THE EFFECT OF VIRTUAL REALITY ON OCULOMOTOR FUNCTION

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A PROJECT SUBMITTED TO THE DEPARTMENT OF OPTOMETRY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY.

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CERTIFICATE OF APPROVAL

This is to certify that this research project titled: **THE EFFECT OF VIRTUAL REALITY ON OCULOMOTOR FUNCTION** was carried out by **AHUNUN OBEHI ANNE** in the Department of Optometry, Faculty of Life Sciences, University of Benin in partial fulfillment of the requirement for the DOCTOR OF OPTOMETRY (OD) degree in the 2022/2023 Academic Session.

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DEDICATION

This work is dedicated to GOD Almighty for his unconditional love and abundant grace of a sound mind and wisdom, knowledge and understanding, protection and guidance through out my study years and to my amazing family who have been sacrificial and supportive towards my growth and development through the years.

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ABSTRACT

Virtual reality (VR) has become a mainstay with it's increasing application in diverse fields. The use of head-mounted display (HMD) provides a more immersive computer generated world when compared to other video formats. It is therefore essential to understand the effects of VR on oculomotor function. The purpose of this study was to determine the effect of VR on oculomotor function. A total of 29 participants with mean age 24.41 ± 1.98 comprising 14 males and 15 females, who met the inclusion criteria were recruited for this study. The clinical accommodative and vergence measurements linked to the oculomotor system that were of interest in this study were collected before and after watching a 3D movie with a VR-HMD for 45 minutes. The Baseline measurements were analyzed using the One-Sample t test. The Paired-Samples t test was used to compare the mean values of the baseline measurements with those recorded after the virtual reality. The study revealed significant change in AOA in the right eye (p=0.005), no significant difference in the left eye (p= 0.199) and other accommodative measurements (p=0.076 and p=0.725 for NRA AND PRA respectively). PFV break at near showed a significant difference (p=0.003) but there was no significant difference for other vergence measurements' break components (p=0.414 and p= 0.257 for NPC and NFV). There was no significant difference for vergence measurements' recovery components (p= 0.191 for NPC, p= 0.361 for NFV and p= 0.561 for PFV). In conclusion VR-HMD was found to have significant effect on certain occulomotor functions.

Keywords: Virtual reality, Head-mounted display, Oculomotor function, Accommodative measurements, and Vergence measurements.

CHAPTER ONE

1.0 INTRODUCTION

Since the debut of the Google Cardboard in 2014, virtual reality (VR) effects have become more accessible and affordable through electronic devices, fueling the industry's growth. When using immersive Virtual Reality on mobile devices, the screen's close proximity to the eyes (15 cm) causes pupil constriction, ciliary muscle contraction, lens adjustment, and extraocular muscle contraction or relaxation (Cumming and DeAngelis, 2001).

Virtual Reality entails a computer-simulated environment where artificial visual and potentially other sensory stimuli respond to the participant's actions. Virtual and augmented reality systems convey these visual stimuli and other sensory channels (touch, smell, sound, taste) (Rebenitsch and Owen, 2016).

The users perceive virtual objects as being distant through the use of high convex lenses. The illusion of depth is created through a lateral offset between the objects presented to each eye, resulting in retinal image disparity. The object appears to be closer as the lateral offset increases. Users employ both version and vergence eye movements to avoid double vision when shifting gaze between objects, minimizing retinal disparity for each eye and enabling binocular perception of the object of interest. In the real world, vergence eye movements are linked with accommodation changes to focus on objects at varying depths. In contrast, the focal distance in VR is constant, necessitating eye convergence without accommodation to maintain a clear retinal image (Vienne *et al.,* 2014).. This disconnect between convergence and accommodation in VR head-mounted displays (HMDs) may contribute to visual discomfort (Lambooji *et al.,* 2009). The long-term effects of this dissociation are unknown (Rushton *et al*., 1999), but one study using an early VR HMD system reported a shift toward esophoria and an increased near point of binocular convergence after just 10 minutes of VR exposure (Mon-Williams *et al.,* 1999). While VR technology has evolved in recent years, current VR HMDs still face the same optical limitations (Wann *et al*., 1999).

1.1 BACKGROUND INFORMATION

Virtual Reality has experienced significant growth in recent years, particularly VR headsets that mount smartphones running VR games to create an immersive experience for users (Desai *et al.,* 2014). Despite being a relatively new concept, VR has gained widespread acceptance. Since the 1950s, researchers have explored devices that enable users to experience different environments. Advances in head-mounted displays and other components have since enhanced the immersive experience.

Phoria patterns tend to shift with reduced convergence abilities. During the viewing of 3D stereoscopic images in head-mounted devices, the eyes attempt to converge for binocular fusion despite accommodation-vergence conflicts. This sustained convergence effort may strain extraocular muscles, leading to reduced fusion vergence and potential visual fatigue symptoms like blurred vision, double vision, and headaches (Zhuo, 2017; Karpicka and Howarth, 2013; Morse and Jiang, 1999).

Users frequently report symptoms of cyber-sickness, including nausea, disorientation, and eye strain, while using HMDs to navigate virtual environments (Rebenitsch & Owen, 2016; Gallagher and Ferre, 2018).

The study by Munafo *et al.,* (2020) investigated the potential effects of VR on cognitive function and emotional well-being. They discovered that immersive VR experiences may enhance cognitive abilities like memory, attention, and problem-solving, as well as positively impact emotional states by reducing stress and promoting relaxation (Munafo et *al*., 2020).

1.1.1 HEAD-MOUNTED DISPLAY SYSTEMS

Head-Mounted displays (HMDs) systems consist of an electronically driven light modulator perceived through an integrated optical setup. This ensemble is then securely attached to the user's cranium through a headgear or helmet. The spatial arrangement of the light sources, optical elements, and mechanical components relative to the head imposes stringent specifications on the overall design. Essential elements of HMDs include display panels, optical systems, tracking sensors, and ergonomic features. Visual coupling systems (i.e., tracking devices) are indispensable for generating appropriate perspectives for users based on their head position and potentially their gaze direction. The realization that tracking inaccuracies were a primary source of visual distortions in augmented reality displays stimulated considerable research efforts over the last ten years, focusing on enhancing tracking performance to minimize visual errors (Steuer, 1992).

Samsung Gear(a)
Cardboard (b)
Oculus(c)
HTC Vive (d)
LG (e)
Playstation VR (PSVR) (f)
Hololens (g)
Meta (h)
Moverio BT200 (k)

Popular models of Head Mounted Displays for VR and AR in 2016(Martin-Gutierrez et *al*., 2017).

Head-mounted displays (HMDs) have emerged as a revolutionary technology with applications ranging from virtual reality (VR) and augmented reality (AR) to healthcare and education (Cipresso et *al*., 2018). Advancements in display technology, optics, tracking systems, and computational power have driven substantial evolution in HMD technology (Milgram & Kishino, 1994). Despite their potential, HMDs face obstacles such as visual discomfort, motion sickness, and social acceptance (Rebenitsch and Owen, 2016). To overcome the challenges hindering HMD adoption, interdisciplinary research and collaboration across optics, human-computer interaction, and neuroscience are crucial (Cipresso *et al.,* 2018).

Head-mounted displays represent a promising technology with immense scope for innovation and influence across diverse fields (Steuer, 1992).

1.1.2 THE OCULOMOTOR SYSTEM

Oculomotor function encompasses the control and coordination of eye movements, essential for visual perception and cognitive processes. The oculomotor system comprises a complex network of muscles, nerves, and brain structures responsible for eye movements and coordination. Key components of oculomotor function include: Saccades, Smooth Pursuit, Fixation and Vergence eye movements (Leigh & Zee, 2015).

Saccades are rapid, ballistic eye movements that shift gaze from one point to another, enabling quick scanning of the environment and facilitating visual attention. Saccadic eye movements are influenced by cognitive factors such as attention and decision-making (Hallett, 1993).

Smooth Pursuits are eye movements that continuously track moving objects to maintain foveation, the central part of the retina responsible for detailed vision. Smooth pursuit is essential for tasks such as following moving targets while driving or playing sports. Impairments in smooth pursuit can lead to difficulties with visual tracking and depth perception (Leigh and Zee, 2015).

Fixation is the ability to maintain stable gaze on a stationary object, crucial for tasks requiring sustained attention, such as reading or watching a movie. Dysfunctions in fixation can result in ocular instability and difficulty maintaining focus on a target (Leigh & Zee, 2015).

Research on the effects of VR on oculomotor function has gained attention due to the widespread adoption of VR technology. Studies have shown that prolonged exposure to VR environments can lead to changes in oculomotor behavior, including alterations in saccadic patterns, reduced smooth pursuit accuracy, and increased visual fatigue (Carnahan *et al*., 2020).

A study by Kim *et al*., (2019) demonstrated that engaging in virtual reality (VR) tasks can enhance oculomotor function. They found that participants who underwent VR training had improved saccadic eye movements and smooth pursuit tracking compared to those who did not engage in VR tasks. This suggests that interacting with virtual reality can positively impact eye movement coordination and accuracy.

Additionally, VR has potential therapeutic applications in rehabilitation settings. In a study by Solaro et *a*l., (2020), individuals with acquired brain injury participated in a virtual reality intervention targeting their oculomotor function. The intervention involved specific eye movement exercises performed within a VR environment. The results showed significant improvements in oculomotor parameters, indicating that VR-based interventions can enhance oculomotor function in clinical populations.

Another consideration is the potential impact of prolonged VR use on oculomotor function. Some studies have expressed concerns about the occurrence of oculomotor disturbances, such as eye strain, dizziness, and nausea, among individuals using VR extensively. A study by Jerald et *al*., (2018) investigated the potential effects of prolonged VR usage on oculomotor function. They found that extended exposure to VR environments led to increased eye fatigue and changes in oculomotor patterns, including alterations in saccadic eye movements and convergence abilities. These changes were associated with symptoms such as blurred vision, double vision, and headaches, highlighting the potential impact of prolonged VR usage on oculomotor function (Jerald et *al*., 2018).

1.1.3 THE ACCOMMODATIVE AND VERGENCE SYSTEM

The accommodative system is crucial for human vision, allowing individuals to adjust their focus to perceive objects clearly at varying distances. This complex process involves the coordination of several anatomical structures within the eye, including the ciliary muscle, lens, and pupillary reflexes (Atchison and Smith, 2023). The mechanisms underlying accommodation are governed by a complex interplay of neural and biomechanical factors (Ciuffreda *et al.,* 2008). Visual stimuli trigger the accommodative reflex through feedback loops between the visual cortex, midbrain nuclei, and the autonomic nervous system, ultimately leading to adjustments in lens shape and pupil size to maintain clear vision (Atchison and Smith, 2023).

The vergence reflex, facilitated by the midbrain and brainstem nuclei, integrates inputs from the visual cortex and proprioceptive feedback from the extraocular muscles (Leigh and Zee, 2015). This interplay synthesizes visual cues, such as retinal disparities and accommodative changes, with proprioceptive feedback from the eye muscles, leading to synchronized eye movements for binocular vision and depth perception (Ciuffreda et *al*, 2008). The disparity between retinal images provides depth cues, enabling distance estimation (Howard and Rogers, 1995).

The vergence system intricately interacts with the accommodative system, with accommodation adjustments often inducing corresponding vergence shifts to maintain binocular alignment

(Gamlin, 2002). These systems are inextricably linked, with accommodative vergence and vergence accommodation reflexes coordinating responses to retinal blur and depth cues (Hung and Nichani, 2001). Accommodation and convergence, as complementary ocular systems, facilitate binocular vision. Disturbances in one system may impact the other (Shiomi et *al*., 2013). Virtual reality (VR) imposes demands on these systems, potentially leading to visual impairments due to ocular discomfort (Barnes, 2016). Furthermore, stereoscopic viewing can cause discomfort due to the necessity for rapid vergence adaptation despite opposing accommodation cues (Hoffman *et al*., 2008; Lambooij *et al*., 2009).

Studies have revealed a notable influence of VR on accommodation and convergence (Mon-Williams et *al*., 1993; Kooi & Toet, 2004; Rebenitsch and Owen, 2016), resulting from a disruption in the coordinated action of these systems. Shiomi *et al.,* (2013) observed instances of misalignment between accommodation and convergence, leading to complaints of visual weariness after sustained VR immersion.

1.1.4 AMPLITUDE OF ACCOMMODATION

Accommodation refers to the eye's capacity to alter the refractive power of the lens for automatic focusing on objects at varying distances. It involves a intricate interplay of sensory, neuromuscular, and biophysical processes, leading to rapid shifts in the eye's overall refractive power for clear retinal imaging of objects at differing observation distances (Croft and Kaufman, 2006). The amplitude of accommodation (AOA) represents the range over which the eye can adjust its optical power to achieve sharp focus on objects (Gwiazda *et al.,* 1993).

Adequate AOA allows for effortless focus transitions between near and distant objects, facilitating activities such as reading, driving, and outdoor engagements. Sufficient AOA is crucial for precise accommodation, ensuring clarity and precision in object perception across various distances. Individuals with reduced AOA may face challenges in focusing on near objects, resulting in blurred vision, eye strain, and discomfort (Schor and Bharadwaj, 2006). The evaluation of AOA plays a significant role in diagnosing and managing vision conditions like presbyopia and accommodative insufficiency (Charman and Radhakrishnan, 2010).

The increased use of small display screen devices, such as smartphones, has been linked to higher levels of accommodation compared to traditional near-vision activities (Hoffman *et al.,* 2017). High-resolution displays with accurate focal distances and rapid refresh rates have been found to facilitate better AOA responses and reduce visual discomfort (Yifan *et al.,* 2022). VR systems frequently introduce a conflict between vergence and accommodation, as the eyes are required to converge at a different depth than the accommodative response. Prolonged exposure to vergence accommodative conflict can lead to a reduction in AOA and visual fatigue (Hoffman *et al.,* 2017). Individual differences also affect AOA responses to VR stimuli, with factors such as age, refractive error, and other visual characteristics influencing the extent of accommodation (Lee and Allen, 2020). Elderly individuals and those with certain visual impairments may have more difficulty accommodating to VR stimuli.

Adaptations of display techniques have been suggested as a means to reduce visual fatigue in VR. Dynamic depth-of-field rendering and other adaptive techniques have been proposed to address vergence accommodative conflict and optimize AOA responses in VR (Yifan *et al.,* 2022)

1.1.5 NEGATIVE RELATIVE ACCOMMODATION AND POSTIVE RELATIVE ACCOMMODATION

Negative relative accommodation (NRA) occurs when the eye focuses on a point closer to the observer than the current fixation point. This primarily involves adjustments in the crystalline lens shape and curvature, resulting in increased optical power to bring near objects into focus (Gilmartin, 2004). In contrast, positive relative accommodation (PRA) occurs when the eye focuses on a point further away from the observer than the current fixation point. This mechanism involves relaxation of the ciliary muscle and flattening of the crystalline lens to reduce optical power, allowing for clear vision of distant objects (Gilmartin, 2004). NRA and PRA are guided by complex interactions between the ciliary muscle, crystalline lens, and visual feedback mechanisms. Changes in the tension of the zonules, which are fibers that suspend the lens within the eye, influence the lens's shape and curvature, thereby altering optical power (Schor and Bharadwaj, 2006). NRA and PRA are fundamental for maintaining visual function across a range of viewing distances. NRA facilitates clear vision of nearby objects, enabling tasks such as reading, writing, and interacting with electronic devices (Charman & Radhakrishnan, 2010). Conversely, PRA allows individuals to focus on distant objects, which is essential for activities such as driving, outdoor navigation, and viewing panoramic scenes (Gilmartin, 2004).

NRA and PRA contribute to accommodative versatility, enabling the eye to quickly and accurately adjust its focus in response to changes in viewing distance. This adaptability is critical for tasks that require frequent focus shifts, such as reading a book with varying font sizes or switching between near and far objects in the environment (Gilmartin, 2004), making NRA and PRA essential for vision correction techniques like eyeglasses, contact lenses, and intraocular lenses. Presbyopia, a common age-related condition characterized by decreased accommodative ability, impacts NRA and PRA and can be addressed through various treatment options (Charman and Radhakrishnan, 2010).

Striking a balance between NRA and PRA is crucial for optimal visual comfort and efficiency. An appropriate allocation of relative accommodation allows individuals to perceive their visual environment comfortably and without unnecessary strain. Imbalances in NRA and PRA may lead to visual discomfort, eyestrain, and fatigue, especially during prolonged near work or extended periods of screen time (Charman and Radhakrishnan, 2010).

1.1.6 NEAR POINT OF CONVERGENCE

The Near Point of Convergence (NPC) represents the closest distance at which an individual can maintain single binocular vision while focusing on a near target. It serves as a fundamental measure of the eye's ability to converge precisely on close objects (Rouse and Borsting, 2015). Assessment of NPC plays a critical role in diagnosing binocular vision anomalies such as convergence insufficiency, convergence excess, and convergence spasm. Abnormal NPC values may indicate underlying oculomotor dysfunction or binocular vision disorders, necessitating further evaluation and intervention (Rouse and Borsting, 2015). This assessment guides the development of personalized vision therapy interventions aimed at enhancing oculomotor function and binocular vision. Vision therapy techniques such as vergence exercises, accommodative training, and visual-motor integration tasks target specific aspects of NPC and promote efficient binocular vision (Ciuffreda *et al.,* 2008).

Several factors can influence NPC measurements, including age, refractive error, convergence insufficiency, and neurological conditions like concussion or traumatic brain injury. Understanding these factors is vital for accurate interpretation of NPC measurements and appropriate management of underlying conditions (Rouse and Borsting, 2015).

Various methods are used to assess NPC, including the ruler method, penlight or accommodative target method, and automated instruments such as the RAF rule or synoptophore. Each technique has its advantages and limitations, and the choice of method depends on the specific clinical context and available resources (Rouse and Borsting, 2015).

1.1.7 NEGATIVE FUSIONAL VERGENCE AND POSITIVE FUSIONAL VERGENCE

Negative Fusional Vergence (NFV) describes the capacity of the eyes to diverge or move outward when a visual stimulus approaches the observer. It represents the maximum divergence achievable by the visual system to maintain synchronized binocular vision (Scheiman et *al*., 2007). This action is mediated by the divergence of the visual axes through the lateral rectus muscles. NFV is essential for clear vision when focusing on close objects and prevents double vision during convergence tasks (Scheiman *et al.,* 2007).

Positive Fusional Vergence (PFV) refers to the ability of the eyes to converge or move inward when a visual stimulus moves away from the observer. It is the maximum convergence achievable by the visual system to maintain synchronized binocular vision (Rouse and Borsting, 2015). This action is mediated by the convergence of the visual axes through the medial rectus muscles. PFV is crucial for clear vision when focusing on distant objects and is particularly important for activities requiring sustained convergence, such as reading or computer work (Rouse and Borsting, 2015).

NFV and PFV are critical for maintaining binocular alignment, ensuring that the visual axes converge or diverge appropriately for clear, single vision (Rouse and Borsting, 2015). They can be clinically assessed using techniques such as prism bar vergence testing, fusional vergence range, and stereoscopic tests like the Worth 4-Dot Test or Von Graefe Test. These assessments quantify the range and efficiency of fusional vergence, aiding in the diagnosis of binocular vision disorders (Scheiman *et al*., 2007).

NFV and PFV play vital roles in diagnosing and managing binocular vision disorders like convergence insufficiency, convergence excess, and divergence excess. Abnormal NFV and PFV measurements may indicate underlying oculomotor dysfunctions, requiring specific vision therapy interventions (Rouse and Borsting, 2015).

NFV and PFV measurements provide valuable insights into oculomotor function and vergence system efficiency. They serve as objective indicators of the eye's ability to converge or diverge in response to changing vergence demands (Cooper, 2012). Abnormal NFV and PFV measurements may indicate underlying binocular vision disorders like convergence insufficiency or divergence excess, making their assessment crucial for the diagnosis and management of these conditions (Rouse and Borsting, 2015)

1.2 STATEMENT OF STUDY

1. Further research is required to explore the short-term effects of VR on oculomotor function, mitigating any potential accommodative and vergence risks.
2. Knowledge gaps exist regarding the effects of virtual reality on oculomotor function in African populations.
3. Understanding the effects of virtual reality on oculomotor function is essential for optimizing management of clinical cases with a history of VR-HMD use, as well as for the design and implementation of VR technologies.

1.3 AIM AND OBJECTIVES

1.3.1 AIM OF THE STUDY

This study aims to determine the effect of virtual reality on oculomotor function.

1.3.2 OBJECTIVE OF THE STUDY

The specific objectives of this study are:

1. To determine the baseline accommodative and vergence function.
2. To determine the short term influence of virtual reality on the accommodative system.
3. To determine the short term influence of virtual reality on the vergence system.

1.4 HYPOTHESIS/RESEARCH QUESTIONS

Null Hypothesis (Ho): There is no statistical significant effect of virtual reality on oculomotor function.

Alternate Hypothesis (Ha): There is statistically significant effect of virtual reality on oculomotor function.

1.5 SIGNIFICANCE OF THE STUDY

1. The study will help to understand how Virtual Reality affects oculomotor function.

2. The study can help identify any implicit pitfalls or benefits associated with its operation. Virtual Reality frequently involve immersive surroundings, which can stimulate the visual system and demand the eyes to swiftly acclimate and move.

3. Research in this area can be linked to multiple fields, including healthcare, gaming, sports, and entertainment.

4. This study can potentially be used to design VR experiences that minimize negative result on eye health.

1.6 DEFINITION OF TERMS

The significant terms used in this research are essential to ensuring understanding throughout the course of the study. The terms related to this study are defined below:

- Virtual reality: Virtual reality (VR) can be defined as a computer- generated simulation of an experience or environment that fully immerses the user in a three-dimensional and interactive experience (Bicocca and Levy, 1995). This technology creates a sense of presence and absorption by stimulating sensory environment, allowing users to perceive and interact with virtual objects or surroundings as if they were real.

- Head-mounted display: A head-mounted display (HMD) is a device worn on the head that incorporates a small display screen or screens placed in front of the user’s eyes to produce a virtual reality (VR) or augmented reality (AR) experience. HMDs generally comprise of a display unit, lenses to focus the images, and a tracking system to follow the user’s head movements and change the displayed images consequently (Azuma, 1997). This system can be tethered to a computer or mobile device for processing and content delivery, or it can be standalone, incorporating all necessary components internally.
- Oculomotor function: Oculomotor function involves complex neural pathways and feedback mechanisms to insure precise control and coordination of eye movements. Dysfunction in oculomotor function can lead to several visual impairments, including hypermetropia (misalignment of the eyes), nystagmus (involuntary eye movements), and impaired gaze stability (Leigh and Zee, 2015).
- Accommodation: Accommodation refers to the capability of the eye to adapt its focus in order to maintain clear vision at different distances. This adaptation is primarily achieved through changes in the shape of the crystalline lens, which alters its refractive power to bring objects into sharp focus on the retina (Atchison and Smith, 2000).
- Accommodation measurements: Accommodation measurements describe the several ways and assessments used to estimate the accommodative function of the eye, including its amplitude, accuracy, and responsiveness to techniques. These measures can be performed using different procedures usually routine, such as subjective refraction, dynamic retinoscopy, and accommodative lag assessments (Croft & Kaufman, 2006). Objective techniques, which include autorefractors and aberrometers, give quantitative data on accommodative parameters, while

subjective tests like the push-up and push-down amplitude of accommodation tests depend on the patient's response to assess accommodation.

- Vergence: Vergence refers to the coordinated movement of the eyes in different directions to maintain single binocular vision and depth perception. Convergence involves inward movement of the eyes to concentrate on near objects, while divergence entails outward movemet to concentrate on distant objects (Leigh and Zee, 2015).
- Vergence measurements: Vergence measurements relate to the several ways used to assess the binocular alignment and coordination of the eyes, particularly in terms of convergence and divergence eye movements. These measurementss help estimate the effectiveness and accuracy of the vergence system in maintaining single binocular vision and depth perception. Objective techniques include prism cover tests, which assess the deviation of each eye relative to the primary position of gaze, and tracking systems (objective) which quantify the vergence movements during visual tasks (Jaschinski and Groner, 2020). , and subjective test like the near point of convergence and the fusional vergence ranges, give information on the capability of the eyes to converge or diverge to maintain binocular alignment.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.1 INVESTIGATION OF VIRTUAL REALITY EFFECTS ON AMPLITUDE OF ACCOMMODATION

A study by Long *et al.,* (2020) assessed the impact of consumer-grade virtual reality headsets on the visual performance of adults. Forty participants (mean age: 28.6 years) engaged in 10-minute VR sessions twice daily for two weeks. Their results indicated a significant increase in the amplitude of accommodation by 0.53, while other factors like visual acuity, refractive error, and pupil diameter remained unaffected. The researchers concluded that while the VR headset improved the amplitude of accommodation of the adults studied, it did not impact overall visual acuity or refractive error.

Turnbull *et al.,* (2017) conducted a study to investigate the binocular function of young adults following virtual reality headset usage. Nineteen participants aged 18–35 years experienced real and virtual environments in various conditions. Their analysis revealed no substantial variations in binocular status, including distance and near focus, gaze stability, amplitude of accommodation, and stereopsis, across the four environments tested. The authors deduced that the VR device did not adversely affect the binocular function in the short term.

Yoon *et al*., (2021) conducted a randomized controlled trial to determine the effects of prolonged virtual reality smartphone-based head-mounted display (VR SHMD) usage on visual parameters. 58 participants underwent VR SHMD or smartphone use for 2 hours, with significant changes observed in near-point convergence, accommodation, exophoric deviation, stereopsis, and accommodative lag after VR SHMD use but not after smartphone use. They also noted that participants with lesser accommodation and convergence ability exhibited reduced susceptibility to changes in these parameters, and those with larger exophoria were more likely to experience worsening exophoria.

Lin *et al.,* (2022) conducted a study to assess the changes in intraocular pressure and visual parameters before and after using mobile virtual reality glasses. 50 participants with refractive errors ranging from 0 D to -5.00 D wore +3.00 D glasses and underwent a 5-minute relaxation adjustment. The participants then used VR glasses to watch a movie for 10 minutes. The study found no significant changes in near-horizontal vergence or refractive error after VR use but observed a significant reduction in the amplitude of accommodation, intraocular pressure, divergence/convergence, and stereopsis.

2.1.2 INVESTIGATION OF VIRTUAL REALITY EFFECTS ON NEAR POINT OF CONVERGENCE

A study by Boon *et al.* (2021) examined the use of virtual reality and anaglyph-based training programs to address convergence insufficiency. Two interventions, anaglyphs and a virtual reality game of Snakes, were assessed for their efficacy in treating adults with convergence insufficiency. The training regimen included 20-minute sessions three times per week for six weeks. Visual assessments were conducted before and after the treatment period. Of the 18 participants with convergence insufficiency, nine were randomly assigned to each intervention. Statistical analyses indicated a significant change in near point of convergence, near positive fusional reserves break and recovery over time, but no significant differences between the two interventions.

In a separate study by Li *et al.* (2022), virtual reality-based vision therapy was compared to office-based vergence/accommodative therapy in the treatment of convergence insufficiency and accommodative dysfunction. Thirty-three patients with convergence insufficiency and 30 with accommodative dysfunction were randomly assigned to either virtual reality-based vision therapy or office-based vergence/accommodative therapy. Both groups received therapy for 12 weeks, with weekly one-hour sessions. After 12 weeks of treatment, both groups showed significant improvements in Convergence Insufficiency Symptom Survey scores, near point of convergence, positive fusional vergence, and near horizontal phoria. Additionally, both groups experienced improvements in monocular accommodative amplitude and facility. While significant differences were observed in monocular accommodative facility between the groups, no such differences were noted in other vergence and accommodative functions.

2..1.3 INVESTIGATION OF VIRTUAL REALITY EFFECTS ON OCULOMOTOR FUNCTION

Research conducted by Alhassan *et al.,* (2021) assessed the impact of virtual reality on eye movement functions after playing 3D video games using a VR-HMD system for 45 minutes. Twenty-six young adults (aged 19-27) with normal binocular vision participated. Various accommodative and vergence measurements were recorded before and after gaming. Additionally, visual and non-visual symptoms were assessed using the Simulator Sickness Questionnaire. Results indicated significant alterations in accommodative parameters, including negative relative accommodation, accommodative accuracy, and monocular and binocular accommodative facilities. Vergence system measurements also exhibited notable changes, primarily affecting horizontal negative fusional vergence range at near and vergence facility test outcomes. A significant increase in various symptoms (visual and nonvisual) was also observed post-gaming. It was concluded that playing 3D video games using VR-HMD systems can lead to impairments in specific oculomotor functions (accommodative and vergence systems) and can cause eye strain and discomfort after just 45 minutes of play.

Morse and Jiang, (1999) conducted a study to differentiate the oculomotor responses of symptomatic and asymptomatic individuals after virtual reality use. They measured phorias, fixation disparity, gradient accommodative convergence to accommodation ratio (AC/A), stereopsis, and near point of convergence before and after 20 minutes of biocular VR-HMD use. A near point exophoric shift was observed in most subjects, while farpoint phoria remained unchanged. Notably, the phoric shift at far and near was strongly correlated for asymptomatic subjects but not for symptomatic subjects. Additionally, the (stimulus) AC/A ratio decreased in symptomatic subjects post-VR use, while it remained stable in asymptomatic subjects. Based on these findings, it was concluded that oculomotor changes in symptomatic subjects (increased near exophoria and reduced AC/A) suggest a reduced accommodative response. In contrast, asymptomatic subjects showed changes (correlated changes in phorias) that align with potential adaptations in the tonic component of vergence and/or accommodation.

Ha *et al.,* (2016) evaluated the impact of virtual reality (VR) headsets on oculomotor functions and refractive errors in teenagers. Sixty subjects (ages 13-18) viewed a 3D film and a VR app for 30 minutes using VR headsets. Refractive error, convergence angle, near accommodation point, and stereopsis were assessed pre-use, post-use, and 10 minutes later. Refractive error was recorded as spherical equivalent (SE). Myopic shifts greater than 0.15 D were noted every 10 minutes after use. Results showed no significant alterations in SE, near accommodation point, or stereopsis in either eye following 30 minutes of VR headset use. An esophoric shift was observed immediately post-use, but it was not statistically significant. Transient myopic shifts ranged from 17.2% to 30% immediately post-use in both groups but fully recovered within 40 minutes. The study concluded that 30 minutes of VR headset use did not have clinically meaningful effects on the eyes of healthy adolescents. While temporary changes in refractive error and binocular alignment were observed, they were not substantial.

Szpak *et al.,* (2020) examined the post-effects of VR exergaming using Beat Saber. Thirty-six participants played Beat Saber with an HMD in a within-subject design. Changes in vision, cognition, and well-being were evaluated after brief (10 min) and prolonged (50 min) VR exposure. Accommodation, convergence, decision speed, movement speed, and self-reported discomfort were measured at three intervals: pre-VR, immediately post-VR, and 40 minutes post-VR (late). Results indicated that Beat Saber was generally well-tolerated, with no withdrawals due to discomfort. For most participants, immediate post-effects were transient and returned to baseline within 40 minutes post-VR. Both short and long exposures induced changes in accommodation and convergence; however, participants returned to baseline levels during the late test phase. Cognitive measures were not affected. Simulator sickness questionnaire (SSQ) scores elevated after VR exposure and were higher for long compared to short exposures, but no differences were found between exposure durations during the late test period, with scores returning to baseline levels. While group-level discomfort levels returned to baseline within 40 minutes post-VR, approximately 14% of participants reported persistent high discomfort levels during the late test period after playing 50 minutes of Beat Saber. The study concluded that while there was no compelling evidence for adverse effects 40 minutes after VR exposure at a group level, some individuals remained with high levels of VR discomfort at this point. It is suggested that users allow for a waiting period after VR use to ensure any post-effects have diminished. HMD-based exergames offer potential for exercise promotion but require further research, and the post-effects of exergaming should be closely monitored to maximize their potential.

Banstola *et al*., (2022) investigated visual changes after virtual reality gameplay. Participants played "Beat Saber" for 15 minutes, showing decreased convergence range and improved accommodation flexibility. Fusion and convergence abilities were temporarily affected, but accommodation and divergence functions improved. The study highlights the need for long-term monitoring and research in healthy individuals.

Kozulin *et al.,* (2009) studied the impact of a head-mounted display on children's oculomotor systems. After 30 minutes of viewing virtual imagery, symptoms such as tiredness and eye strain increased but subsided within 10 minutes. Viewing for 80 minutes led to more persistent symptoms. Near vision temporarily worsened after both 30 and 80 minutes of viewing. The study suggests that head-mounted displays have minor additional negative effects compared to conventional screens and are comfortable for extended use.

Elias *et al.,* (2019) examined the effects of VR gaming on young adults. After 30 minutes of play, participants experienced increased accommodation (focusing) and decreased convergence (eye alignment). Visual symptoms such as nausea and dizziness were reported. VR immersion led to an imbalance between accommodation and convergence, with subjects tending to overfocus and shift towards exophoria (outward eye deviation). The study demonstrates that VR gaming can affect visual functions and cause discomfort.

Tychen and Foeller, (2019) explored how using an immersive virtual reality (VR) headset impacts the visuo-motor coordination, balance, and motion-induced discomfort in early childhood. They examined 50 children between 4 and 10 years old using a Sony PlayStation VR headset and a three-dimensional flying game. The children participated in two 30-minute VR play sessions, and their visual motor skills were measured prior to and after each session. The findings indicated that VR exposure did not lead to notable alterations in binocular vision clarity, refractive errors, eye coordination, or depth perception. However, there was a slight decline in balance and an increase in reports of eye and head/neck discomfort, exhaustion, and motion sickness after VR use. The majority of children tolerated VR play well, with only a small number discontinuing due to minor discomfort or loss of interest. The study suggests that young children can engage in immersive VR gameplay without substantial consequences for visuo-motor skills, balance, or vestibular-ocular reflex adaptation.

Yoon *et al.,* (2020) examined the effects of virtual reality (VR) on ocular parameters, contrasting immersive and non-immersive play modes. They enrolled 23 visually healthy volunteers with normal vision. Participants engaged in VR games for 30 minutes under both immersive and non-immersive conditions. Eye function was evaluated before and after VR use. Findings revealed no changes in refractive error with either VR mode, but both near point of accommodation (NPA) and near point of convergence (NPC) exhibited notable increases after the immersive mode. Conversely, the non-immersive mode produced no alterations in refraction or accommodation. Immersive mode, however, led to significant increases in NPA, NPC, and subjective symptom ratings. Correlation analysis uncovered a positive relationship between baseline near exophoria and mean accommodative lag in the dominant eye, along with a negative correlation between NPA and mean accommodative lag in the non-dominant eye. This study implies that VR usage, particularly in its immersive form, may impact NPA and NPC, warranting caution among users possessing certain visual traits.

2.1.4 INVESTIGATIONS INTO VIRTUAL REALITY EFFECTS ON VISUAL COMFORT

Zeri and Livi, (2015) embarked on a research endeavor to examine the spectrum of discomfort symptoms associated with Stereoscopic three-dimensional (S3D) cinematic viewing experiences.

Their objective was to ascertain the prevalence and nature of visual discomfort during S3D movie viewing and compare it to its 2D counterpart. Post-screening surveys were disseminated among 854 cinema attendees who had recently viewed either S3D or 2D films. The study identified two primary categories of factors underlying these symptoms: External Symptoms Factors (ESF), encompassing symptoms like eye irritation, strain, and tearing, and Internal Symptoms Factors (ISF), which include symptoms such as blur, double vision, and dizziness. Their analysis revealed that external symptoms were considerably more prevalent than internal symptoms, with females reporting more pronounced symptoms and nearsighted individuals experiencing higher ISF scores than farsighted individuals. Contrastingly, newer movies elicited lower ESF scores compared to older movies, and the duration of wearing S3D glasses was inversely related to the severity of symptoms. Notably, symptoms were markedly more pronounced for S3D compared to 2D movies. In summary, the study concluded that S3D movie viewers experienced higher levels of external symptoms and discomfort compared to internal symptoms, and S3D viewing induced more symptoms than 2D viewing.

LaViola Jr. (2000) explored the subject of cybersickness in virtual environments (VEs), emphasizing its significance as a significant hurdle. Cybersickness, akin to traditional motion sickness, manifests in users during or after VE experiences, despite their stationary position, due to the perception of self-motion induced by moving visual imagery. The paper examined the diverse factors that contribute to cybersickness, presents conflicting theories regarding its cause, and suggests pragmatic strategies for alleviating this issue within VEs.

Pölönen *et al.,* (2012) investigated the viewing comfort of both children and adults during stereoscopic three-dimensional (3D) film viewing and computer game playing. They observed subtle changes in visual function, such as heterophoria and near point of accommodation values, along with levels of eyestrain and visually induced motion sickness. Their study demonstrated that the viewing system influenced overall viewing comfort, particularly in terms of eyestrain levels, but they found no significant difference between two- and three-dimensional systems. Additionally, they noted some slight variations in visual functions and visually induced motion sickness levels between adults and children. Despite these findings, subjective opinions generally supported the idea that using a stereoscopic 3D system for up to 2 hours was generally acceptable for most users, regardless of age.

Tam *et al*., (2011) examined the critical topic of visual comfort in the context of three-dimensional television (3D-TV). They underscored the importance of addressing the visual discomfort experienced by some viewers when watching stereoscopic displays to prevent hindering the widespread adoption of 3D-TV technology. The paper offers a concise overview of key factors affecting visual comfort and is valuable for various stakeholders such as end users, content creators, broadcasters, display manufacturers, and researchers involved in the development and deployment of 3D-TV systems.

Lee *et al.,* (2010) conducted a study to address the issue of eyestrain induced by 3D displays, which had become a major concern without previous objective research comparing it to 2D displays. The researchers quantitatively compared eyestrain by measuring blink frequency using a near-infrared pupil detection device, with greater blink frequency indicating higher levels of eyestrain. Their study employed three innovative approaches: quantitatively comparing eyestrain from 2D and 3D displays, analyzing the significance of display type and viewing distance, and correlating objective blink frequency results with subjective survey results. Results from the design analysis revealed that eyestrain was more severe when watching 3D displays, particularly at closer viewing distances. The study demonstrated a strong correlation between quantitative blink frequency results and subjective assessments from a questionnaire survey, suggesting the reliability of blink frequency as a measure of eyestrain. Additionally, the developed pupil tracking device and blink-rate-based measurement could be seamlessly integrated into market-ready glasses-based 3D display systems.

2.2 GAPS IN LITERATURE

Notwithstanding the expanding body of knowledge regarding virtual reality's (VR) implications for oculomotor function, several questions linger.

Firstly, the long-term consequences of VR on oculomotor function remain relatively unexplored. To grasp the full extent of VR's protracted effects, an upsurge in longitudinal investigations is warranted. The majority of current research on VR and oculomotor function entails cross-sectional or brief experimental designs. Longitudinal studies that chart oculomotor alterations over time are crucial for gaining` insights into the cumulative effects of VR engagement among various populations.

Secondly, the specific nature of VR content may exert an influence on oculomotor function. Research endeavors could delve into how divergent genres of VR content—encompassing gaming, educational simulations, entertainment, and therapeutic applications—impact oculomotor performance.

Thirdly, individual variations merit exploration; oculomotor responses to VR might be modulated by factors such as age, gender, race, pre-existing ophthalmic conditions, and the extent of VR experience.

In essence, research is needed to elucidate the effects of 3D VR films on a specific age group within the African population with no prior VR exposure. Parameters such as variations in ocular anatomy, binocular vision, and visual processing mechanisms could shape how individuals from different racial or ethnic backgrounds experience and acclimate to VR environments. Bridging these research gaps will expand our understanding of VR's impact on oculomotor function and inform the formulation of guidelines for its judicious and efficacious utilization.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 RESEARCH DESIGN

This study was an observatory cross sectional study. This research design is advantageous for exploratory analyses and provides a valuable approach which is an efficient and cost-effective insight into understanding the relationship between virtual reality and oculomotor function in a diverse population.

3.2 RESEARCH LOCATION

This study was conducted at the Department of Optometry Teaching clinic, University of Benin, Benin City, Edo State. This location was selected for it's feasibility and accessibility to a diverse population, state-of-the-art equipment, facilities, and resources that are essential for conducting the research.

3.3 STUDY POPULATION

The study population was made up of young adults age 18 – 29 years who meet the inclusion criteria.

3.4 SAMPLING TECHNIQUE/SAMPLE SIZE DETERMINATION

3.4.1 SAMPLING TECHNIQUE

A convenience sampling technique was used for this study to recruit participants easily from the university of Benin who met the inclusion criteria.

3.4.2 SAMPLE SIZE

The sample size was:

n = 29 (Alhassan et *al*., 2021).

Alhassan et *al*., conducted an experimental study on 26 subjects but a sample size of n=29 was used for this study.

3.5 RESEARCH MATERIALS

- Snellen visual acuity chart: A Snellen visual acuity chart is a standardized chart which was used to measure visual acuity, It consists of several lines of letters, with each line progressively smaller than the previous one. The chart was placed at a specific distance from the patient (6 meters).
- 3D VR Shinecon 6.0: The VR Shinecon which was used for this research is a virtual reality (VR) headset designed for use with smartphones. It typically consists of a headset with adjustable straps to secure it to the user's head, lenses to view content in 3D, and compartments to hold a smartphone. Users can download VR apps or videos onto their smartphones and then insert the device into the headset to experience immersive virtual reality content. The 3D aspect is achieved through the lenses, which separate the image into two slightly different perspectives, one for each eye, creating a stereoscopic effect.
- Ocluder: An occluder was used specifically to cover or block vision in one eye.
- Ruler: A ruler was used to measure lengths accurately.
- N notation card: This cards was used to measure near vision acuity. The N notation represents the size of the letters on the card.
- Phoropter: The spherical lens system was used during the measurements to determine the NRA and PRA. The rotary prisms were used for the smooth Negative and Positive Fusional vergence measurements.

- Accommodative target: An accommodative target was used to provide visual stimulus during the measurements to assess the focusing ability of the eyes.. This target consisted of a detailed letter placed at a specific distance from the patient.
- Data recording tools: Data recording instruments and software used to collect, store, and organize data systematically were used. These tools come in various forms, ranging from traditional pen-and-paper methods to sophisticated computer software.

3.6 INCLUSION/EXCLUSION CRITERIA

The Inclusion and exclusion criteria determined for this research study design which helped ensure the recruitment of appropriate participants and the validity of research findings.

3.6.1 INCLUSION CRITERIA

1. Healthy adult participants aged 18- 29 years.
2. Individuals with normal or corrected visual acuity of 6/6 in each eye.
3. Individuals with normal or corrected visual acuity of N5 in each eye.
4. Individuals who have normal binocular vision.
5. Participants who do not have any known ocular or neurological disorders that may affect oculomotor function.
6. Participants who are able to provide informed consent and comply with study procedures.
7. Individuals who have no history of prior exposure to virtual reality environment.
8. Participants who are willing and able to participate in the required experimental sessions.

3.6.2 EXCLUSION CRITERIA

1. Individuals who have a history of any visual impairments or ophthalmological disorders that may affect ocular function such as strabismus and presbyopia.

2. Participants with a history of any neurological disorders or conditions that may affect oculomotor function, such as cranial nerve palsies, multiple sclerosis, or stroke.
3. Participants who are currently receiving active treatment for any ocular or neurological conditions.
4. Individuals who have a known history of motion sickness or severe vertigo when exposed to virtual reality environments.
5. Subjects who are unable to provide informed consent, such as minors or individuals with cognitive or communication impairments.
6. Participants who have previously participated in studies investigating the effect of virtual reality on oculomotor function.
7. Individuals who are pregnant or breastfeeding due to severe motion sickness or vertigo which may be experienced when exposed to virtual reality environments.
8. Subjects with any uncontrolled medical conditions or significant systemic diseases that may affect ocular functioning, such as uncontrolled diabetes or hypertension.

3.7 DESCRIPTION OF PROCEDURE

After informed consent was gotten from the participants, the study commenced.

The participants were informed of the study and the procedures to be carried out were duly explained.

This study consisted of four stages:

PRELIMINARY MEASUREMENTS

In this stage different visual functions, including monocular visual acuity at distance and near was assessed using the Snellen visual acuity chart and N notation chart. A cover test for determining the presence or absence of strabismus at both distance and near was examined to determine whether participants met the criterion for inclusion (normal binocular vision) in this study.

1. Monocular Visual Acuity at distance (Carlson & Kurtz, 2016).
    - The testing environment was well-lit and free from distractions, with the Snellen chart at a distance of 20 feet (6 meters) from the participant.
    - The participant used their habitual correction for distance vision, this was set up in the phoropter.
    - The participant was informed that they will be asked to read letters on the chart with one eye covered at a time.
    - The participants left eye was occluded with the phoropter while keeping the right eye open.
    - The participant read aloud the letters on the top row of the chart to the smallest line of letters the participant could read accurately. Mistakes if any were noted..
    - The process was repeated for the left eye, occluding the right eye this time.
    - The visual acuity measurements for each eye was recorded separately. Visual acuity is typically recorded as a fraction, with the numerator representing the testing distance (20 feet or 6 meters) and the denominator representing the smallest line read correctly.

    Participants with a visual acuity of 6/6 or better were included and participants with less were excluded.

2. Monocular Visual Acuity at Near (Carlson & Kurtz, 2016).

    - The testing area was well lit with adequate illumination, the near card was highly illuminated from above to avoid glare. The participant was seated comfortably at the appropriate testing distance(40 centimeters) for near vision testing.
    - The participant was informed that they would be asked to read letters from a chart at close range.
    - The participant's left eye was occluded with the phoropter while keeping the right eye open.
    - The near visual acuity chart was presented to the patient at the designated distance (0.4 meters). The chart was held or positioned securely and at the correct angle for optimal viewing.
    - Starting from the top of the chart, The participant was asked to read the N5 line of characters aloud.
    - The process was repeated for the left eye, occluding the right eye this time.
    - The visual acuity measurements for each eye at near was recorded separately.

    Participants with a visual acuity of N5 or better were included and participants with less were excluded.

3. Cover test at Distance (Carlson & Kurtz, 2016).

    - The examination room had the standard lighting and the participant was seated comfortably at a distance of approximately 6 meters (20 feet) from a visual target.
    - The cover test procedure was explained to the participant, informing them that they would be asked to focus on the target while their eyes are alternately covered with an occluder.

- With the participant sitting comfortably and facing the target directly with both eyes opened a hand-held occluder was used to cover one eye at a time during the test.
- While the participant fixated on the target, the uncovered right eye was watched for any movement paying attention to any movement of the uncovered eye, such as a shift in gaze or the appearance of a manifest deviation.
- After a few seconds of observation, the occluder was quickly removed from the covered eye and the uncovered eye is observe any movement or adjustment..
- The procedure was repeated for the participants other eye by covering the previously tested eye and observing the uncovered eye's response.
- The results of the cover test was documented including any observed deviations or phorias.

Participants with Orthophoria were included and participants with deviations were excluded.

4. Cover test at Near (Carlson & Kurtz, 2016).

- The examination room had the standard lighting and the participant was seated comfortably at a near distance of approximately 0.4M from an accommodative target.
- The cover test procedure was explained to the participant informing them that they will be asked to focus on the near target while their eyes are alternately covered with an occluder.

- With the participant sitted comfortably and facing the near target directly with both eyes open a hand-held occluder was used to cover one eye at a time during the test
- Starting with the left eye covered by placing the occluder over it. The participant was instructed keep looking at the near target with the uncovered eye.
- While the participant fixated on the near target with the uncovered eye, the uncovered eye was observed for any movement. Paying attention to any movement of the uncovered eye, such as a shift in gaze or the appearance of a manifest deviation.
- After a few seconds of observation, the occluder was quickly removed from the covered eye and the uncovered eye observed for any movement or adjustment.
- The procedure was repeated for the participant's left eye by occluding the previously tested eye and observing the uncovered eye's response.

Participants with Orthophoria were included and participants with deviations are excluded.

PRE-VIRTUAL REALITY CLINICAL MEASUREMENTS

Next, baseline clinical measurements of both the accommodation and vergence systems were collected. Clinical parameters linked to the accommodation system that are of interest in this study include the amplitude of accommodation(AOA); assessed using the minus lens to blur method, negative relative accommodation (NRA) and positive relative accommodation (PRA). Meanwhile, clinical parameters linked to the vergence system that are of interest in this study include the near point of convergence (NPC); assessed using accommodative targeting, the horizontal negative fusional vergence (NFV) and positive fusional vergences (PFV) ranges at near, assessed using Risley prisms.

1. Amplitude of Accommodation (Carlson & Kurtz, 2016).

- The examination room had the standard lighting and the participant was seated comfortably at a near distance of approximately 0.4M from a near target which was adequately illuminated with good contrast between the object being viewed and its background.
- The AOA test procedure is explained to the participant informing them that they would be asked to focus on the near target while they reported the first sustained blur point.
- The participant used their habitual correction for distance vision, this was set up in the phoropter.
- The participant's left eye was occluded with the phoropter while keeping the right eye open.
- With the participant looking at the near target minus lenses were added -0.25D at a time, allowing 5 to 10 secs to clear the letters until the participant reported first sustained blur. This signified the ended point of the test.
- The amount of minus lens added during the test plus 2.50D (accommodative demand at 0.4M) is the total Amplitude of Accommodation.
- The procedure was repeated for the participant's left eye after occluding the previously tested right eye.

2. Negative Relative Accommodation (Carlson & Kurtz, 2016).

- The examination room had the standard lighting and the participant was seated comfortably at a near distance of approximately 0.4M from a near target with was adequately illuminated.
- The NRA test procedure was explained to the participant informing them that they will be asked to focus on the near target while they report the first sustained blur point.
- The participant used their habitual correction for vision, this was set up in the phoropter.
- The participant was fixated on the near target as plus lenses were introduced to both eyes simultaneously. The power of the plus lenses was increased in +0.25DS steps, allowing for 5-10 seconds to clear the lens, until the participant reported that the target becomes noticeably blurred.
- The lens power at which the participant first reported blur is recorded. This represents the endpoint of Positive Relative Accommodation.
- The plus lenses were gradually removed in +0.25DS steps.

3. Positive Relative Accommodation (Carlson & Kurtz, 2016).
    - The examination room had the standard lighting and the participant was seated comfortably at a near distance of approximately 0.4M from a near target which was adequately illuminated.
    - The PRA test procedure was explained to the participant informing them that they would be asked to focus on the near target while they reported the first sustained blur point.

- The participant used their habitual correction for vision, this was set up in the phoropter.
- Minus lenses were gradually introduced in front of both eyes in -0.25DS steps, allowing for 5-10 seconds to clear the lens while the participant fixated on the near target. The power of the minus lenses were increased until the participant first reported blur.
- The lens power at which the participant first reported blur is recorded. This represents the endpoint of Positive Relative Accommodation.
- The minus lenses were gradually removed in -0.25DS steps.

4. Near point of Convergence (Carlson & Kurtz, 2016).
    - The examination room had the standard lighting and the participant was seated comfortably at a near distance of approximately 0.4M from a accommodative target which was adequately illuminated.
    - The NPC test procedure was explained to the participant informing them that they will be asked to focus on the accommodative target while they signify when the target doubles and fusion is restored(when the diplopia clears).
    - The participant used their habitual correction for distance vision.
    - The participant is instructed to focus on the accommodative target which was slowly moved closer to the participant's eyes along the midline of their body, maintaining the target at the same height as the participant's eyes.
    - The target was slowly moved closer to the participant eyes along the midline of their body, maintaining the target at the same height as the participant's eyes.

- The target was stopped as soon as the participant exhibited a deviation in eye alignment, loss of fusion, or reports double vision. This point represented the break point of NPC and the distance was measured with a ruler and recorded.
- The target was slowly moved away from the participant's eyes along the midline of their body, maintaining the target at the same height as the participant's eyes.
- The target was stopped as soon as the participant reported fusion of the target. This point represented the recovery point of NPC and the distance was measured with a ruler and recorded.

5. Negative Fusional Vergence at near (Carlson & Kurtz 2016).

- The examination room had the standard lighting and the participant was seated comfortably at a near distance of approximately 0.4M from a accommodative target which was adequately illuminated.
- The NFV test procedure was explained to the participant informing them that they would be asked to focus on the accommodative target while they signify when the target blurs, doubles and is restored(when the diplopia clears).
- The participant used their habitual correction for vision, this was set up in the phoropter.
- The participant was instructed to focus on the near target.
- Base in prism was introduced slowly in the right eye to move the target outward.
- As the target moved outward the participant reported when the target blurred and doubled. The base in prism was increased by 5 prism diopters after break then gradually reduced until the participant reported fusion being restored.
- The blur, break and recovery points were recorded.

6. Positive Fusional Vergence at near (Carlson & Kurtz, 2016).
    - The examination room had the standard lighting and the participant was seated comfortably at a near distance of approximately 0.4M from an accommodative target which is adequately illuminated.
    - The PFV test procedure was explained to the participant informing them that they would be asked to focus on the accommodative target while they signify when the target blurs, doubles and is restored(when the diplopia clears).
    - The participant used their habitual correction for distance vision, this was set up in the phoropter.
    - The participant was instructed to focus on the near target.
    - Base out prism was introduced slowly in the right eye to move the target outward.
    - As the target moves inward the participant reported when the target blurred and doubled. The base out prism was increased by 5 prism diopters after break then gradually reduced until the participant reported fusion being restored.
    - The blur, break and recovery points were recorded.

3D VIRTUAL REALITY MOVIE WATCH

In this stage all participants watched a commercially available 3D movie using the 3D VR Shinecon 6.0 standard edition headset helmet. Participants were asked to spend 45 minutes watching this movie which placed different accommodative and vergence demands on their eyes.

POST-VIRTUAL REALITY CLINICAL MESUREMENTS

In the final stage right after the movie session was over, the clinical measurements of parameters relating to the accommodation and vergence systems were re-measured to allow for differences between before and after the VR experience to be revealed. All measurements were recorded after participants' VR movie and collected within 20 minutes of the end of their watching time.

3.8 DATA ANALYSIS

The Baseline clinical accommodative and vergence measurements were analyzed using the One-Sample t test. The Paired-Samples t test was used to compare the baseline measurements of median values of accommodative parameters and vergence parameters with those recorded after the virtual reality movie. The analysis was carried out using the IBM SPSS version 22 software program (IBM Corporation, Armonk, NY, USA)

3.9 ETHICAL CONSIDERATIONS

- Ethical approval was obtained from the Department of Research and Ethic Committee of the Department of Optometry, University of Benin in accordance with the tenets of the declaration of Helsinki.
- Informed consent was obtained from each of the participants and only consenting participants were recruited for the study.
- A letter of approval was obtained from the Director of clinics to gain access to the clinic rooms and clinic materials to carry out the study.

3.10 LIMITATIONS OF THE STUDY

- The study utilized convenience sampling, which may introduce bias which may limit generalizability to a broader population.
- The small sample size can limit the generalizability of findings to a broader population.
- Variables not accounted for in the study design may influence the relationship between the independent and dependent variables, leading to inaccurate conclusion.
- The objective nature of recording some measurements may introduce researcher bias and could affect the reliability of the data collected.
- The subjective nature of recording some measurements may introduce individual participant bias and could affect the reliability of the data collected.

CHAPTER FOUR

4.0 RESULTS

Table 4.1: Sociodemographics of Participants.

Variable	**Frequency**	**Percent**
Gender		
Male	14	48.3
Female	15	51.7
Total	29	100
Age (24.41 ± 1.918)		
21-23	10	34.5
24-26	14	48.3
27-29	5	17.2
Total	29	100

There were 14 males and 15 females in the study, representing 48.3% and 51.7% respectively, making a total of 29 participants in this study. Participants age 21-23 were the majority (48.3%). 34.5% were age 21-23. 17.2% were age 27-29.

Table 4.2: Descriptive Statistics of Baseline Accommodative clinical measures.

Variable	**Mean ± SD**
Amplitude of Accommodation	
Right Eye	10.0000 ± 1.62019
Left Eye	9.59138 ± 1.73298
Negative Relative Accommodation	3.0948 ± 0.76009
Positive Relative Accommodation	-3.5690 ± 1.16668

The baseline Amplitude of Accommodation in the study population was 10.000 ± 1.62019 diopter (D) and 9.59138 ± 1.73298 diopter (D) for the right and left eye respectively.

The baseline Negative Relative Accommodation in the study population was 3.0948 ± 0.76009 diopter (D).

The baseline Positive Relative Accommodation in the study population was -3.5690 ± 1.16668 diopter (D).

Table 4.3: Descriptive Statistics of Baseline Vergence clinical.

Variable	**Mean ± SD**
Near Point of Convergence	
Break	
Recovery	9.1724 ± 2.73951
	12.2069 ± 2.71740
Negative Fusional Vergence	
Break	
Recovery	22.5517 ± 7.12935
	12.3103 ± 5.42549
Positive Fusional Vergence	
Break	23.9655 ± 6.26488
Recovery	15.6897± 5.16239

The baseline Near Point of Convergence in the study population was 9.1724 ± 2.73951 prism diopter (break component) and 12.2069 ± 2.71740 prism diopter (recovery component).

The baseline Negative Fusional Vergence in the study population was 22.5517 ± 7.12935 prism diopter (break component) and 12.3103 ± 5.42549 prism diopter (recovery component).

The baseline Positive Fusional Vergence in the study population was 23.9655 ± 6.26488 prism diopter (break component) and 15.6897 ± 5.16239 prism diopter (recovery component).

Table 4.4: Mean Difference of Accommodative findings in Participants Before and After Virtual Reality.

Variable	**Mean**	**SD**	**t**	**df**	***p*-value**
Amplitude of Accommodation					
Right Eye	0.49655	0.87769	3.047	28	0.005**
Left Eye	0.26379	1.08009	1.315	28	0.199
Negative Relative Accommodation	0.23276	0.68116	1.840	28	0.076
Positive Relative Accommodation	-0.06897	1.04347	-0.356	28	0.725

***: Statistically significant; VR HMD: Virtual Reality Head Mounted Device.*

From the findings of this study there is significant difference in the Amplitude of Accommodation in the right eye before and after VR HMD use (*p*=0.005).

There is no significant difference in the Amplitude of Accommodation in the left eye before and after VR HMD use (*p*=0.199).

Negative Relative Accommodation values after VR HMD use did not differ significantly from the baseline values (*p*=0.076).

Positive Relative Accommodation values after VR HMD use did not differ significantly from the baseline values (*p*=0.725).

Table 4.5: Mean Difference of Vergence findings in Participants Before and After Virtual Reality.

Variable	**Mean**	**SD**	**t**	**df**	***p*-value**
Near Point of Convergence	-0.46552	3.02351	-0.829	28	0.414
Break	-0.79310	3.18624	-1.340	28	0.191
Recovery					
Negative Fusional Vergence					
Break	0.86207	4.01536	1.156	28	0.257
Recovery	-0.41379	2.39817	-0.929	28	0.361
Positive Fusional Vergence					
Break	-2.06897	3.43232	-3.246	28	0.003**
Recovery	-0.31034	2.84233	-0.588	28	0.561

***: Statistically significant; VR HMD: Virtual Reality Head Mounted Device.*

From the findings of this study there is no significant difference in Near Point of Convergence break values before and after VR HMD use (*p*=0.414).

There is no significant difference Near Point of Convergence recovery values before and after VR HMD use (*p*=0.191).

There is no significant difference in the Negative Fusional Vergence break values before and after VR HMD use (*p*=0.257).

Negative Fusional Vergence recovery values after VR HMD use did not differ significantly from the baseline values (*p*=0.361).

Positive Fusional Vergence break values after VR HMD differed significantly from the baseline values (*p*=0.003).

There is no significant difference in the Positive Fusional Vergence recovery values before and after VR HMD use (*p*=0.561).

CHAPTER FIVE

5.0 DISCUSSION

Virtual reality holds immense importance in today's world as a versatile and transformative technology with the potential to revolutionize various aspects of human experience, from entertainment and education to healthcare and beyond. As VR becomes more prevalent in entertainment, education, healthcare, and other sectors, understanding its impact on human physiology, cognition, and well-being is crucial to advancing our understanding of human-computer interaction, optimizing VR technology, improving therapeutic interventions, and enhancing user experience in virtual environments. This study aimed to determine the effect of virtual reality on oculomotor function after 45mins of movie watch with a 3D VR Shinecon 6.0 Head Mounted Display unit. The Accommodative clinical parameters that were investigated for this study were Amplitude of Accommodation (AOA), Negative Relative Accommodation (NRA) and Positive Relative Accommodation (PRA) and the Vergence clinical parameters that were investigated for this study were Near Point of Convergence (NPC), Negative Fusional Vergence (NFV) and Positive Fusional Vergence (PFV) which are routinely accessed in Optometry clinics. The study also sought to determine the baseline accommodative and vergence function in the study population.

This study reavealed that the baseline Amplitude of Accommodation (AOA) in the study population was 10.000 ± 1.62019 diopter (D) and 9.59138 ± 1.73298 diopter (D) for the right and left eye respectively. Therefore Donder's table (Carlson & Kurtz, 2016) which predicts a range of 10-7 diopters (D) of amplitude of accommodation for age 20-30 years did predict the Amplitude of Accommodation among the 22-28 age range of the study population.

The baseline Negative Relative Accommodation in the study population was +3.0948 ± 0.76009 diopter (D), which signified a higher value than the normal expected baseline which is +2.00 ± 0.50 diopter (D) (Carlson & Kurtz, 2016). High NRA values > 2.50 diopter (D) which could result from over minused prescriptions, uncorrected hyperopia or latent hyperopia was observed in this study with a maximum of +5.00 diopter (D) and a minimum of +1.75 diopter (D) recorded. In a 2020 study by Masihuzzaman et *al.,* the mean value of NRA was +2.88 ± 0.74 diopter (D) maximum in hyperopic participants. this value differs largely from the values obtained in this study. In study by Yekta et *al.,* (2017) the mean NRA was +2.08 ± 0.33 diopter (D) which was highest in hyperopic participants, this value differs largely from the values obtained in this study. The baseline Positive Relative Accommodation in this study population was -3.5690 ± 1.16668 diopter (D). The normal expected mean PRA is -2.37± 1.00 diopter (D) (Carlson & Kurtz, 2016). High PRA >-3.50 diopter (D) values could results from disorders involving accommodative excess. Those with accommodative insufficiency usually have PRA values below -1.50 diopter (D). In this study a maximum baseline PRA value of -6.50 diopter (D) and a minimum of -1.50 diopter (D) was recorded. In a 2020 study by Masihuzzaman et *al.,* the mean value of PRA was -3.54 ± 1.15 diopter (D), they observed no difference in PRA with refractive errors as PRA was almost the same in myopic and hyperopic subjects. In study by Yekta et *al*., (2017) the mean PRA was -2.92 ± 0.76 diopters (D) which was highest in myopic participants. García-Muñoz et *al.,* in 2002 reported that low values of NRA and PRA were not associated with any particular disorder. High values of PRA (> or = -3.50 D) were related to the disorders associated with accommodative excess, whereas high values of NRA (> or = 2.50 D) were not related to accommodative excess, and statistical differences suggested that a high value of PRA could distinguish between anomalies. Sensitivity analysis revealed that high PRA was the most sensitive sign in patients with convergence insufficiency combined with accommodative excess and one of the most sensitive signs for subjects with accommodative excess and for those with convergence excess combined with accommodative excess.

The baseline Near Point of Convergence in the study population was 9.1724 ± 2.73951 cm (break component) and 12.2069 ± 2.71740 cm (recovery component), with the NPC baseline break a minimum of 5 cm and a maximum of 15 cm while recovery was a minimum of 8 cm and a maximum of 17 cm. In a 2021 study by Heick and Bay, the mean NPC was found to be 7.11 ± 3.67 cm (break component) while in a 2003 study by Scheiman *et al.,* results suggested a clinical cutoff value of 5 cm for the near point of convergence break and 7 cm for the near point of convergence recovery with either an an adaptable target or a light source with crimson and verdant lenses. As evidenced in Yekta et al.'s 2016 investigation, the mean NPC was 5.1 cm. The NPC was found to increase by 0.08 cm per month of age and was 0.10 cm higher in boys compared to girls. Based on NPC, 61.58% of the study population were symptomatic for convergence insufficiency. The near point of convergence (NPC) is a good indicator for differentiating symptomatic individual from asymptomatic individuals in cases of Convergence Insufficiency (Yekta *et al.*, 2016).

The baseline Negative Fusional Vergence in the study population at near was 22.5517 ± 7.12935 (break component) and 12.3103 ± 5.42549 (recovery component). At 0.33 meters the NFV range at near is 20-25/18-22 diopter (D) for break and recovery component respectively (Duane et *al.,* 2011). In a 2020 study by Masihuzzaman et *al.,* the mean value of NFV at near was 14.71 ± 5.48 prism diopter (PD). In a 2021 study by Jamshed et *al.,* the mean value of NFV at near was 15.00 ± 11.00 prism diopter (PD) break component and 11.00 ± 4 recovery component. These values differ significantly from the values obtained in this study.

The baseline Positive Fusional Vergence in the study population was 23.9655 ± 6.26488 prism diopters (break component) and 15.6897 ± 5.16239 prism diopters (recovery component) at near. At 0.33 meters the PFV range at near is 12/9 diopter (D) for break and recovery component respectively (Duane et *al.,* 2011). In a 2020 study by Masihuzzaman et *al.,* the mean value of PFV at near was 21.58 ± 10.65 prism diopter (PD). In a 2021 study by Jamshed et *al.,* the mean value of PFV at near was 26.00 ± 10.00 prism diopter (PD) break component and 21.00 ± 10 recovery component.

Based on Accommodative measurements the study revealed there was significant difference in the Amplitude of Accommodation in the right eye before and after VR HMD use (p=0.005). There was no significant difference in the Amplitude of Accommodation in the left eye before and after VR HMD use (p=0.199). The difference in significance could result from sight dominance, A recent study in 2022 by Ikram et *al.,* showed a higher level of accommodative function in all aspects of accommodative factor such as Monocular estimated method (MEM), near the point of accommodation (NPA) and accommodative facility in the dominant eye. The Mean and Standard deviation value showed a significant difference in all parameters in the dominant eye when comparing with the Non dominant eye. However the test for sight dominance was not carried out in this study but Odigie et *al.,* 2019 showed that the right eye was dominant in 62.5% of subjects and that the dominant eye has more accommodative amplitude, facility and lag than the non-dominant eye but this difference was not statistically significant. A study by Momeni-Moghaddam et *al.,* 2014 reported that the right eye was dominant in 76 % of subjects. Superior statistically significant Amplitude of Accommodation and Accommodative Facility was found in the dominant eye as determined by hole-in-the card method in young healthy adults, although those differences were perhaps not of clinical significance (<0.50

dioptres and <2 cycles per minute). Negative Relative Accommodation values after VR HMD use did not differ significantly from the baseline values (*p*=0.076). Positive Relative Accommodation values after VR HMD use did not differ significantly from the baseline values (*p*=0.725). In a 2021 study by Alhassan et *al.,* a direct comparisons of different accommodative measurements based on median values showed that, among all accommodative measurements, the effect of playing VR video games was statistically significant for NRA (this differs from the results of this study). Other measurements did not present significant differences. At first, the PRA test result was observed to be approaching a significant effect level but ultimately did not reach this goal; however, even though the PRA did not reveal a statistically significant difference, the result appears clinically significant since the difference between before and after values of 0.5D was observed. In a 2017 study by Turnbull et *al.,* there was no significant difference in amplitude of accommodation. In a 2022 study by Li et *al.,* after 12 weeks virtual reality based treatment for convergence insufficiency the Amplitude of Accommodation and Accommodative Facility but not in other Accommodation function showed a statistically significant difference. This brings into light the the comparison of the results obtained from longitudinal studies and those obtained from short term cross sectional studies. A 2020 study by Szpak et *al.,* investigated for both short and long term aftereffects of VR exposures, there were statistically significant changes in both short term (10 mins) and long term (50 mins) exposure in accommodation and convergence however, in the late test period, participants returned to baseline levels.

Based on Vergence measurements the study revealed there was no significant difference in Near Point of Convergence break values before and after VR HMD use (*p*=0.414). There was no significant difference Near Point of Convergence recovery values before and after VR HMD use (*p*=0.191). There is no significant difference in the Negative Fusional Vergence break values before and after VR HMD use (*p*=0.257). Negative Fusional Vergence recovery values after VR HMD use did not differ significantly from the baseline values (*p*=0.361). Positive Fusional Vergence break values after VR HMD differed significantly from the baseline values (*p*=0.003). There was no significant difference in the Positive Fusional Vergence recovery values before and after VR HMD use (*p*=0.561). Concerning vergence assessments, the bulk of direct comparisons in the 2021 study by Alhassan et al., centered on a review of median values, suggested no considerable distinction between pre- and post-virtual reality (VR) video game play, aligning with findings in this study, excluding Positive Fusional Vergence (PFV). In a 2022 study by Li et al., following a 12-week virtual reality-based intervention for convergence insufficiency, while Near Point of Convergence (NPC) and Positive Fusional Vergence showed significant improvements, Negative Fusional Vergence did not, corresponding to this study's findings, except for NPC.

CHAPTER SIX

6.0 CONCLUSION

In conclusion, results from this study has elucidated that watching 3D movies using VR-HMDs for 45 minutes undoubtedly induced some clinical oculomotor changes. The significant oculomotor changes affected were: Amplitude of Accommodation in the right eye and Positive Fusional Vergence break at near. The oculomotor functions with no statistically significant changes were: Amplitude of Accommodation in the left eye, Negative Relative Accommodation at near, Positive Relative Accommodation at near, Near Point of Convergence, Negative Fusional Vergence at near and Positive Fusional Vergence recovery at near.

In addition, most of the study participants subjectively reported increments in visual and nonvisual symptoms such as eyestrains, headaches and dizziness. The baseline accommodative and vergence data gotten has shed more light on the state of oculomotor function in the study population which requires further investigations.

6.1 RECOMMENDATIONS

1. Given these findings 3D movie watchers are encouraged to check their eyes on a routine basis, especially their binocular vision functions, to prevent or minimize oculomotor changes that may occur watching 3D movies and may need to be cautious with their use of virtual reality head mounted displays.
2. The effect of virtual reality on oculomotor function requires further short term and longitudinal investigations across diverse populations with larger samples.
3. Research on the design of VR technologies should address the problem of discomfort experienced by users and vergence accommodation conflicts.

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APPENDIX

APPENDIX I

Distribution of ages across gender

	Mean ± SD	**Range**	**n**
Gender			
Male	24.79 ± 2.007	22-28	14
Female	24.07 ± 1.831	21-28	15
Total	24.41 ± 1.918	21-28	29

APPENDIX II

Paired t test comparism of Baseline Refractive error values in the Right and Left Eye.

Variable	Mean	SD	t	df	*p*-value
Distance Visual Acuity					
Right Eye Before					
Left Eye Before	-0.00897	0.05115	-0.944	28	0.353

APPENDIX III

Paired t test comparism of Baseline Amplitude of Accommodation values in the Right and Left Eye.

Variable	Mean	SD	t	df	*p*-value
Amplitude of Accommodation Right Eye Before Left Eye Before	0.40862	1.09854	2.003	28	0.055

APPENDIX IV

Descriptive Statistics of Baseline Negative Relative Accommodation

Variable	N	Minimum	Maximum	Mean	SD
Negative Relative Accommodation Before	29	1.75	5.00	3.0948	0.76009

APPENDIX V

Descriptive Statistics of Baseline Positive Relative Accommodation

Variable	N	Minimum	Maximum	Mean	SD
Positive Relative Accommodation Before	29	-1.50	-6.50	-3.5690	1.16668

APPENDIX VI

Descriptive Statistics of Baseline Near Point of Convergence

Variable	N	Minimum	Maximum	Mean	SD
Near Point of Convergence					
Before	29	5.00	15.00	9.1724	2.73951
Break	29	8.00	17.00	12.2069	2.71740
Recovery					

APPENDIX VII

Accommodative Measurements Paired Sample Statistics.

Variables		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Amplitude of Accommodation RE before	10.0000	29	1.62019	.30086
	Amplitude of Accommodation RE after	9.5034	29	1.66229	.30868
Pair 2	Amplitude of Accommodation LE before	9.5914	29	1.73298	.32181
	Amplitude of Accommodation LE after	9.3276	29	1.74231	.32354
Pair 3	Negative Relative Accommodation before	3.0948	29	.76009	.14115
	Negative Relative Accommodation after	2.8621	29	.68330	.12689
Pair 4	Positive Relative Accommodation before	-3.5690	29	1.16668	.21665
	Positive Relative Accommodation after	-3.5000	29	1.36113	.25276

APPENDIX VIII

Vergence Measurements Paired Sample Statistics.

Variable		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Near Point of Convergence Break before	9.1724	29	2.73951	.50871
	Near Point of Convergence Break after	9.6379	29	3.38298	.62820
Pair 2	Near Point of Convergence Recovery before	12.2069	29	2.71740	.50461
	Near Point of Convergence Recovery after	13.0000	29	3.52288	.65418
Pair 3	Negative Fusional Vergence Break before	22.5517	29	7.12935	1.32389
	Negative Fusional Vergence Break after	21.6897	29	6.63919	1.23287
Pair 4	Negative Fusional Vergence Recovery before	12.3103	29	5.42549	1.00749
	Negative Fusional Vergence Recovery after	12.7241	29	4.45531	.82733
Pair 5	Positive Fusional Vergence Break before	23.9655	29	6.26488	1.16336
	Positive Fusional Vergence Break after	26.0345	29	6.76906	1.25698
Pair 6	Positive Fusional Vergence Recovery before	15.6897	29	5.16239	.95863
	Positive Fusional Vergence Recovery after	16.0000	29	5.30498	.98511