condition one, subject was standing with eyes open and fore platform fixed, assessing mainly somatosensory system. Condition two, fixed force plate and closed eyes, for somatosensory system. Third condition, for assessing somatosensory, fixed fore platform, open eyes with moving of visual surrounds which move relative to subject sway. Forth condition, using visual system, eyes open and moving fore platform, as subject sways force platform sways. Condition five, eyes closed and platform sways, to assess vestibular system. Sixth condition, with sway of both force platform and visual surrounds, using vestibular system. In (Table.2), the sensory ratios of different sensory systems participating during the SOT test.

In MCT, there are two main conditions with force platform translation movements, backward and forward, each direction of translation movement has three magnitudes small, medium and large. Eyes always open in this test.

After completion of pre-testing of dynamic postural stability of SOT and MCT. There was directly applying of 3D video of Roller Coaster with time duration 5 minutes, while subject was in standing position. The application of VR was provided by using Samsung Gear goggles and Samsung Galaxy S7.

Upon completion of pre-testing of dynamic postural stability, of both SOT and MCT, and application of 3D VR. Then subjects were placed in testing position for post-testing of dynamic postural stability.

Subjects were asked about their subjective feelings during whole procedure (pre-testing, application of VR and post-testing).

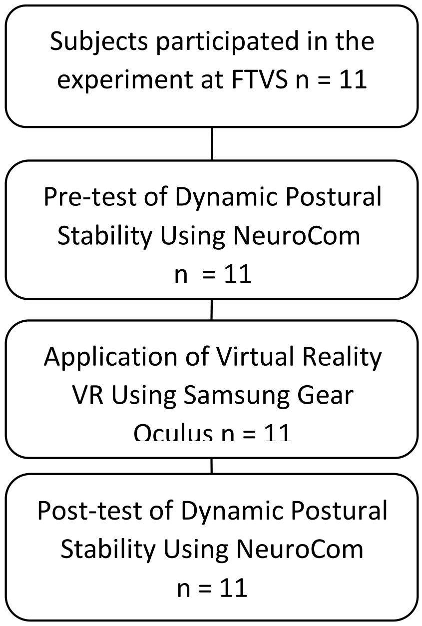

Figure 18. Diagram of the experimental procedure

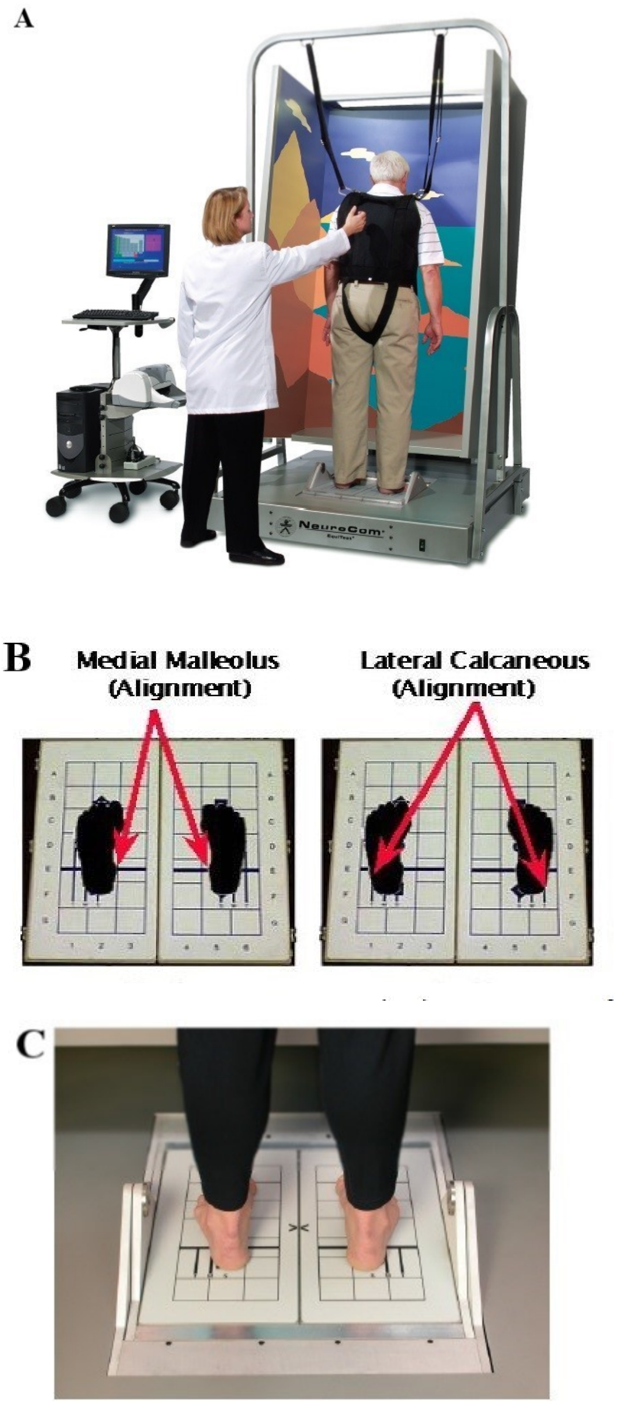

Figure 19. A. Smart Balance Master System, position of subject on force platform. B. Position of foot on force platform, medial malleolus and lateral calcaneus. C. Subject foot positioned on force platform. (Balance and Mobility Academy, 2017)

Table 2. Sensory Analysis Ratios

Ratio	Condition Comparison
Somtosensory (SOM)	2/1
Visual (VIS)	4/1
Vestibular (VEST)	5/1
Preference (PREF)	(3+6)/(2+5)

Data analysis

Descriptive statistics, means and standard deviations (±SD) were calculated for each variable. Data were computed in SMART Balance Master® (NeuroCom International Inc., Clackamas, OR). From Sensory Organization Test SOT, Sensory Ratios (SOM, VIS and VEST) and Preference PREF and Composite Equilibrium and Motor Control Test MCT, Weight Symmetry, as results of dynamic postural stability evaluation. Participants were evaluated with SOT and MCT at baseline or pre-test and immediately after application of virtual reality VR post-test.

Statistical analysis

All statistical analysis was performed by using Microsoft Excel. Mans and standard deviations of demographic data, sensory organization test SOT, motor control test MCT and comparison of test and re-test were performed by using Microsoft Excel. Pre and Post-testing data were analyzed using paired t-test, using means and standard deviations of differences between pre and post-tests. Results considered to be significant if p-value < 0.05. All data are presented as means ± standard deviations.

4. Results

4.1. Subjects Demographic Data

11 subjects met the inclusion criteria and were participating in the study for whole experiment procedure. Demographic Data for Participants are listed in Table (3), with subjects age range between 21 to 39 years, their height ranged from 160 to 185 cm, their weight ranged from 50 kg to 108 kg and there were 7 males and 4 females.

Table 3. Demographic Data for Participants

Parameters	Participants (n=11)
Age, years	27 (4.56)
Height, cm	171.54 (6.8)
Weight, kg	69.27 (18.69)
Gender (Female/Male)	4/7

Values are mean (S.D.)

4.2. SMART Equitest Balance

There were no significant differences in sensory ratios (SOM, VIS and VEST), composite equilibrium and weight symmetry in compare between pre and post-testing of Sensory Organization Test SOT and Motor Control Test MCT on dynamic postural stability after exposure to 3D VR application, whereas all results were > p 0.05. After statistical analysis by using pf the paired t-test.

Each participant scores of the Sensory Organization Test SOT are shown in Table (4), and the Motor Control Test MCT scores are shown in Table (5).

Table (6), shows comparison of dynamic postural stability results by the Sensory Organization Test SOT and Table (7), for Motor Control Test MCT. The means and standard deviations of the SOT sensory ratios (SOM, VIS and VEST and PREF), equilibrium composite score and the Motor Control Test MCT weight symmetry of all participants prior and immediately post VR exposure.

Table 4. Each participant SOT Scores

Parameter	SOM		VIS		VEST		PREF		Composite Equilibrium	
Participant	**Prior**	**Post**	**Prior**	**Post**	**Prior**	**Post**	**Prior**	**Post**	**Prior**	**Post**
1	95	98	88	90	76	80	104	102	82	84
2	98	93	85	67	78	67	85	87	76	68
3	97	98	95	98	85	81	99	105	88	87
4	96	98	85	93	72	89	104	96	82	87
5	99	98	64	66	63	50	97	97	71	66
6	96	97	88	97	63	68	105	92	77	79
7	97	96	87	97	86	82	94	98	83	84
8	98	98	66	64	55	52	86	87	65	63
9	98	90	77	85	60	65	101	106	75	78
10	97	98	94	91	60	68	99	100	76	80
11	98	97	56	46	73	65	89	80	70	61

Table 5. Each participants MCT Scores

Parameter	Wight Symmetry	
Participant	**Prior**	**Post**
1	93.83	99.66
2	84.33	87.33
3	102.33	97.5
4	113.5	106
5	94.33	95.5
6	104.16	99.33
7	85.83	85.83
8	102.33	98.83
9	101	98.33
10	103.16	109
11	102.66	110.66

4.2.1. Sensory Organization Test SOT Outcome Scores

Outcome measurements of the Sensory Organization Test SOT. Composite equilibrium score, scores from visual (VIS), vestibular (VEST) and somatosensory (SOM) systems and preference (PREF) score, whereas green bars indicate normal balance and better than normative scores and red bars below normal. The outcome measurements sample is shown in Figure (18).

Descriptive statistics for the Sensory Organization Test SOT component. And scores are based on anterior posterior sway in relation to limits of stability on Somatosensory (SOM), Visual (VIS) and Vestibular (VEST) Systems, Preference (PREF) and Composite Equilibrium are presented in Table (6).

There were no significant differences when comparing between pre-test and post-test after the Virtual Reality VR application in sensory ratios Somatosensory (SOM) $p > 0.05$, Visual (VIS) $p > 0.05$, and Vestibular (VEST) $p > 0.05$, Composite Equilibrium $p > 0.05$, p-values are shown in Table (8).

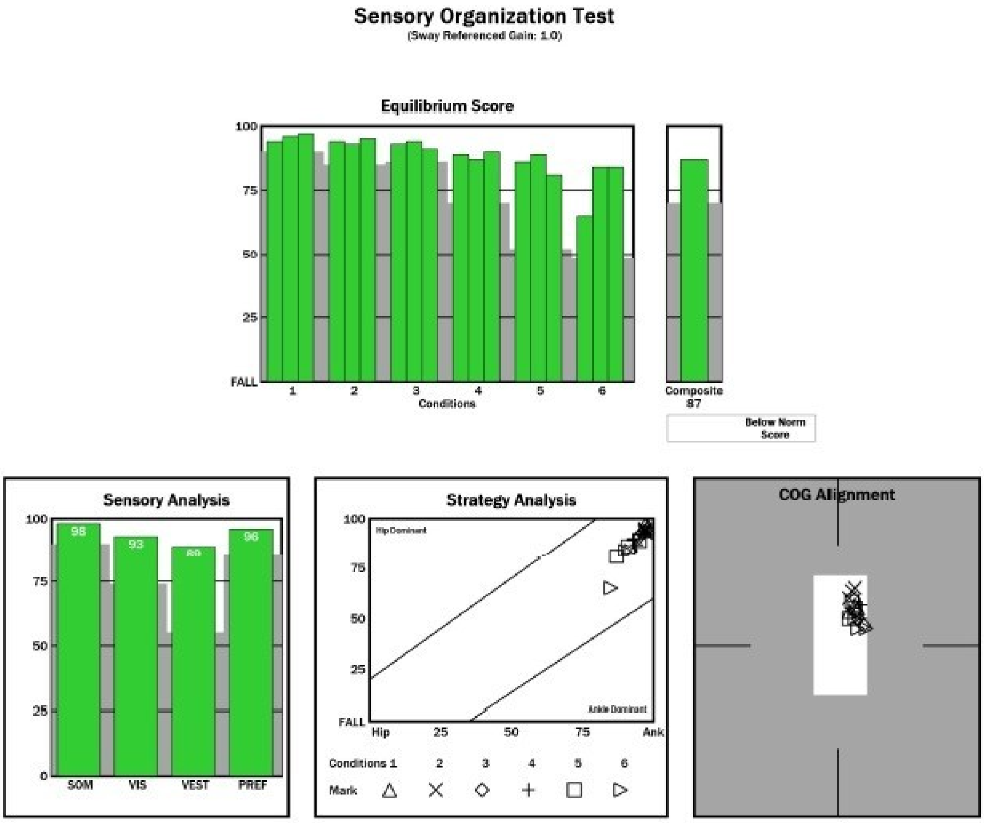

Figure 20. SOT Results of Composite Equilibrium and Sensory Analysis of SOM, VIS, VEST and PREF. The data are compared to normative dataset, whereas green bars indicate normal balance and red bars within the gray area. Composite equilibrium score indicates overall equilibrium of the six conditions. Sensory analysis indicates balance from sensory systems (SOM, VIS, VEST and PREF), whereas bars represent sensory ratio score (from 0 to 100, whereas 100 indicates optimal balance and 0 indicates balance loss).

4.2.2. Motor Control Test MCT Outcome Scores

Parameter of MCT, Weight Symmetry shows distribution of weight in both legs prior to translation movements backward and forward. 100 indicates symmetry of weight distribution on both right and left leg, as shown in Figure (19)

Descriptive statistics of Motor Control Test MCT for weight symmetry is in Table (7). There was no significant difference in comparing between pre-test and post-test after the Virtual Reality VR application in Motor Control Test MCT, using Weight Symmetry $p > 0.05$, as shown in MCT p-values Table (9).

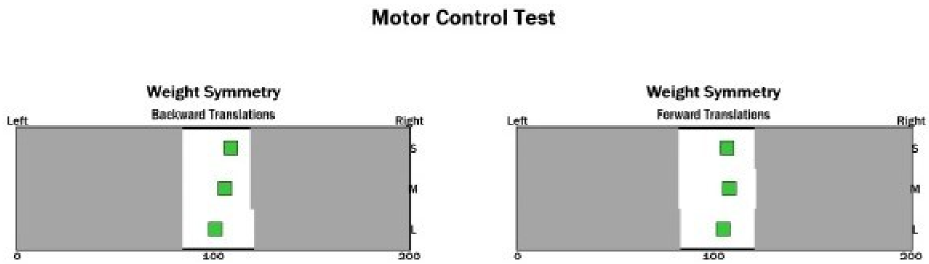

Figure 21. MCT Result of Weight Symmetry. The data are compared to normative dataset and considered to be below normal within gray area whereas green color indicate normal balance. Weight symmetry indicates weight distribution in right and left lower extremities prior to backward and forward translation movements of force platform.

Table 6. Comparison of Sensory Organization Test (SOT) Results for All Participant

Parameters	**Values** **Participants (n=11)**	
Sensory Organization Test SOT	Pre test	Post test
Somatosensory	97.18 (1.16)	96.45 (2.62)
Visual	80.45 (12.97)	81.27 (17.53)
Vestibular	70.09 (10.56)	69.72 (12.31)
Preference PREF	96.63 (7.22)	95.45 (8.17)
Equilibrium, Composite Score	76.81 (6.64)	76.09 (9.78)

Values are mean (±S.D.)

Table 7. Comparison of Motor Control Test (MCT) Results for All Participants

Parameter	Values Participants (n=11)	
Motor Control Test MCT	**Pre test**	**Post test**
Weight Symmetry	**98.86 (8.54)**	**98.90 (5.14)**

Values are mean (±S.D)

Table 8. P-values of all participants of SOT

Parameters	p-value
Sensory Organization Test SOT	
Somatosensory (SOM)	**p = 0.23**
Visual (VIS)	**P = 0.38**
Vestibular (VEST)	**P = 0.44**
Preference (PREF)	**P = 0.27**
Composite Equilibrium	**p = 0.31**

Values: p-value

Table 9. p-values of all participants of MCT

Parameter	p-value
Motor Control Test MCT	
Weight Symmetry	**p = 0.48**

Values: p-value

4.3. Subjective Feedback of Participants

Most of participants feedback about the 3D Virtual Reality VR application, they enjoyed it, felt more about body posture, one subject felt imbalance at the beginning of the Virtual Reality VR but then he felt normal, another subject felt some imbalance during the Virtual Reality VR exposure, another subject said that she felt dizzy in some parts during the Virtual Reality VR application, another subject felt dizzy after the Virtual Reality VR exposure and during the Sensory Organization Test SOT in post-test in condition 3 while moving of visual surrounds and he found it harder to maintain balance during closed eyes conditions, another subject was feeling that he still under the effect of the Virtual Reality VR exposure after the application immediately for few minutes. In addition, most of participants complain about feeling tired, exhaustion or fatigue in low back and lower extremities due to long time standing during pre-testing, the Virtual Reality VR application and post-testing procedures. Almost all of participants didn't have any symptoms of headache or vertigo.

5. Discussion

The objective of this study was to evaluate the dynamic postural stability in healthy young adults using Smart Equitest System, using Sensory Organization Test SOT and Motor Control Test MCT before and after 3D virtual reality VR application.

We hypothesized that would be positive effect post of the VR application on dynamic postural stability. However, the results we found showed that there were no significant differences in SOT equilibrium composite scores, sensory ratios scores (SOM, VIS, VEST and PREF) and in MCT weight symmetry score in the participants after virtual reality VR application, whereas ($p > 0.05$). Then our hypothesis was rejected.

We can interpret our results in number of ways. There could be efficacy of VR on postural stability in different outcome measures we didn't use in the study. It could be that VR application had no significant effect on postural stability due to the short time of VR application in five minutes duration and the number of exposure to VR application which was once among pre and post testing. It may be also because of the stimulus was not strong enough to induce changes in postural stability. Another interpretation could be due to the participants conditions who were healthy college adults with no neurological or vestibular disorders.

Upon to the results we found with no statistical differences in dynamic postural stability post Virtual Reality application, we suggest that it could be due to different causes:

First, the participants health state while they are healthy with no neurological problems affecting their balance and stability, so we think that the results maybe because of decreased physical performance and not because of deficits neurologically based.

Second, due to the time of procedure which lasts around 30 minutes in standing position during pre and post testing and while Virtual Reality video playing. Most of the participants feedbacks mentioned that they felt tired from long time standing in low back and lower extremities, we suggest that modifying testing procedure by having time lags or interval between pre-test, the VR application and post-test would help in avoiding fatigue and may change the participants results.

Third, it maybe because of the time duration of the 3D Virtual Reality video, which lasts only five minutes, suggesting that it provokes postural imbalance due to sensory conflicts induced by the 3D VR video, which maybe be short to reach adaptation of the sensory perturbation and reweighed after decreasing in visual reliance of maintaining postural stability. However, in a study by (Lee, Lee, & Park, 2014) on 24 healthy young participants with 25 minutes of the VR exercising for 3 times a week with 6 weeks duration showed significant improvement in dynamic balance of healthy participants ($p<0.05$). While (Nishiike et al., 2013) study on 11 healthy young subjects with 5 min VR immersion, resulted in postural instability and increasing of simulation symptoms. Furthermore, in (Bergeron, Lortie, & Guitton, 2015) comprehensive analysis on the peripheral vestibular disorders rehabilitation using VR, reported that, time duration is contributing in reaching effective VR based rehabilitation, while longer time duration appeared in the higher efficacy studies within this comprehensive analysis study.

Forth, it could be because of design of the played video that it is not good stimulus enough to work on healthy adults and we may need to design something different for those type of participants.

Fifth, about the number of exposure to the Virtual Reality application, in this study we used the virtual reality one time only for 5 minutes duration. We suggest that if we increase the number of exposure to the virtual reality, it could be more effective. In (Bergeron, Lortie, & Guitton, 2015) study on the vestibular rehabilitation, the included studies split into higher efficacy and lower efficacy, the lower ones demonstrated less number of exposure to the VR, which showed that times of exposure to the VR is collaborating factor in increase efficacy of the rehabilitation using the VR.

Sixth, adaptation to the VR is also playing a role, whereas the adaptation to the virtual reality reduce depending on visual information while sensory systems conflict, which reflected on reweighting on other sensory systems like vestibular and proprioception to control body posture and balance. Time duration to the virtual reality exposure is contributing factor in adaptation, while short time exposure seems not to be sufficient to create the adaptation, the longer time of simulation is needed to reach the adaptation. (Reed-Jones, Vallis, Reed-Jones, & Trick, 2008). In a (Nishiike et al., 2013) study on 11 healthy adults, with 5 minutes virtual reality application, resulted in significant increase of postural instability and dizziness, in contrast, decreased in visual reliance on postural stability, which resulted from motor sickness that induced by the sensory conflicts and limited adaptation to the virtual reality due to the short time of the VR. Our study and this study had the same time duration and number of participants we have in our study and our findings partially agree with their findings, in the presence of motion sickness symptoms during and after the VR, but we did not correspond with their findings of postural instability. While in previous study by (Akizukia et al., 2005) on thirty two healthy adults with thirty nine minutes of HMD virtual reality immersion, fifteen minutes at first immersion and eight times with three minutes duration with five minutes intervals, resulted in significant increase in body sway during the VR immersion, however, there was no significant difference of body sway in both eyes open and closed conditions, Romberg Ratio significantly decreased, motion sickness symptoms were slightly after first 15 minutes VR exposure but not in the rest of 8 times VR immersion. In contrast of our study, the previous mentioned study had longer time of VR application and with time intervals between them, their findings of slight motion sickness symptoms in first VR and no motion sickness in the followed VR exposure, which differ from our findings that showed some subjective reported motion sickness symptoms during the VR application.

From the two mentioned studies above (Nishiike et al., 2013; Akizukia et al., 2005), which showed the effect of adaptation to the virtual reality and visual dependency on postural control and stability, while in (Nishiike, S et al, 2013) study, we had the same time duration of the VR exposure with 5 minutes and presence of motion sickness symptoms and decreased of visual dependency in postural stability, we suggest that this short time of the VR application lead to reduction or incomplete of adaptation to the VR, however in (Akizukia et al., 2005), with 39 minutes of the VR immersion showed slight motion sickness symptoms in first VR immersion and no more symptoms in the rest of the immersion phases, there were also significant decrease of the visual reliance in postural stability, which suggest that the adaptation increase with increasing time duration and repetition of the VR application, which means decreasing of visual reliance and enhancing and increasing of relying on vestibular and somatosensory systems more to control body posture and balance, to adapt and accommodate to the new environments by overcoming the sensory conflicts occurred between visual, somatosensory and vestibular systems, which integrate in the cerebellum, vestibular nuclei and cerebral cortex.

Seventh, the immediate testing after the VR application might be a factor contribute in getting these results and maybe if there was a pause or break time between the VR application and post testing, it would lead us to other results with increasing in dynamic stability if the subjects were free of any simulation symptoms that may affect their balance and postural control. In (Akiduki et al., 2003) which already mentioned above, there was an increase of body sway instantly post the VR and showed significant increase of the body sway in compare with control group, and there was significant increase of motion sickness symptoms which increased gradually during the VR although that these symptoms were decreased after the VR, however, the significant increase comparing to control group is still present.

5.1. Sensory Organization Test SOT and Motor Control Test MCT

In the results of sensory outcome measure of SOM, which had no significant differences compared between pre and post the VR application, we suggest that there were no effects of the VR application on the somatosensory system of examined participants. In comparing of the VIS findings, which showed a slight increase of 7 out of 11 of the participants, however, there were no significant differences before and after the VR exposure, we suggest that there was no clear impact on this VR application on the participants visual system. The VEST outcome measure showed no significant difference in compare between pre and post the VR exposure, we suggest that this application of the VR had no effects on vestibular system of this study participants. PREF scores pre and post the VR showed no significant differences, which suggested that there is no impact of the VR application presented to the subjects on degree of reliance on visual inputs even if they were inappropriate or incorrect. Regarding to the result of composite equilibrium scores before and after the VR exposure, which showed no significant difference, we suggest that this VR application was used on the subjects had no change on equilibrium and dynamic postural stability. Due to the statistical results of

MCT, of weight symmetry outcome measure, which showed no significant difference between pre and post the VR application on dynamic postural stability, we suggest that there is almost no clear effect of the VR application on the motor response and weight distribution between both right and left lower limbs in these subjects.

The highest result of p value was of weight symmetry outcome measure from Motor Control Test MCT with ($p = 0.48$), which indicates better weight distribution in both legs and give information about subjects motor response that their responses was not fast and strong enough. Whereas the lowest p value was ($p = 0.23$) of Somatosensory SOM outcome measure in Sensory Organization Test SOT, which is responsible for somatosensory or and proprioception input to maintain balance, which gives information that the subjects used the somatosensory system and rely on it to keep their stability.

A comparison between our results and previous studies is somehow limited due to the lack of studies which are working on healthy adults, whereas most of the studies we found were concerned more about diseases and disorders.

5.2. Virtual Reality Effects on Postural stability

The use of Virtual Reality VR technology could improve the postural stability and balance. Although that in our study there were no significant differences of dynamic postural stability of the healthy young adults. However, in a study by (Horlings et al., 2009), on 17 healthy young adults, to assess the influence of VR on postural control in quiet standing, showed that VR and eyes closed conditions had similar degree of body sway on foam surface compared to firm surface ($p < 0.0167$). In a (Lee, Lee, & Park, 2014) study, on 24 healthy young adults dividing into group of indoor horse riding and virtual reality training group, the VR training group on Nintendo Wii Fit lasting 25 minutes for six weeks and three times a week, results using The Biodex Balance System showed that all groups significantly improved in dynamic postural stability ($p<0.05$). However, (Nishiike et al., 2013) study on 11 healthy adults, resulted in significant increase in postural sway in both eyes open and eyes closed conditions after 5 minutes VR exposure and increased in Graybiel's and Hamilton's questionnaires scores of motion sickness. However, Ibrahim, Mattar, and Elhafez (2016) reported that 30 healthy adults divided into two groups virtual reality balance training using Nintendo Wii Fit Plus and

Biodex Balance System training groups, they showed significant differences of balance in both groups ($p<0.05$), however, there were no significant differences between the two groups or the two methods used. Moreover, in contrast to our findings, (Wada et al., 2016) experiment on 42 young healthy adults, using repeated snowboarding virtual reality program with time lags, concluded that, there were frequent exposure to this VR program with time lags made subjects more adapted to the sensory conflict, which resulted in dynamic postural stability and motor performance improvement with no reporting of motion sickness symptoms while or post the VR program. However, the mentioned studies above (Akiduki et al., 2003; Akizukia et al., 2005) showed significant increase of body sway during and after the VR exposure.

5.3. Virtual Reality Using in Different Diagnosis

The utilization of the virtual reality is not limited to healthy individuals or used only for playing and enjoyment, however, there are many diseases and disorders that could be treated and rehabilitated by utilizing the technology of the virtual reality. (Mao, Chen, Li, & Huang, 2014) reported that virtual reality improves neurological based diseases like spinal cord injury, cerebral palsy, motor function and activity of daily living of patients. By activating cerebral cortex and increase spatial orientation which lead to improve balance and motion functions. Despite of that in our study we chose healthy subjects. However, (Yeh et al., 2014) reported that 3D VR for six treatment sessions on 49 patients with dysfunction of vestibular, showed significant improvement in performance and balance indices in medio-lateral directions. However, In a systematic review and meta analysis of impaired balance adults, replacing conventional treatment by virtual reality training for improving their balance showed that there was no significant difference of utilizing the virtual reality training in these patients (Booth, Masud, Connell, & Bath-Hextall, 2014), In contrast, in (Bergeron, Lortie, & Guitton, 2015) study on peripheral vestibular disorders virtual reality treatment, reported that, there were obvious improving in patients symptoms post the VR based treatment in all studies included in this systematic review and meta analysis study. Moreover, in (Alahmari et al., 2014) study on vestibular disorders patients, with using VR based treatment on 20 patients and physiotherapy treatment on 18 patients, with procedure of six weeks, concluded that there were significant improvements of patients symptoms in both types of treatments post the first week and at the six months follow up. In addition, in study of (Chiarovano et al., 2017), on 116 healthy and 10 patients with total vestibular loss, using different visual conditions of eyes open, closed, stable VR and perturbed VR assessing by Wii Balance Board (WBB) on firm and foam surfaces, concluded that in total vestibular loss patients under WBB on foam surface induced falls in both closed eyes and perturbed VR conditions, while there were less percentage of falls in stable VR in compare to closed eyes condition.

In using of the VR on Parkinson's disease patients, a study by (Yen et al., 2011) on 42 patients with Parkinson’s disease, with 6 weeks training sessions, resulted in significant differences in SOT 6 condition of virtual reality based balance training group ($p<0.001$). Moreover, in (Kim, Darakjian, & Finley, 2017) study on 33 subjects divided into eleven subjects for each group, these groups categorized by healthy young adults, healthy old adults and Parkinson’s disease patients, after they walked on treadmill in immersive VR for twenty minutes duration, concluded that, there were no significant differences in all groups in simulation symptoms, static and dynamic balance outcome measures post the VR immersion.

One of the VR technology utilization is for stroke patients, in a systematic review and meta analysis study (Corbetta, Imeri, & Gatti, 2015), showed significant improvement in mobility, balance and gait speed of patients after stroke by using virtual reality based treatment instead of conventional treatment. Additionally, with stroke patients, (Park et al., 2016) study on 30 patients diagnosed with stroke, using eccentric exercising with virtual reality, which resulted in significant improve of lower leg muscles activation and balance using slow velocity eccentric exercising with the VR in these patients with stroke ($p<0.05$).

5.4. Virtual Reality Applications Types

There are many types of the virtual reality tools and devices could be used in rehabilitation and fields of researching. In our study we used Samsung Gear Oculus Goggles which is working with Samsung Galaxy S7. The virtual reality devices vary from Head Mounted Display HMD (Horlings et al., 2009; Cobb & Nichols, 1998), driving simulator on screen (Reed-Jones, Vallis, Reed-Jones, & Trick, 2008), Cave (Nishiike et al., 2013; Ohyama et al., 2007) and gaming (Booth, Masud, Connell, & Bath-

Hextall, 2014). In (Bergeron, Lortie, & Guitton, 2015) study on vestibular disorders rehabilitation using the VR reported that, kinds of the VR tools which included goggles and screens had no participation in the VR efficacy, also the active and passive sort of the VR tools showed no significant differences on the efficacy of the vestibular rehabilitation based on the virtual reality.

5.5. Virtual Reality Side Effects

Although that using the virtual reality devices is easy and safe, however, some considerations and precautions should be taken to prevent any harm that may affects the subjects after using it. Adverse events of the virtual reality that may lead to motor sickness symptoms with feeling of vertigo, dizziness, nausea or headache. Subjects must be instructed to avoid activities that needs full awareness and concentration like driving or operating with machines that may harm them (Cobb & Nichols, 1998). Moreover, the sensory systems information conflict induces motor sickness symptoms, the sensory conflict increase depending more on visual signals that subjects see from the virtual reality scene presented to them, and that resulted in postural responses due to the visual information from the virtual reality not from the real environment and gravitational force that are really working on subjects body posture and their spatial orientation in space.

In our study some participants complain of feeling dizzy while playing the virtual reality video in some parts, while others said that they felt imbalance at the video playing, whereas one participant felt dizzy after the virtual reality exposure during post-testing on the force platform in condition 3 of the Sensory Organization Test SOT, we suggest that was due to visual disturbance and sensory conflicts induced by the VR and maybe because of decreased reliance on visual input and enhancing somatosensory and vestibular systems more because the subject said that it was harder to maintain balance in closed eyes conditions. Furthermore, one participant said that he felt like he is still under the effects of the virtual reality, however, they found it enjoyable and motivational with no feeling of headache or vertigo. In agree with our findings, (Ohyama al., 2007) study on 10 healthy participants with using of immersion virtual reality for fourteen minutes, there were gradual increase of motor sickness symptoms during exposure of immersion virtual reality with significant differences in Graybiel's criteria and Hamilton's criteria scores at the second VR exposure, however, the motor sickness symptoms decreased at post VR period. In addition, in (Cobb & Nichols, 1998) study showed effect of virtual reality in post test on subjects, while they reported simulation sickness symptoms and unstable posture were correlated ($p < 0.001$), even though the VR was provocative but it was not enough to emphasize the relation between postural control and simulation sickness symptoms. However, in contrast of our findings and previous mentioned studies findings, in (Corbetta, Imeri, & Gatti, 2015) study on stroke patients using virtual reality based training, resulted in no adverse effects, but they were more motivated and active during the virtual reality based treatment.

In agreement with our findings of motion sickness symptoms during and after the VR a study by (Akiduki et al., 2003) on 9 healthy young adults, with using VR for 20 minutes, measured the motion sickness symptoms and postural stability, concluded that, there was significant increase of motion sickness during and post the VR, and there was increasing of body sway post to the VR and there was significantly body sway increase comparing to control group, however, there was no change in body sway during the VR, which we did not examine in our study and it needs to be investigated more in the future. Similar results to our study and (Akiduki et al., 2003) study results about subjective motion sickness presentation , a study by (Ohyma et al., 2007), on ten young healthy adults, using immersion VR for fourteen minutes, with assessing simulation symptoms during the VR exposure twice at first 7 minutes and at 14 minutes of the VR and after the VR, reported that, there was gradual increase of motion sickness symptoms during the VR application reach the significant increase in the second VR exposure, however, these simulation symptoms decreased after the VR immersion.

6. Conclusion

In this study we aimed to examine the effects of the virtual reality application on dynamic postural stability in young healthy adults. The results showed that there were no significant differences in the dynamic postural stability outcome measures by using Computerized Dynamic Posturography when compared between prior and post of the virtual reality application. There was presentation of simulation symptoms in some subjects during or and after the virtual reality application as they mentioned in subjective feedback.

There were numbers of limitations of this study, which include The study design is experimental pilot study, with small numbers of participants who were only 11, further, there were only one session of the virtual reality application lasting 5 minutes with immediate post test with no follow up to control the efficacy if it would be many times exposures to the VR application. Moreover, this small number of participants will not allow us to generalize the results and increase the level of their accuracy.

Mobility, portability and cost of the Smart Balance Master system, which occupies large space and its high cost to buy, in addition, the tests we had were limited in its directions of force platform, which examine in anterior and posterior directions only.

In limitations of the virtual reality, software were computer graphics in three dimensional which maybe not be in high quality, furthermore, hardware which is low cost HMD, which may not be the newest and the best to use but it was available in the laboratory. Additionally, there is one limitation should be mentioned, which is availability and accessing to researches and articles in databases, which were not available with our system access.

Recommendations that we suggest to examine all directions of postural stability using force platform. Increase time duration and number of exposure to the virtual reality. Using modern and advanced virtual reality tool. Increase the number of subjects participating to study and choose different design of study to enable generalizing study results. More investigation needs to be done on healthy adults using the virtual reality.

7. Bibliography

3D-VR-360 VIDEOS. (2017, June 9). VR Avatar 3D Split Screen VR Roller Coaster 3D SBS for VR BOX 3D not 360 VR [Video file]. Retrieved November 10, 2017, from https://www.youtube.com/watch?v=ocvuEI0w0g8

Akiduki, H., Nishiike, S., Watanabe, H., Matsuoka, K., Kubo, T., & Takeda, N. (2003). Visual-vestibular conflict induced by virtual reality in humans. *Neuroscience letters*, *340*(3), 197-200.

Alahmari, K. A., Sparto, P. J., Marchetti, G. F., Redfern, M. S., Furman, J. M., & Whitney, S. L. (2014). Comparison of virtual reality based therapy with customized vestibular physical therapy for the treatment of vestibular disorders. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *22*(2), 389-399.

Alexandrov, A. V., Frolov, A. A., Horak, F. B., Carlson-Kuhta, P., & Park, S. (2005). Feedback equilibrium control during human standing. *Biological cybernetics*, *93*(5), 309-322.

Aydoğ, E., Bal, A., Aydoğ, S. T., & Çakci, A. (2006). Evaluation of dynamic postural balance using the Biodex Stability System in rheumatoid arthritis patients. *Clinical rheumatology*, *25*(4), 462-467.

Aydoğ, E., Aydoğ, S. T., Cakci, A., & Doral, M. N. (2006). Dynamic postural stability in blind athletes using the biodex stability system. *International journal of sports medicine*, *27*(05), 415-418.

Balance and Mobility Academy. (2017). *Balance Manager Systems – Instructions For Use (IFU)*. Retrieved November 27, 2017, from http://balanceandmobility.academy/download/balance-manager-systems-instructions-for-use-ifu/

Baloh, R. W., & Honrubia, V. (2001). *Clinical neurophysiology of the vestibular system* (3rd ed.). USA: Oxford University Press. ISBN: 0-19-513982-8. Retrieved November 23, 2017, from https://books.google.cz/books?hl=en&lr=&id=QRgynJASsi8C&oi=fnd&pg=PA1&ots=7rW1GpA7LG&sig=O_PSuTmhGILya8Tj4WYkHSrgV4I&redir_esc=y#v=onepage&q&f=false

Bartlett, H. L., Ting, L. H., & Bingham, J. T. (2014). Accuracy of force and center of pressure measures of the Wii Balance Board. *Gait & posture*, *39*(1), 224-228.

Bell, D. R., Guskiewicz, K. M., Clark, M. A., & Padua, D. A. (2011). Systematic review of the balance error scoring system. *Sports health, 3*(3), 287-295.

Benoudiba, F., Toulgoat, F., & Sarrazin, J. L. (2013). The vestibulocochlear nerve (VIII). *Diagnostic and interventional imaging*, *94*(10), 1043-1050.

Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J., & Wood-Dauphinee, S. L. (1992). Clinical and laboratory measures of postural balance in an elderly population. *Archives of physical medicine and rehabilitation, 73*(11), 1073-1080.

Bergeron, M., Lortie, C. L., & Guitton, M. J. (2015). Use of virtual reality tools for vestibular disorders rehabilitation: a comprehensive analysis. *Advances in medicine*, 2015. DOI: http://dx.doi.org/10.1155/2015/916735

Bernstein, J., & Burkard, R. (2009). Test order effects of computerized dynamic posturography and calorics. *American journal of audiology*, *18*(1), 34-44.

Black, F. O. (2001). Clinical status of computerized dynamic posturography in neurotology. *Current Opinion in Otolaryngology & Head and Neck Surgery*, *9*(5), 314-318.

Booth, V., Masud, T., Connell, L., & Bath-Hextall, F. (2014). The effectiveness of virtual reality interventions in improving balance in adults with impaired balance compared with standard or no treatment: a systematic review and meta-analysis. *Clinical rehabilitation*, *28*(5), 419-431.

Botella, C., Quero, S., Baños, R. M., Perpiña, C., Garcia-Palacios, A., & Riva, G. (2004). Virtual reality and psychotherapy. *Cybertherapy*, *99*, 37-52.

Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: how much immersion is enough?. *Computer*, *40*(7), 36-43. DOI: 10.1109/MC.2007.257.

Boulgarides, L. K., McGinty, S. M., Willett, J. A., & Barnes, C. W. (2003). Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. *Physical therapy, 83*(4), 328-339.

Brandt, T., Wist, E. R., & Dichgans, J. (1975). Foreground and background in dynamic spatial orientation. *Perception & Psychophysics*, *17*(5), 497-503.

Broglio, S. P., Zhu, W., Sopiarz, K., & Park, Y. (2009). Generalizability theory analysis of balance error scoring system reliability in healthy young adults. *Journal of athletic training, 44*(5), 497-502.

Buń, P. K., Wichniarek, R., Górski, F., Grajewski, D., Zawadzki, P., & Hamrol, A. (2017). Possibilities and Determinants of Using Low-Cost Devices in Virtual Education Applications. *Eurasia Journal of Mathematics, Science & Technology Education*, *13*(2). DOI: 10.12973/eurasia.2017.00622a

Buń, P., Górski, F., Wichniarek, R., Kuczko, W., Hamrol, A., & Zawadzki, P. (2015). Application of professional and low-cost head mounted devices in immersive educational application. *Procedia Computer Science*, *75*, 173-181.

Burdea, G. C., & Coiffet, P. (2003). *Virtual reality technology* (2nd ed.). New Jersey: John Wiley & Sons. ISBN: 0-471-36089-9. Retrieved November 15, 2017, from https://books.google.cz/books?hl=en&lr=&id=0xWgPZbcz4AC&oi=fnd&pg=PR13&dq=Virtual+Reality+Technology&ots=LDgujY3R9t&sig=muRtMiAxCiHj98oYu

Gewn05cA3k&redir_esc=y#v=onepage&q=Virtual%20Reality%20Technology&f=false

Cachupe, W. J., Shifflett, B., Kahanov, L., & Wughalter, E. H. (2001). Reliability of biodex balance system measures. *Measurement in physical education and exercise science*, *5*(2), 97-108.

Calabrò, R. S., Naro, A., Russo, M., Leo, A., De Luca, R., Balletta, T., ... & Bramanti, P. (2017). The role of virtual reality in improving motor performance as revealed by EEG: a randomized clinical trial. *Journal of neuroengineering and rehabilitation*, *14*(1), 53. DOI: 10.1186/s12984-017-0268-4.

Chang, W. D., Chang, W. Y., Lee, C. L., & Feng, C. Y. (2013). Validity and reliability of wii fit balance board for the assessment of balance of healthy young adults and the elderly. *Journal of physical therapy science*, *25*(10), 1251-1253.

Chen, Y., Fanchiang, H. D., & Howard, A. (2017). Effectiveness of Virtual Reality in Children With Cerebral Palsy: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Physical therapy*, *98*(1), 63-77.

Chiarovano, E., Wang, W., Rogers, S. J., MacDougall, H. G., Curthoys, I. S., & De Waele, C. (2017). Balance in virtual reality: effect of age and bilateral vestibular loss. *Frontiers in neurology*, *8*, 5. DOI: 10.3389/fneur.2017.00005

Cho, K. H., Lee, K. J., & Song, C. H. (2012). Virtual-reality balance training with a video-game system improves dynamic balance in chronic stroke patients. *The Tohoku journal of experimental medicine*, *228*(1), 69-74.

Clark, R. A., Bryant, A. L., Pua, Y., McCrory, P., Bennell, K., & Hunt, M. (2010). Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. *Gait & posture*, *31*(3), 307-310.

Cobb, S. V. G., & Nichols, S. C. (1998). Static posture tests for the assessment of postural instability after virtual environment use. *Brain Research Bulletin*, *47*(5), 459-464.

Cochrane, T. (2018). *Virtual and Augmented Reality: Concepts, Methodologies, Tools, and Applications: Concepts, Methodologies, Tools, and Applications.* The United States of America. IGI Global. ISBN: 9781522554707. Retrieved November 25, 2017, from https://books.google.cz/books?hl=en&lr=&id=-w9MDwAAQBAJ&oi=fnd&pg=PA293&ots=ZFAyBBCskg&sig=W_o1q_yY2EMegLr5El2v-amsNkc&redir_esc=y#v=onepage&q&f=false

Coelho, C. M., Waters, A. M., Hine, T. J., & Wallis, G. (2009). The use of virtual reality in acrophobia research and treatment. *Journal of Anxiety disorders*, *23*(5), 563-574.

Coluccia, E., & Louse, G. (2004). Gender differences in spatial orientation: A review. *Journal of environmental psychology*, *24*(3), 329-340.

Corbetta, D., Imeri, F., & Gatti, R. (2015). Rehabilitation that incorporates virtual reality is more effective than standard rehabilitation for improving walking speed, balance and mobility after stroke: a systematic review. *Journal of physiotherapy*, *61*(3), 117-124.

Kim, H., Choi, W., Lee, K., & Song, C. (2015). Virtual dual-task treadmill training using video recording for gait of chronic stroke survivors: a randomized controlled trial. *Journal of physical therapy science*, *27*(12), 3693-3697.

Kim, A., Darakjian, N., & Finley, J. M. (2017). Walking in fully immersive virtual environments: an evaluation of potential adverse effects in older adults and individuals with Parkinson's disease. *Journal of neuroengineering and rehabilitation*, *14*(1), 16. DOI: 10.1186/s12984-017-0225-2.

Arias, P., Robles-García, V., Sanmartín, G., Flores, J., & Cudeiro, J. (2012). Virtual reality as a tool for evaluation of repetitive rhythmic movements in the elderly and Parkinson's disease patients. *PloS one*, *7*(1), e30021. DOI: 10.1371/journal.pone.0030021

Cote, K. P., Brunet, M. E., Gansneder, B. M., & Shultz, S. J. (2005). Effects of Pronated and Supinated Foot Postures on Static and Dynamic Postural Stability. *Journal of*

Athletic Training, *40*(1), 41–46.

Cullen, K. E. (2012). The vestibular system: multimodal integration and encoding of self-motion for motor control. *Trends in neurosciences*, *35*(3), 185-196.

Cullen, K. E., & Roy, J. E. (2004). Signal processing in the vestibular system during active versus passive head movements. *Journal of neurophysiology*, *91*(5), 1919-1933.

Darekar, A., McFadyen, B. J., Lamontagne, A., & Fung, J. (2015). Efficacy of virtual reality-based intervention on balance and mobility disorders post-stroke: a scoping review. *Journal of neuroengineering and rehabilitation*, *12*(1), 46. DOI: 10.1186/s12984-015-0035-3.

Daube, J. (2002). *Clinical Neurophysiology* (2nd ed.). New York: Oxford University Press. ISBN: 0-19-514080-X. Retrieved November 24, 2017, from https://books.google.cz/books?id=K5QiZzacCjgC&pg=PA432&lpg=PA432&dq=what+pref+in+neurocom&source=bl&ots=aJbD-ANajF&sig=Ikw6WL2oIczYxyZi2JwqfnjIh_A&hl=en&sa=X&ved=2ahUKEwistenjocvaAhVLb1AKHUfTC68Q6AEwCHoFCAAQhQE#v=onepage&q=what%20pref%20in%20neurocom&f=false

Delahunt, E., McGrath, A., Doran, N., & Coughlan, G. F. (2010). Effect of taping on actual and perceived dynamic postural stability in persons with chronic ankle instability. *Archives of physical medicine and rehabilitation*, *91*(9), 1383-1389.

Diniz-Filho, A., Boer, E. R., Gracitelli, C. P., Abe, R. Y., van Driel, N., Yang, Z., & Medeiros, F. A. (2015). Evaluation of postural control in patients with glaucoma using a virtual reality environment. *Ophthalmology*, *122*(6), 1131-1138.

Docherty, C. L., McLeod, T. C. V., & Shultz, S. J. (2006). Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. *Clinical Journal of Sport Medicine, 16*(3), 203-208.

Emmelkamp, P. M. G., Krijn, M., Hulsbosch, A. M., De Vries, S., Schuemie, M. J., & Van der Mast, C. A. P. G. (2002). Virtual reality treatment versus exposure in vivo: a comparative evaluation in acrophobia. *Behaviour research and therapy*, *40*(5), 509-516.

Emmelkamp, P. M., Bruynzeel, M., Drost, L., & van der Mast, C. A. G. (2001). Virtual reality treatment in acrophobia: a comparison with exposure in vivo. *CyberPsychology & Behavior*, *4*(3), 335-339.

Finnoff, J. T., Peterson, V. J., Hollman, J. H., & Smith, J. (2009). Intrarater and interrater reliability of the Balance Error Scoring System (BESS). *Pm&r, 1(*1), 50-54.

Flansbjer, U. B., Blom, J., & Brogårdh, C. (2012). The reproducibility of Berg Balance Scale and the Single-leg Stance in chronic stroke and the relationship between the two tests. *PM&R, 4*(3), 165-170.

Gago, M. F., Fernandes, V., Ferreira, J., Yelshyna, D., Silva, H. D., Rodrigues, M. L., & Sousa, N. (2015). Role of the visual and auditory systems in postural stability in Alzheimer's disease. *Journal of Alzheimer's Disease*, *46*(2), 441-449.

Gago, M. F., Yelshyna, D., Bicho, E., Silva, H. D., Rocha, L., Rodrigues, M. L., … & Sousa, N. (2016). Compensatory postural adjustments in an oculus virtual reality environment and the risk of falling in Alzheimer's disease. *Dementia and geriatric cognitive disorders extra*, *6*(2), 252-267.

Garrett, B., Taverner, T., Masinde, W., Gromala, D., Shaw, C., & Negraeff, M. (2014). A rapid evidence assessment of immersive virtual reality as an adjunct therapy in acute pain management in clinical practice. *The Clinical journal of pain*, *30*(12), 1089-1098.

Gil-Gómez, J. A., Lloréns, R., Alcañiz, M., & Colomer, C. (2011). Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury. *Journal of neuroengineering and rehabilitation*, *8*(1), 30. DOI: https://doi.org/10.1186/1743-0003-8-30

Goebel, J. A. (2008). *Practical management of the dizzy patient* (2^{nd} ed.). The US: Lippincott Williams & Wilkins. Retrieved November 20, 2017, from https://books.google.cz/books?id=ecrwrKCRr7YC&pg=PA166&lpg=PA166&dq=preference+sot+function&source=bl&ots=hQDd6M5XMC&sig=4BdZ_dZ0r-UUi9Jzq9X7pWvWF28&hl=cs&sa=X&ved=0ahUKEwiroL6du9raAhWILlAKHTmLB8sQ6AEIQTAD#v=onepage&q=preference%20sot%20function&f=false

Goldberg, J. M., Wilson, V. J., Angelaki, D. E., & Cullen, K. E. (2012). *The vestibular system: a sixth sense*. New York: Oxford University Press. ISBN: 978-0-19-516708-5. Retrieved November 3, 2017, from https://books.google.cz/books?hl=cs&lr=&id=dMixjJPwKdQC&oi=fnd&pg=PP1&dq=anatomy+and+physiology+of+vestibular+system&ots=9VUZNWHCR1&sig=bLemFUETRt_lEFRLx9ey-qDsTH0&redir_esc=y#v=onepage&q=anatomy%20and%20physiology%20of%20vestibular%20system&f=false

Gribble, P. A., & Hertel, J. (2003). Considerations for normalizing measures of the Star Excursion Balance Test. *Measurement in physical education and exercise science, 7*(2), 89-100.

Guskiewicz, K. M. (2001). Postural stability assessment following concussion: one piece of the puzzle. *Clinical Journal of Sport Medicine*, *11*(3), 182-189.

Heebner, N. R., Akins, J. S., Lephart, S. M., & Sell, T. C. (2015). Reliability and validity of an accelerometry based measure of static and dynamic postural stability in healthy and active individuals. *Gait & posture*, *41*(2), 535-539.

Hertel, J., Gay, M. R., & Denegar, C. R. (2002). Differences in postural control during single-leg stance among healthy individuals with different foot types. *Journal of athletic training, 37*(2), 129-132.

Hettinger, L. J., & Haas, M. W. (2003). *Virtual and adaptive environments: Applications, implications, and human performance issues*. Mahawah, New Jersey. Lawrence Erlbaum. ISBN: 1-4106-0888-3. Retrieved November 4, 2017, from https://books.google.cz/books?id=bvM1z29JWcUC&printsec=frontcover&dq=Virtual+and+adaptive+environments:+Applications,+implications,+and+human+performance+issues&hl=cs&sa=X&ved=0ahUKEwj61cC3ss_cAhVE_KQKHUnRCfMQ6AEIJzAA#v=onepage&q=Virtual%20and%20adaptive%20environments%3A%20Applications%2C%20implications%2C%20and%20human%20performance%20issues&f=false

Highstein, S. M., Fay, R. R., & Popper, A. N. (2004). *The vestibular system*. Berlin: Springer. ISBN 0-387-98314-7. Retrieved November 3, 2017, from https://s3.amazonaws.com/academia.edu.documents/37112618/The_Vestibular_System.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1534223705&Signature=Dwk3xJ%2FQrqF0sYV8rV5OtM1uyKI%3D&response-content-disposition=inline%3B%20filename%3DThe_Vestibular_System.pdf

Holden, M. K. (2005). Virtual environments for motor rehabilitation. *Cyberpsychology & behavior*, *8*(3), 187-211.

Holmes, J. D., Jenkins, M. E., Johnson, A. M., Hunt, M. A., & Clark, R. A. (2013). Validity of the Nintendo Wii® balance board for the assessment of standing balance in Parkinson's disease. *Clinical Rehabilitation*, *27*(4), 361-366.

Honrubia, V., & Hoffman, L. F. (1997). Practical anatomy and physiology of the vestibular system. In G. Jacobson, C. Newman, & J. Kartush. (eds.), *Handbook of balance function testing* (pp, 9-29). Retrieved November 22, 2017, from http://users.clas.ufl.edu/sgriff/courses/SPA6317/jnk-2.pdf

Horak, F. B. (1997). Clinical assessment of balance disorders. *Gait & Posture, 6*(1), 76-84.

Horak, F. B. (2006). Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?. *Age and ageing*, *35*(suppl_2), ii7-ii11.

Huang, H. M., Liaw, S. S., & Lai, C. M. (2016). Exploring learner acceptance of the use of virtual reality in medical education: a case study of desktop and projection-based display systems. *Interactive Learning Environments*, *24*(1), 3-19.

Hunter, M. C., & Hoffman, M. A. (2001). Postural control: visual and cognitive manipulations. *Gait & Posture*, *13*(1), 41-48.

Ibrahim, M. S., Mattar, A. G., & Elhafez, S. M. (2016). Efficacy of virtual reality-based balance training versus the Biodex balance system training on the body balance of adults. *Journal of physical therapy science*, *28*(1), 20-26.

In, T., Lee, K., & Song, C. (2016). Virtual reality reflection therapy improves balance and gait in patients with chronic stroke: randomized controlled trials. *Medical science monitor: international medical journal of experimental and clinical research*, *22*, 4046-4053.

Ionescu, E., Morlet, T., Froehlich, P., & Ferber-Viart, C. (2006). Vestibular assessment with Balance Quest: normative data for children and young adults. *International journal of pediatric otorhinolaryngology*, *70*(8), 1457-1465.

Jacobson, G. P., & Shephard, N. T. (2014). *Balance function assessment and management* (2nd ed.). San Diego, CA: Plural Publishing. ISBN: 978-1-59756-547-9. Retrieved November 3, 2017, from https://books.google.cz/books?hl=en&lr=&id=nmxyDgAAQBAJ&oi=fnd&pg=PA1&dq=Practical+anatomy+and+physiology+of+the+vestibular+system&ots=ESyUNsV8y9&sig=mqT-xGS5ol2OsOya8sufKTDoN8g&redir_esc=y#v=onepage&q=Practical%20anatomy%20and%20physiology%20of%20the%20vestibular%20system&f=false

Jonsdottir, J., & Cattaneo, D. (2007). Reliability and validity of the dynamic gait index in persons with chronic stroke. *Archives of physical medicine and rehabilitation, 88*(11), 1410-1415.

Jonsson, E., Henriksson, M., & Hirschfeld, H. (2003). Does the functional reach test reflect stability limits in elderly people?. *Journal of rehabilitation medicine, 35*(1), 26-30.

Kalajainen, A. (2015). *Comparison of the Balance error Scoring System and the NeuroCom Sensory Organization Test in healthy, physically active adults* (Master Thesis). Retrieved November 29, 2017, from University of Pittsburgh http://d-scholarship.pitt.edu/24288/1/KalajainenA.pdf

Karimi, M. T., & Solomonidis, S. (2011). The relationship between parameters of static and dynamic stability tests. *JRMS*, *16*(4), 530-535.

Keshner, E. A., & Kenyon, R. V. (2009). Postural and spatial orientation driven by virtual reality. *Studies in health technology and informatics*, *145*, 209-228.

Kesser, B. W., & Gleason, A. T. (2011). *Vertigo and Dizziness across the Lifespan, An Issue of Otolaryngologic*. Philadelphia: Elsevier Health Sciences. ISBN: 978-1-4557-0481-1. Retrieved November 20, 2017, from https://books.google.cz/books?hl=en&lr=&id=q4_gGnYJGQoC&oi=fnd&pg=PT6&dq=Vertigo+and+Dizziness+across+the+Lifespan,+An+Issue+of+Otolaryngologic&ots=3hT7kPpLag&sig=dU2eYp0TYUt-ndTe3zzA91FzjiQ&redir_esc=y#v=onepage&q=Vertigo%20and%20Dizziness%20across%20the%20Lifespan%2C%20An%20Issue%20of%20Otolaryngologic&f=false

Khan, S., & Chang, R. (2013). Anatomy of the vestibular system: a review. *NeuroRehabilitation, 32*(3), 437-443.

Kim, N., Park, Y., & Lee, B. H. (2015). Effects of community-based virtual reality treadmill training on balance ability in patients with chronic stroke. *Journal of physical therapy science*, *27*(3), 655-658.

Kinzey, S. J., & Armstrong, C. W. (1998). The reliability of the star-excursion test in assessing dynamic balance. *Journal of orthopaedic & sports physical therapy, 27*(5), 356-360.

Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object manipulation spatial ability and spatial orientation ability. *Memory & Cognition*, *29*(5), 745-756.

Lanska, D. J. (2002). The Romberg sign and early instruments for measuring postural sway. *Seminars in neurology, 22(*4), 409-418.

Lanska, D. J., & Goetz, C. G. (2000). Romberg's sign development, adoption, and adaptation in the 19th century. *Neurology, 55*(8), 1201-1206.

Laurens, J., Awai, L., Bockisch, C. J., Hegemann, S., Van Hedel, H. J. A., Dietz, V., & Straumann, D. (2010). Visual contribution to postural stability: interaction between target fixation or tracking and static or dynamic large-field stimulus. *Gait & posture*, *31*(1), 37-41.

Leach, J. M., Mancini, M., Peterka, R. J., Hayes, T. L., & Horak, F. B. (2014). Validating and calibrating the Nintendo Wii balance board to derive reliable center of pressure measures. *Sensors*, *14*(10), 18244-18267.

Lee, D., Lee, S., & Park, J. (2014). Effects of indoor horseback riding and virtual reality exercises on the dynamic balance ability of normal healthy adults. *Journal of physical therapy science*, *26*(12), 1903-1905.

Lee, H. R. (2014). *Reliability of the Sensory Organization Test over clinical administration time intervals of concussion assessment* (Doctoral dissertation). Retrieved November 26, 2017, from University of Georgia https://getd.libs.uga.edu/pdfs/lee_hyung-rock_201405_phd.pdf

Lee, H. Y., Kim, Y. L., & Lee, S. M. (2015). Effects of virtual reality-based training and task-oriented training on balance performance in stroke patients. *Journal of physical therapy science*, *27*(6), 1883-1888.

Lee, K. (2012). Augmented reality in education and training. *TechTrends*, *56*(2), 13-21.

Mancini, M., & Horak, F. B. (2010). The relevance of clinical balance assessment tools to differentiate balance deficits. *European Journal of Physical and Rehabilitation Medicine, 46*(2), 239–248.

Mao, Y., Chen, P., Li, L., & Huang, D. (2014). Virtual reality training improves balance function. *Neural regeneration research*, *9*(17), 1628-1634.

Maranhão-Filho, P., Maranhão, E., Lima, M., & Silva, M. (2011B). Rethinking the neurological examination II: dynamic balance assessment. *Arquivos de neuro-psiquiatria*, *69*(6), 959-963.

Maranhão-Filho, P., Maranhão, E., Silva, M., & Lima, M. (2011A). Rethinking the neurological examination I: static balance assessment. *Arquivos de neuro-psiquiatria, 69*(6), 954-958.

Marieb, E. N., & Hoehn, K. (2007). *Human anatomy & physiology* (7th ed.). San Francisco, CA: Pearson Education. Retrieved November 10, 2017, from https://books.google.cz/books?hl=en&lr=&id=x1uEB68iitwC&oi=fnd&pg=PA1&ots=Oo7XlyX4L6&sig=QjvqtGlJ0Y8ydwSpNJyIbyx2dtw&redir_esc=y#v=onepage&q=eye&f=false

Mazuryk, T., & Gervautz, M. (1996). *Virtual reality-history, applications, technology and future*. Retrieved November 29, 2017, from CiteSeer http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.42.7849&rep=rep1&type=pdf

McCollum, G., Shupert, C. L., & Nashner, L. M. (1996). Organizing sensory information for postural control in altered sensory environments. *Journal of theoretical biology*, *180*(3), 257-270.

Meldrum, D., Glennon, A., Herdman, S., Murray, D., & McConn-Walsh, R. (2012). Virtual reality rehabilitation of balance: assessment of the usability of the Nintendo Wii® Fit Plus. *Disability and rehabilitation: assistive technology*, *7*(3), 205-210.

Merians, A. S., Fluet, G., Tunik, E., Qiu, Q., Saleh, S., & Adamovich, S. (2014). Movement rehabilitation in virtual reality from then to now: how are we doing?. *International Journal on Disability and Human Development*, *13*(3), 311-317.

Merians, A. S., Tunik, E., & Adamovich, S. V. (2009). Virtual reality to maximize function for hand and arm rehabilitation: exploration of neural mechanisms. *Studies in health technology and informatics*, *145*, 109-125.

Mosadeghi, S., Reid, M. W., Martinez, B., Rosen, B. T., & Spiegel, B. M. R. (2016). Feasibility of an immersive virtual reality intervention for hospitalized patients: an observational cohort study. *JMIR mental health*, *3*(2), e28. DOI: 10.2196/mental.5801.

Naunton, R. (1975). *The vestibular system*. The US: Academic Press. ISBN: 0-12-514950-6. Retrieved November 3, 2017, from https://books.google.cz/books?hl=en&lr=&id=wb2GAAAAQBAJ&oi=fnd&pg=PP1&dq=The+vestibular+system&ots=KNcjUl7VLv&sig=4P6yT5yG-sPelOkhW-1UYol4l_M&redir_esc=y#v=onepage&q=The%20vestibular%20system&f=false

Netter, F. H. (2017). *Atlas of Human Anatomy* (7th ed.). Philadelphia: Elsevier Health Sciences. ISBN: 978-0-0323-39322-5. Retrieved November 20, 2017, from https://books.google.cz/books?hl=en&lr=&id=6bZEDwAAQBAJ&oi=fnd&pg=PP1&dq=vestibulocochlear+nerve+anatomy&ots=zl5flTsLI8&sig=j1KP3p0SE82Ekb0FQDG4Sac8U_k&redir_esc=y#v=onepage&q=vestibulocochlear%20nerve%20&f=true

NeuroCom® Balance Manager. (2016A). *Sensory Organization Test (SOT)*. Retrieved November, 27, 2017, from Natus Balance and Mobility http://balanceandmobility.com/wpcontent/uploads/018528A_NCM_SOT_brochure_EN-US_lo-res.pdf

NeuroCom® Balance Manager. (2016B). *Motor Control Test (MCT)*. Retrieved November, 27, 2017, from Natus Balance and Mobility http://balanceandmobility.com/wpcontent/uploads/018529A_NCM_MCT_datasheet_EN-US_lo-res.pdf

Nishiike, S., Okazaki, S., Watanabe, H., Akizuki, H., Imai, T., Uno, A., ... & Inohara, H. (2013). The effect of visual-vestibulosomatosensory conflict induced by virtual reality on postural stability in humans. *The Journal of Medical Investigation*, *60*(3.4), 236-239.

Oda, D. T. M., & Ganança, C. F. (2015). Computerized dynamic posturography in the assessment of body balance in individuals with vestibular dysfunction. *Audiology-Communication Research*, *20*(2), 89-95.

Ohyama, S., Nishiike, S., Watanabe, H., Matsuoka, K., Akizuki, H., Takeda, N., & Harada, T. (2007). Autonomic responses during motion sickness induced by virtual reality. *Auris Nasus Larynx*, *34*(3), 303-306.

Olmsted, L. C., Carcia, C. R., Hertel, J., & Shultz, S. J. (2002). Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *Journal of athletic training, 37*(4), 501-506.

Onate, J. A., Beck, B. C., & Van Lunen, B. L. (2007). On-field testing environment and balance error scoring system performance during preseason screening of healthy collegiate baseball players. *Journal of athletic training, 42*(4), 446-451.

Park, D. S., & Lee, G. (2014). Validity and reliability of balance assessment software using the Nintendo Wii balance board: usability and validation. *Journal of neuroengineering and rehabilitation*, *11*(1), 99. DOI: https://doi.org/10.1186/1743-0003-11-99

Park, S. K., Yang, D. J., Uhm, Y. H., Heo, J. W., & Kim, J. H. (2016). The effect of virtual reality-based eccentric training on lower extremity muscle activation and balance in stroke patients. *Journal of physical therapy science*, *28*(7), 2055-2058.

Park, Y. H., Lee, C. H., & Lee, B. H. (2013). Clinical usefulness of the virtual reality-based postural control training on the gait ability in patients with stroke. *Journal of exercise rehabilitation*, *9*(5), 489-494.

Payne, A. J. (2006). *The effects of physical activity on balance control in young adult participants using the balance quest computerized dynamic posturography system* (Doctoral dissertation). Retrieved 15, November, 2017 from ProQuest Central. (UMI No. 3211719). https://search-proquest-com.ezproxy.is.cuni.cz/docview/304911013/8197D84800C1428EPQ/20?accountid=15618

Persky, S., & McBride, C. M. (2009). Immersive virtual environment technology: a promising tool for future social and behavioral genomics research and practice. *Health Communication*, *24*(8), 677-682.

Peterka, R. J. (2002). Sensorimotor integration in human postural control. *Journal of neurophysiology*, *88*(3), 1097-1118.

Peterka, R. J., & Loughlin, P. J. (2004). Dynamic regulation of sensorimotor integration in human postural control. *Journal of neurophysiology*, *91*(1), 410-423.

Pieber, K., Herceg, M., Csapo, R., Wiesinger, G., Quittan, M., Crevenna, R., … & Mittermaier, C. (2016). Effects of a multidisciplinary programme on postural stability in patients with chronic recurrent low back pain: preliminary findings. *European Spine Journal*, *25*(4), 1219-1225.

Ravi, D. K., Kumar, N., & Singhi, P. (2017). Effectiveness of virtual reality rehabilitation for children and adolescents with cerebral palsy: an updated evidence-based systematic review. *Physiotherapy*, *103*(3), 245-258.

Razavi, H. (2017). A Comparison between Static and Dynamic Stability in Postural Sway and Fall Risks. *Journal of Ergonomics, 7(*1), 1-7.

Redfern, M. S., Jennings, J. R., Martin, C., & Furman, J. M. (2001). Attention influences sensory integration for postural control in older adults. *Gait & posture*, *14*(3), 211-216.

Reed-Jones, R. J., Vallis, L. A., Reed-Jones, J. G., & Trick, L. M. (2008). The relationship between postural stability and virtual environment adaptation. *Neuroscience letters*, *435*(3), 204-209.

Akizuki, H., Uno, A., Arai, K., Morioka, S., Ohyama, S., Nishiike, S., ... & Takeda, N. (2005). Effects of immersion in virtual reality on postural control. *Neuroscience* *letters*, *379*(1), 23-26.

Horlings, C. G., Carpenter, M. G., Küng, U. M., Honegger, F., Wiederhold, B., & Allum, J. H. (2009). Influence of virtual reality on postural stability during movements of quiet stance. *Neuroscience letters*, *451*(3), 227-231.

Wada, Y., Nishiike, S., Kitahara, T., Yamanaka, T., Imai, T., Ito, T., ... & Takeda, N. (2016). Effects of repeated snowboard exercise in virtual reality with time lags of visual scene behind body rotation on head stability and subjective slalom run performance in healthy young subjects. *Acta oto-laryngologica*, *136*(11), 1121-1124.

Rendon, A. A. (2011). *Virtual reality gaming as a tool for rehabilitation in physical therapy* (Doctoral dissertation). Retrieved 15, November, 2017 from ProQuest Central. (UMI No. 3464981). https://search-proquest-com.ezproxy.is.cuni.cz/docview/887717714?accountid=15618

Riemann, B. L., Guskiewicz, K. M., & Shields, E. W. (1999). Relationship between clinical and forceplate measures of postural stability. *Journal of sport rehabilitation, 8*(2), 71-82.

Riva, G. (1997). *Virtual reality in neuro-psycho-physiology: cognitive, clinical and methodological issues in assessment and rehabilitation.* Amesterdam, Netherland. IOS Press. ISBN: 9051993641. Retrieved November 22, 2017 from https://books.google.cz/books?hl=en&lr=&id=e3dT_29znBoC&oi=fnd&pg=PA35&dq=Human+factors+consideration+in+clinical+applications+of+virtual+reality&ots=mOFcv2u4Na&sig=M-AqYGcRIWFFEZN0z1xeT1VM-OY&redir_esc=y#v=onepage&q=Human%20factors%20consideration%20in%20clinical%20applications%20of%20virtual%20reality&f=false

Riva, G. (2003). Applications of virtual environments in medicine. *Methods of information in medicine, 42*(05), 524-534.

Riva, G. (2005). Virtual reality in psychotherapy. *Cyberpsychology & behavior*, *8*(3), 220-230.

Riva, G. (2009). Virtual reality: an experiential tool for clinical psychology. *British Journal of Guidance & Counselling*, *37*(3), 337-345.

Riva, G., & Wiederhold, B. K. (2015). The new dawn of virtual reality in health care: medical simulation and experiential interface. *Stud. Health Technol. Inform*, *219*, 3-6.

Rolland, J. P., & Hua, H. (2005). Head-mounted display systems. *Encyclopedia of optical engineering*, 1-13. DOI: 10.1081/E-EOE-120009801.

Ross, S. E., & Guskiewicz, K. M. (2003). Time to stabilization: a method for analyzing dynamic postural stability. *Athletic Therapy Today, 8(*3), 37-39.

Ross, S. E., & Guskiewicz, K. M. (2004). Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clinical Journal of Sport Medicine, 14*(6), 332-338

Santos, B. S., Dias, P., Pimentel, A., Baggerman, J. W., Ferreira, C., Silva, S., … & Madeira, J. (2009). Head-mounted display versus desktop for 3D navigation in virtual reality: a user study. *Multimedia Tools and Applications*, *41*(1), 161-181.

Scaglioni-Solano, P., & Aragón-Vargas, L. F. (2014). Validity and reliability of the Nintendo Wii Balance Board to assess standing balance and sensory integration in highly functional older adults. *International Journal of Rehabilitation Research*, *37*(2), 138-143.

Schroeder, R. (2008). Defining virtual worlds and virtual environments. *Journal For Virtual Worlds Research*, *1*(1). ISSN: 1941 - 8477

Sell, T. C. (2012). An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. *Physical Therapy in Sport*, *13*(2), 80-86.

Shepard, N. T., & Janky, K. (2010). Computerized postural control assessment. In S. Eggers, & D. Zee. (eds.), *Vertigo and Imbalance: Clinical Neurophysiologyof the*

Vestibular System (pp. 238-251). Amsterdam, The Netherlands: Elsevier. Retrieved November 20, 2017, from http://www.framiral.fr/2015/communication/articles/2010_Handbook-of-Clinical-Neurophysiology_Chapter19.pdf

Sherafat, S., Salavati, M., Takamjani, I. E., Akhbari, B., Mohammadirad, S., Mazaheri, M., … & Negahban, H. (2013). Intrasession and intersession reliability of postural control in participants with and without nonspecific low back pain using the Biodex Balance System. *Journal of Manipulative & Physiological Therapeutics*, *36*(2), 111-118.

Sherman, W. R., & Craig, A. B. (2002). *Understanding virtual reality: Interface, application, and design*. The US: Elsevier. ISBN: 1-55860-353-0. Retrieved November 2, 2017, from https://books.google.cz/books?hl=cs&lr=&id=b3OJpAMQikAC&oi=fnd&pg=PP1&dq=Understanding+virtual+reality:+Interface,+application,+and+design&ots=3EHPfkyLUl&sig=DpLuXym4EoGKl0qzV1sGQPEH5Yg&redir_esc=y#v=onepage&q=Understanding%20virtual%20reality%3A%20Interface%2C%20application%2C%20and%20design&f=false

Shier, D., Butler, J., & Lewis, R. (2001). *Human anatomy and physiology* (11th ed.). Boston, MA, USA: McGraw-Hill. ISBN: 978-0-07-282953-2. Retrieved Novenber 15, 2017, from http://www.metaphysicspirit.com/books/Hole's%20Human%20Anatomy%20and%20Physiology.pdf

Singh, D. K. A., Nordin, N. A. M., Aziz, N. A. A., Lim, B. K., & Soh, L. C. (2013). Effects of substituting a portion of standard physiotherapy time with virtual reality games among community-dwelling stroke survivors. *BMC neurology*, *13*(1), 199. DOI: 10.1186/1471-2377-13-199

Smith, J. W. (2015). Immersive virtual environment technology to supplement environmental perception, preference and behavior research: a review with applications. *International journal of environmental research and public health*, *12*(9), 11486-11505.

Song, G., & Park, E. (2015). Effect of virtual reality games on stroke patients' balance, gait, depression, and interpersonal relationships. *Journal of physical therapy science*, *27*(7), 2057-2060.

Sousa, N., & Sampaio, J. (2005). Effects of progressive strength training on the performance of the Functional Reach Test and the Timed Get-Up-and-Go Test in an elderly population from the rural north of Portugal. *American Journal of Human Biology, 17*(6), 746-751.

Spickler, E. M., & Govila, L. (2002). The vestibulocochlear nerve. *Seminars in Ultrasound, CT and MRI, 23*(3), 218-237.

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of communication*, *42*(4), 73-93.

Sveistrup, H. (2004). Motor rehabilitation using virtual reality. *Journal of neuroengineering and rehabilitation*, *1*(1), 10. DOI: 10.1186/1743-0003-1-10.

Tashjian, V. C., Mosadeghi, S., Howard, A. R., Lopez, M., Dupuy, T., Reid, M., ... & Rosen, B. (2017). Virtual reality for management of pain in hospitalized patients: results of a controlled trial. *JMIR mental health*, *4*(1), e9. DOI: 10.2196/mental.7387

Tiron, S., Berteanu, M., Cretu, A., Anton, M., & Gagea, A. (2009). Contributions to the assessment of postural stability and dynamic balance in some neurological dysfunctions, in human normality or performance. *Palestrica Of The Third Millennium Civilization & Sport*, *10*(1), 64-68.

Vanicek, N., King, S. A., Gohil, R., Chetter, I. C., & Coughlin, P. A. (2013). Computerized Dynamic Posturography for Postural Control Assessment in Patients with Intermittent Claudication. *Journal of Visualized Experiments : JoVE*, (82), 51077. DOI: http://doi.org/10.3791/51077

Vaudrey, C. M. (2006). *Computerized dynamic posturography test result dependence on type of subject athletic activity* (Doctoral Dissertation).(UMI No. 3211717). Retrieved November 26, 2017, from ProQuest Central. (UMI No. 3211717) https://search-proquest-com.ezproxy.is.cuni.cz/docview/304910921/8197D84800C1428EPQ/36?accountid=15618

Whitney, S. L., Hudak, M. T., & Marchetti, G. F. (2000). The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. *Journal of Vestibular Research, 10*(2), 99-105.

Whitney, S., Wrisley, D., & Furman, J. (2003). Concurrent validity of the Berg Balance Scale and the Dynamic Gait Index in people with vestibular dysfunction. *Physiotherapy Research International, 8*(4), 178-186.

Wikstrom, E. A., Tillman, M. D., Chmielewski, T. L., Cauraugh, J. H., & Borsa, P. A. (2007). Dynamic postural stability deficits in subjects with self-reported ankle instability. *Medicine & Science in Sports & Exercise*, *39*(3), 397-402.

Wikstrom, E. A., Tillman, M. D., Smith, A. N., & Borsa, P. A. (2005). A New Force-Plate Technology Measure of Dynamic Postural Stability: The Dynamic Postural Stability Index. *Journal of Athletic Training*, *40*(4), 305–309.

Wikstrom, E. A., Arrigenna, M. A., Tillman, M. D., & Borsa, P. A. (2006). Dynamic Postural Stability in Subjects With Braced, Functionally Unstable Ankles. *Journal of Athletic Training*, *41*(3), 245–250.

Wilkins, J. C., McLeod, T. C. V., Perrin, D. H., & Gansneder, B. M. (2004). Performance on the balance error scoring system decreases after fatigue. *Journal of athletic training, 39*(2), 156-161.

Wrisley, D. M., & Whitney, S. L. (2004). The effect of foot position on the modified clinical test of sensory interaction and balance1. *Archives of physical medicine and rehabilitation, 85*(2), 335-338.

Yeh, S. C., Chen, S., Wang, P. C., Su, M. C., Chang, C. H., & Tsai, P. Y. (2014). Interactive 3-dimensional virtual reality rehabilitation for patients with chronic imbalance and vestibular dysfunction. *Technology and Health Care*, *22*(6), 915-921.

Yen, C. Y., Lin, K. H., Hu, M. H., Wu, R. M., Lu, T. W., & Lin, C. H. (2011). Effects of virtual reality–augmented balance training on sensory organization and attentional demand for postural control in people with parkinson disease: a randomized controlled trial. *Physical therapy*, *91*(6), 862-874.

Yin, C., Hsueh, Y. H., Yeh, C. Y., Lo, H. C., & Lan, Y. T. (2016). A virtual reality-cycling training system for lower limb balance improvement. *BioMed research international*, *2016*. DOI: 10.1155/2016/9276508.

Yokota, Y., Aoki, M., Mizuta, K., Ito, Y., & Isu, N. (2005). Motion sickness susceptibility associated with visually induced postural instability and cardiac autonomic responses in healthy subjects. *Acta oto-laryngologica*, *125*(3), 280-285.

Appendices

Appendix I: The Ethics Committee Approved Application

Appendix II: Informed Consent Form

Appendix I:

CHARLES UNIVERSITY
FACULTY OF PHYSICAL EDUCATION AND SPORT
José Martího 31, 162 52 Prague 6-Veleslavín

Application for Approval by UK FTVS Ethics Committee

of a research project, thesis, dissertation or seminar work involving human subjects

The title of a project: Application of Virtual Reality on Dynamic Postural Stability

Project form: Master's Thesis

Period of realization of the project: June, 2018 – August, 2018

Applicant: Bc. Saad Al Amri

Main researcher: Bc. Saad Al Amri

Workplace: Kinesiology Laboratory at The Physiotherapy Department

Co-researcher(s):

Supervisor: MUDr. David Panek, Ph.D.

Financial support: No financial support.

Project description: A pilot experimental study, aimed to evaluate Virtual Reality effects on dynamic postural stability, using Smart Balance Master System (NeuroCom). Sensory Organization Test SOT and Motor Control Test MCT will be used as outcome measures prior and post five minutes duration 3D video on Samsung Oculus Gear Goggles

Characteristics of participants in the research: 11 Healthy adults participants, age ranged between 20 to 40 years. Excluded persons with neurological, vestibular or visual diseases and disorders. Participants will be chosen randomly from the faculty students

Ensuring safety within the research: The experiment will be non-invasive and safe. The tests will be on (NeuroCom) during wearing safety harness to preventing falls in imbalance situation. And there is no high risk of using VR, it may cause motor sickness symptoms which last few minutes. The experiment will be under supervision of MUDr. David Panek, Ph.D.

Ethical aspects of the research:
- The participants are adults and non-vulnerable.
- The gained data will be processed and safely retained in an anonymised form and published in a mater thesis, possibly also in journals, monographs, and presented at conferences, possibly also used in further research at UK FTVS. After the anonymization the personal data will be deleted.
- Taking photographs/videos of the participants: No photos of participants will be used in the experiment.

I shall ensure to the maximum extent possible that the research data will not be misused.

Informed Consent: attached

It is the duty of **all participants of the research team** to protect life, health, dignity, integrity, the right to self-determination, privacy and protection of the personal data of all research subjects, and to undertake all possible precautions. Responsibility for the protection of all research subjects lies on the researcher(s) and not on the research subjects themselves, even if they gave their consent to participation in the research. All participants of the research team must take into consideration ethical, legal and regulative norms and standards of research involving human subjects applicable not only in the Czech Republic but also internationally.

I confirm that this project description corresponds to the plan of the project and, in case of any change, especially of the methods used in the project, I will inform the UK FTVS Ethics Committee, which may require a re-submission of the application form.

In Prague, 22.6.2018 Applicant's signature:

Approval of UK FTVS Ethics Committee

The Committee: Chair: doc. PhDr. Irena Parry Martínková, Ph.D.
Members: prof. PhDr. Pavel Slepička, DrSc.
doc. MUDr. Jan Heller, CSc.
PhDr. Pavel Hráský, Ph.D.
Mgr. Eva Prokešová, Ph.D.
MUDr. Simona Majorová

The research project was approved by UK FTVS Ethics Committee under the registration number: 124/2018

Date of approval: 25.6.2018

UK FTVS Ethics Committee reviewed the submitted research project and **found no contradictions** with valid principles, regulations and international guidelines for carrying out research involving human subjects.

The applicant has met the necessary requirements for receiving approval of UK FTVS Ethics Committee.

UNIVERZITA KARLOVA
Fakulta tělesné výchovy a sportu
José Martího 31, 162 52, Praha 6
-20-

Stamp of UK FTVS

Signature of the Chair of
UK FTVS Ethics Committee

Appendix II:

INFORMED CONSENT

Dear Sir or Madam,

in line with The Universal Declaration of Human Rights, Protection of Personal Data Act No. 101/2000 Coll. as amended, Czech Republic, and other generally binding legal regulations (such as especially the Helsinki declaration, adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964 and its later amendments (Fortaleza, Brazil, 2013); Act No. 372/2011 Coll., on Health Services (especially Section 28, paragraph 1) and the Convention on Human Rights and Biomedicine, Act No. 96/2001 Coll., if applicable), I ask you for your consent to your participation in a research project within my master thesis with the title *"Application of Virtual Reality on Dynamic Postural Stability"*.

1. Our goal is to evaluate Virtual Reality (VR) 3D video effects on dynamic postural stability, by comparing postural stability measures prior and post the VR application.
2. Virtual Reality (VR) application will be provided by using Samsung Gear, Oculus Goggles. In measurements of postural stability we will use Computerized Dynamic Posturography (CDP), Force Platform, Smart Balance Master System (NeuroCom).
3. We will use noninvasive method. Before starting you will be asked to tell us about your name, height, weight and date of birth. Postural stabilitty examination on the force platform will be while you are barefooted, putting on safety harness, standing with arms at the side and looking forward. We will do two tests (SOT and MCT) for measuring postural stability, using Equitest (NeuroCom). Then you will put on theVR goggles to watch 3D video for 5 minutes. Finally you will be retested on the force platform for comparing the results.
4. The experiment will last around 25 minutes for each subject. Each subject will be tested twice, one before and one after the VR video. Each test will last around 10 minutes and the VR video will last 5 minutes.
5. The participant should be healthy with no neurological, vestibula rand visual diseases and disorders. In case of feeling headchae, dizzy, vertigo, disorientation or any other changes you must inform us about it.
6. The participant will be scheduled for the experiment time. He/she will be examined

alone if he/she wanted for ensuring privacy. They can leave after finishing the experimental procedure.

7. There is no reward or benefits of being participating in the experiment.

8. The data and information we will obtain will remain in the private property, possession and used by the researcher only. Personal data will be anonymised and stored in anonymised form.

In case of photographing in the experiment, you will be asked for your permission to use.

9. If you want to know about your results, you can contact the researcher personally, or ask the Faculty of Physical Education and Sport, Charles University in Prague, to view it after thesis publishing.

10. I shall ensure to the maximum extent possible that the research data will not be misused.

Name and surname of the applicant: Saad Al Amri

Name and surname of the main researcher and co-researcher(s): Saad Al Amri Signature: ....

I declare and with my below mentioned personal signature confirm that I voluntarily agree with my participation in the above mentioned project and that I have been given an opportunity to ask questions and consider all relevant information about the research project and my participation, and that I received clear and comprehensible answers to my questions. I was informed about my right to refuse participation within the research project or to withdraw my consent at any time without penalisation, by writing to the UK FTVS Ethics Committee, which will consequently inform the applicant.

Place and date..

Name and surname of participant... Signature: ....