EFFECTIVENESS OF VIRTUAL REALITY BASED REHABILITATION ON MOTOR RECOVERY AMONG STROKE SURVIVORS IN A TERTIARY HEALTH INSTITUTION IN BENIN CITY

BY

UTI, ZABDIEL UGOCHUKWU
BMS1900324

A DISSERTATION SUBMITTED TO THE
DEPARTMENT OF PHYSIOTHERAPY,
SCHOOL OF BASIC MEDICAL SCIENCES,
COLLEGE OF MEDICAL SCIENCES,
UNIVERSITY OF BENIN,
BENIN CITY.

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF PHYSIOTHERAPY DEGREE

OCTOBER, 2025.

DEDICATION

This work is dedicated to Almighty God, for His guidance, protection, and endless blessings throughout my academic journey. I also dedicate this project to my beloved mother, **Mrs. Adeshola Uti**, whose love, sacrifices, and constant encouragement have been my greatest source of strength.

ABSTRACT

Background: Stroke often results in significant motor impairments, affecting the quality of life and independence of survivors. Conventional physiotherapy is effective but sometimes limited by patient engagement and intensity. Virtual reality (VR) has emerged as a promising intervention that provides immersive, interactive environments to enhance motor recovery.

Aim: This study evaluated the effectiveness of virtual reality therapy on motor recovery among stroke survivors in University of Benin Teaching Hospital.

Methods: Forty stroke survivors undergoing rehabilitation were randomly and equally assigned to either the experimental and control groups. Interventions were conducted three times a week for eight weeks, with each session lasting 20 minutes. Motor recovery was assessed through muscular strength, muscular endurance, joint range of motion, balance, and coordination using validated and reliable instruments. Descriptive statistics of frequency, percentage, mean and standard deviation were used to summarize the socio-demographic and clinical characteristics of the participants while inferential statistics of one-way ANOVA was used to test the hypotheses.

Results: Participants in the VR group showed statistically significant improvements in all motor recovery parameters (muscle strength, muscle endurance, range of motion, balance and coordination) compared to the control group ($p < 0.05$). Notably, upper and lower limb strength, endurance, range of motion, and balance improved more in the VR group.

Conclusion: Virtual reality therapy is an effective treatment modality in stroke rehabilitation to enhance motor recovery after stroke. Thus, VR should be regarded as a cornerstone in the management of stroke survivors.

Keywords: Stroke, Virtual Reality, Motor Recovery, Hemiparesis

ACKNOWLEDGEMENT

I am profoundly grateful to Almighty God for His guidance, strength, and wisdom throughout this project and my academic journey.

I would like to express my deepest gratitude to my project supervisor, Dr. Adebisi I. Hammed, whose relentless commitment and dedication ensured my success. Your guidance, constructive critiques, and enduring support were instrumental in shaping this project and my academic journey.

I sincerely appreciate the support of the Head of Department at the University of Benin, Dr. (Mrs.) C. Obaseki, and the Head of Department at the University of Benin Teaching Hospital, Mr. Taiwo Oyewumi, for their guidance and support throughout my academic journey.

My heartfelt thanks go to the lecturers who have shaped my knowledge and skills, including Prof. Kayode Oke, Prof. Joseph Umunnah, Prof. Obinna Ezeukwu, Rev. Sister Dr. Henrietta Fawole, Dr. Mrs. S. Kubeyinje, Mr. R. E. Okhuahesuyi, Dr. Nelson, PT Kayode Aje, and PT Osayi Obarisiagbon. Your mentorship, encouragement, and words of wisdom have been invaluable.

I acknowledge all the directors, physiotherapists, interns, and colleagues who contributed to this project in various ways. Your support, guidance, and encouragement will always be remembered and appreciated. I also especially appreciate PT Ezekiel and PT Adebimpe, for going all out to support me in every possible way.

I am grateful to the non-teaching staff, Mr. Nosa and Mrs. Juliet, whose assistance and support made many aspects of this project easier.

I extend my gratitude to PT Francis Kolawole, and to Miss Veronica Amunega, for her constant presence and support throughout this journey. Her encouragement, patience, and willingness to be there every day, through every challenge, made a tremendous impact in completing this project. I am equally grateful to my course mates, Francis, Victor, Rose, Serena, Ekene, Phillip, Praise, and Mmasi, for their support, motivation, and camaraderie throughout this journey.

I am also deeply thankful to my parents, Mrs. Adeshola Uti and Mr. Edwin, my siblings, Shalom and Daniel, and my entire family, for their steadfast love, encouragement, and sacrifices that have continuously motivated me to reach this milestone.

To everyone who has helped me in one way or the other, I say a heartfelt thank you. This achievement is as much yours as it is mine.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Stroke, also known as a cerebrovascular accident (CVA), occurs when the blood supply to a part of the brain is disrupted due to either a blockage in a vessel or bleeding. This interruption deprives brain tissue of oxygen and essential nutrients, resulting in cell death within minutes (National Heart, Lung, and Blood Institute, 2023). As a leading cause of adult disability and a major contributor to mortality worldwide, stroke poses a significant public health burden. Stroke is a medical emergency that can lead to lasting neurological impairment, long-term disability, or death if not promptly addressed (Feigin *et al.*, 2024). Despite advances in acute care, the long-term consequences of stroke continue to challenge healthcare systems, particularly in low- and middle-income countries (LMICs) where access to timely and adequate rehabilitation is often limited (Feigin et al., 2022).

Although stroke presents in different forms, most commonly ischaemic, followed by haemorrhagic, its aftermath is almost universally disabling. Modifiable risk factors such as hypertension, smoking, obesity, and physical inactivity, alongside non-modifiable factors like age and genetics, continue to drive the global burden of stroke. In Nigeria, stroke accounts for a considerable portion of neurological admissions, with urban centres reporting higher rates than rural settings (Annongu et al., 2022). These figures not only highlight the urgency of preventive strategies but also reinforce the importance of structured rehabilitation in reducing long-term disability and dependence.

Motor impairments are among the most significant and disabling outcomes of stroke. These often include contralateral muscle weakness, spasticity, poor coordination, and reduced endurance, all of which impede a survivor’s ability to perform daily tasks independently.

Notably, these deficits are not only physical but also psychological, as the loss of autonomy can lead to depression, anxiety, and reduced quality of life (Li, 2023). The early post-stroke period, particularly the first three to six months, is critical for motor recovery due to heightened neuroplastic potential. However, appropriately designed interventions can still make meaningful gains beyond this period. Conventional physiotherapy employs task-specific training, manual therapy, and balance and strength exercises to stimulate motor relearning. These methods rely on repetitive, purposeful movements to harness neuroplasticity, the brain's ability to reorganise and form new neural connections in response to activity (National Clinical Guideline for Stroke, 2023). Despite its proven benefits, conventional therapy often faces limitations in LMICs due to inadequate staffing, poor infrastructure, and inconsistent patient follow-up. Moreover, therapy sessions are sometimes perceived as monotonous, leading to reduced patient motivation and adherence.

Virtual reality (VR) has recently emerged as a helpful addition in stroke rehabilitation, particularly in motor recovery. Virtual reality systems create computer-generated environments where patients can perform therapeutic tasks in a motivating and controlled context, guided by real-time feedback. These environments often incorporate elements of gamification, which can enhance user motivation and prolong engagement. These systems can be adapted to match each patient's abilities and goals, supporting targeted and personalised rehabilitation. (Khan et al., 2024). Moreover, virtual reality-based rehabilitation closely aligns with the principles of Motor Relearning Theory, which emphasises task-specific practice, feedback, and active participation as key to regaining functional movement following a neurological injury. According to this framework, effective motor recovery depends on muscle strength and relearning functional movement patterns through purposeful, repetitive tasks in context. Virtual reality systems allow patients to practise goal-directed movements that simulate real-life tasks while receiving immediate, meaningful feedback on their performance. This combination promotes neuroplasticity by engaging cognitive and motor pathways, reinforcing correct movement strategies over time (Bui et al., 2021). Additionally, immersive virtual settings help maintain patient focus and encourage consistent participation, which are vital elements in effective motor relearning.

Furthermore, the application of VR in stroke rehabilitation addresses some of the systemic challenges faced in conventional settings. For instance, virtual reality-based sessions can be concise yet stimulating, reducing therapist strain while sustaining patient involvement. It also has the potential to be used remotely via tele-rehabilitation, thus extending access to patients in rural areas. With the increasing accessibility of VR devices, the technology is becoming more feasible for widespread clinical use, even in resource-constrained environments. Therefore, virtual reality holds significant promise as a complementary or alternative tool for post-stroke motor rehabilitation. While international evidence supports its effectiveness, there is a clear gap in localised research that evaluates its practicality and effectiveness within the Nigerian context.

Despite growing international evidence, limited research is available from tertiary health institutions in Benin City. To date, no known randomised or quasi-randomised trials have evaluated structured VR interventions for stroke motor recovery among Nigerian patients. Most local studies focus on stroke prevalence and acute management, leaving a significant gap in data on VR's feasibility and effectiveness (Annongu et al., 2022).

1.2 Statement of the Problem

Although significant progress has been made in acute stroke management, a large proportion of survivors, estimated at 60% to 80%, continue to experience long-term motor deficits such as hemiparesis, poor coordination, and reduced functional independence (Li, 2023). These impairments interfere with basic daily tasks and hinder full community reintegration. In low- and middle-income countries like Nigeria, the situation is worsened by constant challenges, including a shortage of trained rehabilitation professionals, inadequate facilities, and low therapy adherence due to repetitive routines (Annongu et al., 2022; Owolabi et al., 2015).

Conventional physiotherapy remains the standard of care, yet it often struggles to deliver the high-intensity, task-specific training required to drive optimal neuroplastic changes, especially in under-resourced settings. Additionally, conventional methods' lack of novelty and interactivity can reduce patient motivation and limit functional gains over time (Li, 2023). Virtual reality-based rehabilitation offers a promising solution. It enables immersive, task-oriented, engaging, adaptable practice, allowing stroke survivors to participate in meaningful movement training with real-time feedback (Khan et al., 2024). Several systematic reviews have confirmed that VR, when used alongside conventional therapy, can significantly enhance motor recovery, particularly in the upper limbs (Mekbib et al., 2020; Gelineau et al., 2022). However, most of these studies are concentrated in high-income countries, often involving patients in the chronic phase of recovery and using expensive equipment, raising concerns about applicability in subacute cases or resource-limited hospitals.

To the best of the researcher's knowledge, no known study has been conducted to evaluate structured virtual reality interventions for motor recovery among stroke survivors in any tertiary institution in South-South Nigeria. This leaves clinicians without locally relevant guidance and patients without access to potentially beneficial innovative therapies.

1.3 Research Questions

Based on the background and problem statement, the following research questions were formulated to guide this study:

i. What is the effect of virtual reality-based rehabilitation on upper limb muscular strength?

ii. What is the effect of virtual reality-based rehabilitation on lower limb muscular strength?
iii. What is the effect of virtual reality-based rehabilitation on upper limb muscular endurance?
iv. What is the effect of virtual reality-based rehabilitation on lower limb muscular endurance?
v. What is the effect of virtual reality-based rehabilitation on upper limb joint flexibility?
vi. What is the effect of virtual reality-based rehabilitation on lower limb joint flexibility?
vii. What is the effect of virtual reality-based rehabilitation on balance?
viii. What is the effect of virtual reality-based rehabilitation on upper limb coordination?
ix. What is the effect of virtual reality-based rehabilitation on lower limb coordination?

1.4 Aim of the Study

This study evaluates the effectiveness of virtual reality-based rehabilitation on motor recovery among stroke survivors in a tertiary health institution in Benin City.

1.4.1 Specific Objectives

The specific objectives of this study were to:

i. assess the effect of virtual reality-based rehabilitation on upper limb muscular strength of stroke survivors.
ii. examine the effect of virtual reality-based rehabilitation on lower limb muscular strength of stroke survivors.
iii. evaluate the effect of virtual reality-based rehabilitation on upper limb muscular endurance of stroke survivors.
iv. determine the effect of virtual reality-based rehabilitation on the muscular endurance of the lower limb of stroke survivors.

v. establish the effect of virtual reality-based rehabilitation on upper limb joint flexibility of stroke survivors.

vi. assess the effect of virtual reality-based rehabilitation on lower limb joint flexibility of stroke survivors.

vii. determine the effect of virtual reality-based rehabilitation on balance of stroke survivors.

viii. determine the effect of virtual reality-based rehabilitation on upper limb coordination of stroke survivors.

ix. evaluate the effect of virtual reality-based rehabilitation on lower limb coordination of stroke survivors.

1.5 Hypotheses

1.5.1 Main Hypothesis

There would be no significant difference in motor recovery outcomes for stroke survivors who undergo virtual reality-based rehabilitation.

1.5.2 Sub-Hypotheses

i. There would be no significant difference in upper limb muscular strength of stroke survivors prior to and following virtual reality-based rehabilitation.

ii. There would be no significant difference in lower limb muscular strength of stroke survivors prior to and following virtual reality-based rehabilitation.

iii. There would be no significant difference in upper limb muscular endurance of stroke survivors prior to and following virtual reality-based rehabilitation.

iv. There would be no significant difference in lower limb muscular endurance of stroke survivors prior to and following virtual reality-based rehabilitation.

v. There would be no significant difference in upper limb joint flexibility of stroke survivors prior to and following virtual reality-based rehabilitation.

vi. There would be no significant difference in lower limb joint flexibility of stroke survivors prior to and following virtual reality-based rehabilitation.

vii. There would be no significant difference in the balance of stroke survivors prior to and following virtual reality-based rehabilitation.

viii. There would be no significant difference in upper limb coordination of stroke survivors prior to and following virtual reality-based rehabilitation.

ix. There would be no significant difference in lower limb coordination of stroke survivors prior to and following virtual reality-based rehabilitation.

1.6 Significance of the Study

Stroke rehabilitation is a critical part of recovery, especially for survivors facing challenges with movement and daily activities. In many parts of Nigeria and other low-resource settings, therapy services are often limited due to a lack of trained professionals, poor access to equipment, and low patient motivation. This study offers a chance to explore how VR can help address these issues and improve outcomes for stroke survivors.

Virtual reality-based rehabilitation can offer stroke patients a more interesting and engaging way to regain movement. It could support faster recovery, reduce long-term disability, and help people return to their daily routines more independently. The interactive nature of VR helps sustain interest and encourages patients to engage more actively in their therapy routines, which is often a challenge with traditional physiotherapy. Family members and caregivers would also benefit. When stroke survivors recover more quickly and gain independence, it reduces the emotional, physical, and financial strain on those who care for them.

This study provides physiotherapists and other rehabilitation staff with a new tool for their sessions. VR could help extend therapy time without introducing stress, fatigue, or burnout for the therapist. It also enables therapists to tailor treatment to suit each patient’s ability level. Hospitals and health decision-makers could utilise the findings of this research when contemplating whether to invest in VR systems. If demonstrated to be beneficial, VR could provide a cost-effective solution, particularly in areas where traditional rehabilitation is inaccessible. It could also be employed in tele-rehabilitation, assisting patients in rural regions to receive care without the need to travel to the hospital frequently.

Finally, this study contributes to the limited local evidence on technology-based stroke therapy. While many international studies support the use of VR, scant data is available from Nigeria and other African countries. This project addressed that gap and may serve as a guide for future research, programmes, or policies focused on improving stroke rehabilitation.

1.7 Scope and Delimitation

This study specifically focuses on evaluating the effectiveness of virtual reality-based rehabilitation compared to conventional physiotherapy for improving motor recovery in stroke patients undergoing rehabilitation at the University of Benin Teaching Hospital (UBTH). The scope of the study is delimited in the following areas:

A. Participants

i. The study involved male and female stroke patients aged between 18 and 65 years.
ii. The study involved participants receiving physiotherapy at UBTH and considered medically stable for therapeutic exercise.
iii. All participants were able to understand simple instructions and provide informed consent to take part in the study.
iv. Individuals with severe cognitive impairments, psychiatric conditions, additional neurological disorders, significant hearing or vision problems, or musculoskeletal issues affecting movement were excluded.
v. Eligible participants were randomly divided into two groups: experimental (VR) and control.

B. Instruments and Measures

Each domain of motor recovery was assessed using a single, validated instrument:

i. Muscular strength was measured using the Medical Research Council (MRC) scale for manual muscle testing.
ii. Muscular endurance was assessed using the 30-Second Chair Stand Test for lower limbs and the Arm Curl Test for upper limbs.
iii. Joint flexibility (range of motion) was measured using a standard universal goniometer.
iv. Balance and coordination were evaluated using the Berg Balance Scale (BBS).

Virtual Reality Headset: A commercially available head-mounted display (Meta Quest 3) was used to deliver interactive, immersive virtual reality-based rehabilitation tasks designed to improve upper and lower limb function and balance.

1.8 Limitations

The study was conducted solely at the University of Benin Teaching Hospital, which limited the diversity of the participant pool. A multicentre approach could have provided a broader representation of stroke survivors with varying backgrounds.

Due to the limited availability of virtual reality equipment, only a small number of participants could undergo the intervention at a time.

Despite these challenges, measures were implemented to minimise their impact, and the study was completed, providing valuable insights into the effectiveness of virtual reality combined with conventional physiotherapy for motor recovery in stroke survivors.

1.9 Definition of Terms

Stroke: A neurological deficit caused by a focal vascular event, such as cerebral infarction, intracerebral haemorrhage, or subarachnoid haemorrhage. It includes both symptomatic and clinically silent strokes confirmed by neuroimaging, regardless of symptom duration (Sacco et al., 2013).

Virtual Reality: An interactive, computer-generated environment presented through devices like headsets or screens, that provides immersive or semi-immersive feedback for therapeutic tasks in rehabilitation (Khan et al., 2024).

Motor Recovery: The process by which individuals regain voluntary motor control, coordination, and functional use of limbs following neurological damage, often supported by neuroplasticity and rehabilitation techniques (Li, 2023).

Muscular Strength: The maximal force that a muscle or group of muscles can generate against resistance during a single effort, essential for performing functional movements such as lifting or walking.

Muscular Endurance: the ability of a muscle or muscle group to sustain repeated contractions or maintain a submaximal force over time.

Joint Flexibility: The capacity of a joint to move freely and efficiently through its complete range of motion, affecting movement quality and functional independence.

Balance and Coordination: Balance is the ability to maintain stability in various postures and during movement, while coordination refers to the smooth and efficient integration of body parts during motion.

Tertiary Health Institution: A specialised healthcare facility that provides advanced medical care, including diagnostic, therapeutic, and surgical procedures, typically serving as a referral centre for primary and secondary healthcare services (Annongu et al., 2022).

1.10 List of Abbreviations

BBS – Berg Balance Scale

CVA – Cerebrovascular Accident

LMICs – Low- and Middle-Income Countries

MRC – Medical Research Council

ROM – Range of Motion

UBTH – University of Benin Teaching Hospital

VR – Virtual Reality

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

This chapter presents a comprehensive review of relevant literature that forms the foundation for this study. The review is organised under the following major headings: definition and pathophysiology of stroke, risk factors, clinical presentations, associated complications, types of strokes, anatomy of the brain, physiotherapy interventions, virtual reality in stroke rehabilitation, theoretical framework, empirical literature, and identified gaps in previous studies. The theoretical framework guiding this study is the Motor Relearning Theory proposed by Carr and Shepherd in 1987. This theory emphasises the significance of task-specific, repetitive, and functionally meaningful activities in promoting motor recovery following neurological injury.

2.2 Stroke

2.2.1 Definition

A stroke is a sudden onset of neurological dysfunction resulting from an acute vascular injury to the central nervous system, leading to irreversible damage or death of brain cells in the affected region (Aderinto et al., 2023; Murphy & Werring, 2020). It typically occurs when the blood flow to a part of the brain is either obstructed by a clot or compromised by a ruptured blood vessel, thereby preventing essential oxygen and nutrients from reaching brain tissue.

The World Health Organization (WHO) further describes stroke as a “rapidly developing clinical sign of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than a vascular origin” (WHO, 2021).

2.2.2 Epidemiology

Stroke remains a leading cause of global morbidity and mortality. In 2019, approximately 12 million people experienced a new stroke and 6–7 million died, making stroke the world's second leading cause of death and a significant factor in long-term disability (GBD 2019 Stroke Collaborators, 2021). Low and middle-income countries bear a disproportionate burden; about 70% of stroke deaths and nearly 87% of stroke-related disability occur in these settings (Ogah et al., 2021). In Africa, stroke incidence and mortality remain among the highest globally. Some regions report up to 316 new stroke cases per 100,000 population annually (Ogah et al., 2021). In Nigeria, hospital-based reports indicate that stroke prevalence can reach around 1,460 per 100,000 in specific regions (Okekunle et al., 2023), and outcomes are sobering: approximately 25% of African stroke patients die within one month of onset (Okekunle et al., 2023).

Limited hospital data are available within South-South Nigeria, and particularly in Benin City. Nonetheless, a retrospective review from the University of Benin Teaching Hospital documented that stroke prevalence among neurological admissions was notably high, with hypertension and diabetes mellitus identified as the most common associated risk factors (Annongu et al., 2022). The same centre established Nigeria's first dedicated stroke unit in 2010 (Owolabi et al., 2015).

2.2.3 Pathophysiology

Stroke can be divided into two main groups: ischaemic and haemorrhagic. Each group encompasses interrelated vascular, cellular, and molecular processes that lead to neurological dysfunction. In ischaemic stroke, which accounts for approximately 85% of all strokes globally, an arterial blockage, often due to thrombosis, embolism, or hypoperfusion, leads to a loss of oxygen and glucose supply to the brain tissue (Murphy & Werring, 2020; Bersano & Gatti, 2023). Within minutes, this triggers energy failure in neurons, compromising adenosine triphosphate (ATP) production and leading to the failure of ionic pumps such as the sodium-potassium ATPase. As a result, neurons undergo depolarisation, and large amounts of excitatory neurotransmitters, particularly glutamate, are released into the extracellular space. This excitotoxicity causes an influx of calcium ions, activating enzymes that degrade proteins, lipids, and nucleic acids, thereby worsening neuronal injury.

Simultaneously, oxidative stress caused by excessive reactive oxygen species (ROS) production damages cellular membranes and organelles. An inflammatory response ensues, involving activation of microglia, astrocytes, and infiltration of leukocytes, which release pro-inflammatory cytokines and further exacerbate tissue damage (Bersano & Gatti, 2023). The central region of irreversible injury is called the infarct core, while the surrounding ischaemic penumbra contains hypoperfused but viable cells (Kvernland *et al.*, 2022). In haemorrhagic stroke, which accounts for approximately 15% of stroke cases, a ruptured blood vessel, often due to hypertension, aneurysm, or vascular malformation, results in bleeding into the brain parenchyma or the subarachnoid space. The accumulation of blood exerts mechanical pressure on neural tissue, disrupts normal function, and leads to increased intracranial pressure (ICP), thereby reducing cerebral perfusion. Furthermore, the breakdown products of blood, such as haemoglobin and iron, initiate toxic oxidative reactions and an intense inflammatory response, contributing to perihematomal oedema and further neuronal damage (Bersano & Gatti, 2023).

Ultimately, whether ischaemic or haemorrhagic, the pathophysiological outcomes of stroke include neuronal loss, glial scarring, white matter damage, and disruption of neural networks. These changes impair sensory, motor, cognitive, and autonomic functions, depending on the brain regions affected. The extent and reversibility of injury depend on the duration of impaired perfusion, the collateral blood supply, and the timeliness of therapeutic interventions. In the long term, the brain attempts to compensate through neuroplasticity, involving synaptic reorganisation, dendritic sprouting, and the recruitment of alternate neural pathways to restore lost function (Li, 2023).

2.2.4 Risk Factors

Stroke is a multifactorial condition with several well-established risk factors. These can be broadly classified into:

Non-modifiable Risk Factors: These are inherent factors that cannot be altered or controlled. They include age, sex, ethnicity, and genetic predisposition. The risk of stroke increases significantly with age, particularly in individuals over 60 years, although younger individuals may occasionally be affected (Murphy & Werring, 2020). Additionally, a family history of stroke or inherited genetic disorders can increase an individual's susceptibility to cerebrovascular events.

Modifiable Risk Factors: These are preventable or manageable risk factors that contribute significantly to the overall stroke burden and are key targets in stroke prevention strategies. They include:

i. Hypertension: This is the most important modifiable risk factor for both ischaemic and haemorrhagic stroke. Chronic elevation of blood pressure damages vascular endothelium, promotes atherosclerosis, and weakens cerebral vessels, leading to increased risk of infarction and haemorrhage. Adequate blood pressure control has been shown to reduce stroke incidence significantly (Bersano & Gatti, 2023).
ii. Dyslipidemia: Elevated levels of low-density lipoprotein (LDL) cholesterol contribute to atherosclerotic plaque formation in cerebral and carotid arteries, increasing the risk of ischaemic stroke. Statins and dietary modifications help reduce this risk (Michos et al., 2019)

iii. Diabetes Mellitus: Diabetes promotes endothelial dysfunction and accelerates atherosclerosis, raising the risk of both large-vessel and small-vessel strokes. Glycaemic control is critical in reducing stroke risk in diabetic patients (GBD Stroke Collaborators, 2021).

iv. Cigarette Smoking: Smoking nearly doubles the risk of ischaemic stroke by promoting thrombosis, impairing vascular function, and decreasing protective high-density lipoprotein (HDL) cholesterol. Smoking cessation is among the most effective preventative measures (Murphy & Werring, 2020).

v. Cardiovascular Diseases: Atrial fibrillation (AF) significantly increases the risk of cardioembolic stroke by nearly fivefold, due to the potential for thrombus formation in the atria. Other cardiac conditions, such as recent myocardial infarction, valvular disease, or heart failure, also elevate stroke risk. Oral anticoagulation in eligible AF patients substantially lowers this risk (Bersano & Gatti, 2023).

vi. Obesity and Physical Inactivity: Excess body weight and a sedentary lifestyle contribute indirectly to stroke through their association with hypertension, diabetes, and dyslipidaemia. A review of multiple studies demonstrates that moderate to high levels of physical activity reduce total stroke risk by about 27%, with similar effects on ischemic and haemorrhagic strokes (Lee et al., 2003)

vii. Diet and Alcohol Consumption: Diets rich in saturated fats and salt, and low in fibre, fruits, and vegetables, increase vascular risk. While excessive alcohol use is associated with both ischaemic and haemorrhagic stroke, light-to-moderate intake has a complex and inconsistent association (Khan et al., 2024).

viii. Female-Specific Factors: Risk factors unique to women include pregnancy, the postpartum period, and the use of oestrogen-containing contraceptives or hormone replacement therapy, especially in the presence of migraines or smoking.

ix. Psychosocial and Hematologic Factors: Chronic stress, depression, and certain hypercoagulable states such as antiphospholipid syndrome can also elevate stroke risk (Kvernland *et al.*, 2022)

2.2.5 Types of Strokes

Strokes are broadly classified into two major categories: ischaemic stroke and haemorrhagic stroke, with a third related condition, transient ischaemic attack (TIA), considered a warning sign for future strokes.

Ischaemic stroke accounts for approximately 80–85% of all stroke cases. It occurs when an artery supplying the brain becomes obstructed, resulting in a reduction or complete cessation of blood flow to downstream brain tissue (Murphy & Werring, 2020; Bersano & Gatti, 2023). The most common mechanisms include thrombosis (a clot forming locally within a cerebral artery) and embolism (a clot or debris originating elsewhere, often from the heart or carotid arteries, travelling and lodging in a brain artery). Subtypes of ischaemic stroke include:

i. Large-artery atherosclerotic stroke, typically due to plaque buildup and thromboembolism in the carotid or intracranial arteries;

ii. Small-vessel (lacunar) stroke, often linked to chronic hypertension and lipohyalinosis of penetrating arteries;

iii. Cardioembolic stroke, frequently associated with atrial fibrillation or other cardiac conditions (Murphy & Werring, 2020).

iv. Other less frequent causes include arterial dissection, vasculitis, and hypercoagulable states, especially in younger individuals.

Haemorrhagic stroke, responsible for 15–20% of strokes, occurs when a blood vessel ruptures, leading to bleeding either into the brain tissue or into surrounding spaces (Bersano & Gatti, 2023). There are two major subtypes:

i. Intracerebral haemorrhage (ICH) – bleeding directly into the brain parenchyma, often due to uncontrolled hypertension or cerebral amyloid angiopathy;
ii. Subarachnoid haemorrhage (SAH) – bleeding into the subarachnoid space, usually from the rupture of a cerebral aneurysm or arteriovenous malformation (Murphy & Werring, 2020).

Additionally, transient ischaemic attacks (TIAs), sometimes called “mini-strokes,” involve temporary interruptions in cerebral blood flow without permanent tissue damage. By definition, symptoms resolve within 24 hours. TIAs share similar pathophysiological mechanisms with ischaemic strokes and serve as significant predictors of future stroke risk (Murphy & Werring, 2020).

2.2.6 Anatomy of the Brain

The brain is the central organ of the nervous system, responsible for processing sensory information, regulating vital functions, and coordinating voluntary and involuntary actions. Structurally, it is divided into three major parts: the cerebrum, cerebellum, and brainstem, each with distinct but interconnected roles.

Cerebrum: The brain's largest and most developed region, divided into left and right hemispheres. Each hemisphere contains four lobes:

i. Frontal lobe: Responsible for voluntary motor activity, executive functions, speech production (Broca's area), and emotional expression.
ii. Parietal lobe: Processes somatosensory input such as touch, pain, temperature, and proprioception.

iii. Temporal lobe: Involved in auditory perception, memory formation, and language comprehension (Wernicke's area).

iv. Occipital lobe: Primarily concerned with visual processing and interpretation.

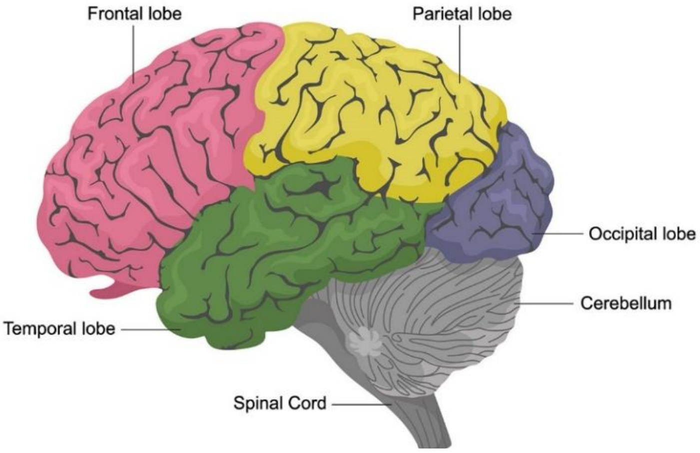


Figure 1: Lobes of the Human Brain
(John Hopkins Medicine, 2025)

Cerebellum: Located posterior to the brainstem and inferior to the occipital lobes, the cerebellum regulates coordination of voluntary movements, muscle tone, balance, and motor learning.

Brainstem: This includes the midbrain, pons, and medulla oblongata. It serves as a relay centre between the spinal cord and the cerebrum and controls essential autonomic functions such as respiration, heart rate, and blood pressure.

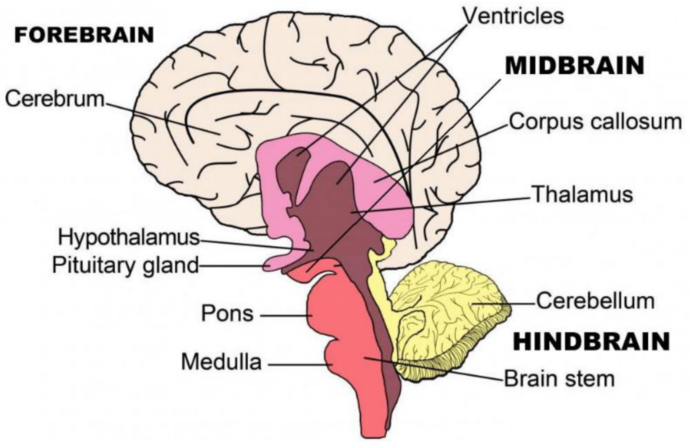


Figure 2: Major parts of the human brain
(Northern Brain Injury Association, 2025)

2.2.7 Clinical Presentations (Signs and Symptoms)

The clinical presentation of stroke is characterized by the sudden onset of neurological deficits. The specific signs and symptoms depend on the region of the brain affected, but commonly include:

i. Sudden weakness or numbness of the face, arm, and/or leg (especially on one side of the body).
ii. Sudden confusion or trouble speaking and understanding speech.
iii. Sudden visual disturbances in one or both eyes (such as partial vision loss or double vision).
iv. Sudden dizziness, loss of balance or coordination, or difficulty walking.
v. Sudden severe headache with no known cause (more typical in haemorrhagic stroke) (American Stroke Association, 2022).

Clinically, the *FAST* acronym is widely used for early stroke recognition: Face drooping, Arm weakness, Speech difficulty, and Time to seek emergency help.

Strokes affecting the anterior circulation (e.g., within the carotid artery territory) often lead to contralateral hemiparesis, hemisensory loss, facial droop, and aphasia, particularly when the dominant hemisphere (usually the left) and the middle cerebral artery are involved. In contrast, right hemisphere strokes may cause neglect of the left side of the body and impaired spatial awareness.

Posterior circulation strokes (vertebrobasilar system) produce symptoms such as vertigo, ataxia, dysarthria, double vision, or limb weakness and sensory deficits. Cranial nerve involvement may also occur, with examples including lateral medullary syndrome, which typically presents with ipsilateral facial numbness, contralateral body sensory loss, dysphagia, hoarseness, and

Horner’s syndrome. In more severe cases, such as large hemispheric strokes or brainstem strokes, patients may present with altered levels of consciousness or coma.

Importantly, stroke symptoms develop rapidly, typically within minutes to hours. In contrast, transient ischaemic attacks (TIAs) produce similar symptoms but resolve completely within 24 hours. TIAs serve as critical warning signs of an impending stroke and warrant urgent medical evaluation (Murphy & Werring, 2020; Aderinto et al., 2023).

2.2.8 Associated Complications

Beyond the immediate neurological deficits, stroke often leads to a wide range of complications, especially when the brain injury is severe or rehabilitation is delayed. Some of these arise directly from the neurological insult, while others develop as secondary effects of prolonged immobility, hospitalisation, or poor systemic management.

Motor impairments and spasticity: Many stroke survivors develop abnormal muscle tone in the weeks following the initial flaccid stage. It is estimated that up to 30% of survivors experience disabling post-stroke spasticity, which may worsen over time without targeted interventions (Li et al., 2021).

Aspiration and pneumonia: Patients may develop dysphagia when a stroke affects the brain areas controlling swallowing or protective airway reflexes. This increases the risk of aspiration, the entry of food or fluids into the lungs, often leading to aspiration pneumonia. Pneumonia remains one of the leading causes of post-stroke morbidity and mortality (Kumar et al., 2010).

Deep vein thrombosis (DVT) and pulmonary embolism: Stroke-related immobility increases the risk of venous thromboembolism in patients. Without proper prophylaxis, patients may develop DVT, which can progress to a life-threatening pulmonary embolism.

Urinary tract infections and incontinence: Neurological damage following stroke often impairs bladder control, leading to incontinence or urinary retention. Use of indwelling catheters, particularly in bedridden patients, further increases the risk of urinary tract infections. Bowel dysfunctions, including constipation or incontinence, are also prevalent.

Pressure ulcers: Reduced mobility and impaired sensation place stroke survivors at high risk for skin breakdown, particularly over bony prominences. Pressure ulcers may develop without proper repositioning and skin care, complicating recovery.

Shoulder subluxation and pain: In patients with hemiparesis, the weakness of stabilising muscles around the shoulder can lead to partial dislocation (subluxation). Spasticity and poor limb positioning further contribute to chronic shoulder pain and limited upper limb use.

Post-stroke depression and anxiety: Psychological complications are common. Up to 50% of stroke survivors experience depression, anxiety, or emotional lability, which negatively affects rehabilitation outcomes and overall quality of life (Kumar et al., 2010).

Cognitive impairment: Depending on lesion location and severity, many stroke survivors suffer from memory problems, attention deficits, executive dysfunction, or even vascular dementia. Cognitive impairment is a key determinant of functional independence and long-term care needs.

Epileptic seizures: Stroke is the most common cause of new-onset seizures in older adults. The risk is especially high in haemorrhagic strokes and cortical infarcts. Seizures may occur early (within days) or later during the recovery phase, and a small proportion of patients develop chronic post-stroke epilepsy (Li et al., 2021).

2.2.9 Physiotherapy Interventions

Stroke rehabilitation relies heavily on physiotherapy interventions to stimulate neuroplasticity and restore motor function. These approaches aim to retrain movement patterns, rebuild strength, improve coordination, and support functional independence. Core rehabilitation methods include task-oriented training, facilitation techniques, strength and balance exercises, intensive-use paradigms, and motor relearning frameworks, each targeting specific impairments and therapeutic goals.

Task-Specific Training: Task-specific training involves repeated practice of goal-directed, meaningful tasks such as reaching, walking, or grasping. This approach is based on the principle that movement patterns are best relearned through functional repetition rather than isolated muscle exercises. Stroke rehabilitation guidelines strongly recommend this method as a cornerstone of therapy (Intercollegiate Stroke Working Party, 2023). Research indicates that even chronic stroke survivors can experience long-term gains in function through consistent task-specific training (Jeon et al., 2015)

Neuro-Facilitation Techniques: Techniques like the Bobath concept (neurodevelopmental treatment) and Proprioceptive Neuromuscular Facilitation (PNF) promote normal movement and muscle tone. While both remain commonly taught, evidence suggests that Bobath-based methods are less effective than task-oriented approaches for improving motor outcomes (Scrivener et al., 2020). In contrast, PNF has shown measurable benefits in improving gait, muscle control, and balance in stroke survivors, particularly during the chronic recovery (Nguyen et al., 2022).

Strength Training: Progressive resistive training is widely used to combat post-stroke muscle weakness. Historically avoided due to concerns about increased spasticity, strength training is now proven safe and effective. Meta-analyses confirm that resistance exercises improve walking speed, functional mobility, and balance (Noguchi et al., 2025). These programmes, which may involve dumbbells, resistance bands, or bodyweight movements, help restore muscle endurance and are vital for regaining independence in everyday activities.

Balance Training: Many stroke survivors experience impaired balance due to hemiplegia, which increases the risk of falls and limits mobility. Balance-focused interventions, such as weight-shifting drills, supported gait training, and stability challenges, are designed to restore postural control. These exercises have been shown to enhance balance confidence and significantly reduce the risk of falls (Tsai et al., 2024). Improved balance directly supports better walking, transfers, and functional movement in stroke rehabilitation.

Constraint-Induced Movement Therapy (CIMT): CIMT is a targeted strategy that aims to improve upper limb function by restricting use of the unaffected arm, thereby encouraging intensive use of the affected limb. This approach addresses learned non-use and promotes neural reorganisation through high-repetition practice.

2.3 Virtual Reality

2.3.1 Definition and Overview

Virtual reality is a computer-generated simulation that enables users to interact with three-dimensional environments in real time. It integrates visual, auditory, and sometimes tactile feedback to create a sense of presence in a digitally constructed world. A distinguishing feature of VR is its interactivity, where users can explore and manipulate the virtual environment, often using motion-tracked devices or controllers (Khan et al., 2024). Levels of immersion vary depending on the system, ranging from fully immersive head-mounted displays to non-immersive setups using standard monitors. Advances in graphics, motion tracking, and sensor integration have expanded VR's applications across industries such as education, design, entertainment, and training.

Figure 3: Virtual Reality Headset with controllers
Meta, 2025

2.3.2 Historical Development of Virtual Reality

The roots of VR date back to the 1950s, beginning with Morton Heilig's "Sensorama," a device that combined visuals, sound, and vibration for a multi-sensory experience. In 1968, Ivan Sutherland introduced the first head-mounted display, laying the groundwork for future VR systems. By the 1980s and 1990s, the technology had evolved further, particularly in aviation, defence, and gaming, with the term "virtual reality" popularised by Jaron Lanier. Early systems were expensive and limited in scope, but significant advancements in computing and motion tracking from the 2000s onward made VR more accessible. The emergence of consumer-friendly platforms like Oculus Rift and HTC Vive in the 2010s marked a turning point in VR's widespread adoption.

2.3.3 Mechanisms and User Experience of Virtual Reality

Modern VR systems synchronise users' physical movements with virtual environments using a combination of hardware and software. Core components include a display device (such as a head-mounted display), motion sensors, and input interfaces. These elements update the visual field in real time based on user movement, maintaining visual coherence and depth (Li, 2023).

Motion sensors, such as gyroscopes, accelerometers, and cameras, track user position and gestures, allowing for seamless interaction within the virtual space.

From the user’s perspective, VR offers a strong sense of presence. Visual and auditory cues, and occasionally haptic feedback, contribute to the immersive experience. Interfaces are often designed to allow natural actions, such as reaching or turning, which enhances engagement. Fully immersive systems replace real-world stimuli with 360-degree virtual visuals, allowing users to feel situated within the environment. Many systems adapt automatically to user behaviour, maintaining a balance between comfort and challenge to sustain attention and minimise fatigue (Moan et al., 2021; Bui et al., 2021).

2.3.4 Classification of Virtual Reality

VR can be classified based on the degree of immersion and interaction:

Immersive VR involves full sensory engagement through head-mounted displays and spatial tracking. Users are wholly surrounded by the virtual environment, creating a heightened sense of presence. This type is commonly used in simulations and high-fidelity training scenarios (Khan et al., 2024).

Non-Immersive VR uses a standard monitor and basic input devices like keyboards or motion controllers. While more accessible and cost-effective, it offers less immersion and realism.

Semi-Immersive VR incorporates large screens or projection domes that provide partial immersion. Users can interact with the environment while being aware of their surroundings. This setup is often found in flight or driving simulators.

VR can also be grouped by use case:

i. Recreational VR: for gaming and entertainment

ii. Educational or Training VR: for learning skills in fields like aviation or surgery

iii. Industrial VR: for design and prototyping

iv. Clinical or Therapeutic VR: for applications in healthcare and rehabilitation.

Figure 4: Supervised Virtual Reality Therapy for Stroke Recovery
(AI generated, 2025)

2.4 Theoretical Framework

The theoretical framework guiding this study is the Motor Relearning Theory (MRT), initially developed by Carr and Shepherd in the 1980s. MRT is based on the principle that motor recovery following neurological injury, such as stroke, is best achieved through active, repetitive, task-specific practice of functional activities. It proposes that relearning motor skills requires movement repetition and meaningful, goal-directed tasks performed in real-life contexts (Carr & Shepherd, 1987). Central to MRT is neuroplasticity, the brain's ability to reorganise and form new neural pathways in response to experience and training. The theory emphasises cognitive involvement, problem-solving, feedback, and environmental relevance as critical elements in facilitating motor relearning. Rather than relying on reflex-based or passive therapy, MRT supports active engagement where patients attempt, correct, and adapt their movements with the guidance of a therapist and through practice.

Virtual reality (VR)-based rehabilitation aligns strongly with MRT principles. VR environments enable users to perform goal-oriented movements, receive real-time sensory feedback, and engage in motivating tasks that simulate daily functional activities. These systems also allow graded difficulty, performance monitoring, and repetitive practice, essential to the motor relearning process and reinforce correct motor patterns through neuroplastic changes (Bui et al., 2021; Khan et al., 2024). The validity of the Motor Relearning Theory (MRT) is reinforced by its alignment with current scientific understanding of neuroplasticity and motor control. Modern clinical guidelines, such as those from the American Heart Association and the UK National Clinical Guideline for Stroke, strongly advocate for task-specific and functional training, which are fundamental to the MRT approach (Intercollegiate Stroke Working Party, 2023). Empirical evidence further supports its validity; studies have demonstrated that interventions built on MRT principles, such as constraint-induced movement therapy (CIMT) and repetitive task training, result in significant improvements in motor function and functional independence, thereby affirming both the construct and content validity of the theory (Langhorne et al., 2011). Regarding reliability, the core principles of MRT have been consistently replicated across diverse clinical settings, patient populations, and therapy modalities. Its widespread adoption and the reproducibility of positive motor outcomes reflect the theory’s robustness and practical reliability in guiding effective stroke rehabilitation.

2.5 Empirical Review of Literature

Table 1: Empirical Studies on the Effectiveness of Virtual Reality on Motor Recovery Parameters in Stroke Survivors

AUTHOR, YEAR, COUNTRY	TITLE	SAMPLE SIZE	AIM OF STUDY	STUDY TYPE	OUTCOME MEASURE	FINDINGS
Aderinto et al., 2023, Nigeria	Exploring the efficacy of virtual reality-based rehabilitation in stroke: a narrative review of current evidence	Narrative (n/a)	To examine the efficacy of virtual reality-based rehabilitation in stroke rehabilitation, focusing on its advantages and challenges.	Narrative Review	General rehabilitation impact	VR is promising but constrained by cost and infrastructure; local adaptation is feasible.
Cai et al., 2021, China	Evaluating the effect of immersive virtual reality technology on gait rehabilitation in stroke patients: a study protocol for a randomized controlled trial	36	To assess the effect of immersive VR-assisted rehabilitation training for stroke patients with gait disorders.	RCT	TUG, Dynamic Gait Index	Unpublished
Ghai et al., 2020, India	Virtual reality training enhances gait poststroke: a systematic review and meta-analysis	32 studies	To provide the current state of evidence for the effects of VR on gait performance	Meta-analysis	Gait speed, stride length, cadence	Moderate effect sizes favour VR over control in all gait parameters.
Hammed et al., 2018, Nigeria	Alterations in gait velocity and grip strength of stroke survivors following a 12-week structured therapeutic exercise programme	30 hemiparetic stroke survivors	To investigate the alterations in gait velocity and grip strength of stroke survivors following a structured therapeutic exercise programme (STEP).	True experimental	Gait velocity, Grip strength	Improved outcomes in gait velocity and grip strength.

Khan et al., 2021, USA	Virtual reality in post-stroke neurorehabilitation – a systematic review and meta-analysis	27 RCTs	To compare VR vs. conventional therapy across motor and cognitive outcomes	Meta-analysis	Fugl-Meyer, Berg Balance Scale, MMSE, 10MWT, TUG	No significant difference in motor outcomes between VR and control when dose is matched; VR remains effective and engaging.
Rodríguez-Hernández et al., 2023, Spain	Can specific virtual reality combined with conventional rehabilitation improve poststroke hand motor function? A randomized clinical trial	43	To verify whether conventional rehabilitation combined with specific virtual reality is more effective than conventional therapy alone in restoring hand motor function and muscle tone after stroke.	RCT	Modified Ashworth Scale, Fugl-Meyer Assessment, Action Research Arm Test	Conventional rehabilitation combined with a specific virtual reality technology system can be more effective than conventional programs alone in improving hand motor function and voluntary movement and in normalizing muscle tone in subacute stroke patients.
Soleimani, M. et al., 2024, Iran	The efficacy of virtual reality for upper limb rehabilitation in stroke patients: a systematic review and meta-analysis	2142 patients (55 RCTs)	To compare virtual reality based rehabilitation with conventional occupational therapy across a spectrum of immersion levels and outcome domains.	Systematic Review and Meta-analysis	Upper limb motor function, spasticity, dexterity, QoL	Virtual reality-based rehabilitation enhances upper limb motor recovery across multiple functional domains compared to conventional occupational therapy alone after stroke.

2.6 Gaps in Literature

Despite the increasing global interest in VR for stroke rehabilitation, several critical gaps remain, particularly regarding its applicability in low-resource contexts. This section outlines key gaps identified in the literature:

i. Lack of Data from Low-Resource Settings: Most VR stroke rehab studies are from high-income countries. There is limited evidence from Nigeria and Africa, where access to equipment is scarce (Khan et al., 2024).

ii. Inconsistent Intervention Methods: Studies differ in VR type, session length, frequency, and task design, making comparing results or creating standard protocols complicated (Laver et al., 2017).

iii. Few Long-Term Follow-Ups: Many studies do not track patients beyond the intervention period, so it is unclear if gains from VR are sustained over time.

iv. Underrepresented Patient Groups: People with severe stroke, cognitive issues, or older adults are often excluded from trials, even though they make up a large part of the real-world population.

v. Limited Understanding of Mechanisms of Action: Limited research on the brain changes caused by VR therapy makes it harder to explain how and why it works.

vi. Limited Data on Cost and Real-Life Use: Few studies explore how VR can be used in regular clinical settings, especially in low-income hospitals. There is also little data on cost-effectiveness.

vii. Few Patient-Centred Measures: Most research focuses on physical improvement. Less is known about how VR affects patients’ quality of life, motivation, or mental health.

CHAPTER THREE

MATERIALS AND METHODS

This chapter describes the materials and methods that were employed to evaluate the effectiveness of virtual reality-based rehabilitation on motor recovery among stroke survivors undergoing rehabilitation at the University of Benin Teaching Hospital (UBTH). It also outlines the study population, sampling approach, selection criteria, instruments, intervention protocols, and statistical analysis techniques.

3.1 Materials

The materials for this study includes a virtual reality headset (Meta Quest 3), standardised rehabilitation software, therapy space with safe flooring, chairs, examination bed, and assessment instruments such as a universal goniometer, the Medical Research Council (MRC) scale, the 30-Second Chair Stand Test, the modified Arm Curl Test, and the Berg Balance Scale (BBS). Data recording sheets, consent forms, and a digital spreadsheet for data entry were also used.

3.1.1 Population

The target population comprised adult stroke survivors receiving physical rehabilitation at the neurology unit, physiotherapy department, University of Benin Teaching Hospital. These individuals were between 18 and 65 years old, medically stable, and experiencing motor impairments in their upper and lower limbs.

3.1.2 Selection Criteria

3.1.2.1 Inclusion Criteria

Participants were included in the study according to the following inclusion criteria:

i. Aged 18 to 65 years.

ii. Stroke survivors undergoing physical rehabilitation at the physiotherapy department, UBTH.

iii. Presence of residual motor impairment (e.g., hemiparesis affecting the arm and leg).

iv. Medically stable and able to engage in exercise therapy.

v. Ability to give informed consent and willingness to participate in either VR or conventional therapy sessions for 8 weeks.

3.1.2.2 Exclusion Criteria

Participants meeting any of the following criteria were excluded from the study:

i. Severe cognitive or communication impairment (e.g., advanced dementia or expressive/receptive aphasia).

ii. Significant visual or sensory deficits (e.g., profound visual impairment, severe proprioceptive or vestibular disorders).

3.1.3 List of Instruments

i. Universal Goniometer – to assess joint flexibility (ROM).
ii. Medical Research Council (MRC) Scale – to assess muscular strength.
iii. 30-Second Chair Stand Test – for lower limb muscular endurance.
iv. Arm Curl Test – for upper limb muscular endurance.
v. Berg Balance Scale (BBS) – for assessing balance and coordination.

3.1.4 Description of Instruments

i. Universal Goniometer:

A 360° plastic or metal protractor-like tool with two arms, used to measure joint range of motion in degrees.

Studies report strong intra-rater reliability (ICC > 0.90) and content validity for measuring ROM (Norkin & White, 2021).

Measurements were recorded in degrees of motion for each targeted joint (shoulder, elbow, wrist, hip, knee, and ankle).

ii. Medical Research Council (MRC) Scale:

A clinical scale from 0 (no contraction) to 5 (normal strength) used for manual muscle testing.

Shown to be valid and reliable in stroke patients with an ICC > 0.85 (Sullivan et al., 2020).

Each tested muscle group were scored from 0 to 5, with total strength scores calculated.

iii. 30-Second Chair Stand Test:

Measures how many times a participant can rise to a full stand from a chair and sit back down in 30 seconds.

Excellent test–retest reliability (r > 0.84) makes it valid for assessing lower limb endurance (Jones et al., 1999).

Scoring: Total number of full stands completed in 30 seconds.

iv. Modified Arm Curl Test

Measures the number of bicep curls a participant can perform in 30 seconds without an external weight/resistance.

Valid and reliable for upper limb endurance in neurologic and geriatric populations (ICC = 0.81) (Rikli & Jones, 2001).

Scoring: Total repetitions completed in 30 seconds.

v. Berg Balance Scale (BBS)

A 14-item scale assessing static and dynamic balance via tasks like standing, turning, and reaching.

ICC = 0.98; widely accepted as valid and reliable for stroke populations (Berg et al., 1992).

Each item is scored 0–4. Maximum score: 56. Scores < 45 indicate increased fall risk.

3.2 Methods

Participants were randomly allocated into two groups:

- Experimental group (virtual reality-ased therapy plus conventional physiotherapy)
- Control group (Conventional physiotherapy)

Randomisation was carried out using a folded-paper draw method. 40 identical sheets of paper were prepared, each clearly marked with either the letter "E" (experimental group) or "C" (control group) in equal numbers. These papers were folded in such a way that the markings were completely concealed and indistinguishable from one another. The folded slips were then thoroughly mixed and placed in a container. At the point of allocation, each participant was asked to pick one folded slip at random. Participants who selected a slip marked "E" were assigned to the experimental group, while those who selected a slip marked "C" were assigned to the control group.

Participants in the control group received conventional physiotherapy for stroke rehabilitation, as routinely provided at the University of Benin Teaching Hospital. These sessions consisted of therapist-guided exercises aimed at improving muscle strength, endurance, joint flexibility, balance, and coordination. Each session lasted approximately 45 minutes and was conducted three times a week for eight weeks, following standard physiotherapy practice for stroke survivors without the use of virtual reality. In contrast, participants in the experimental group received virtual reality-based physiotherapy in addition to conventional physiotherapy. Their sessions lasted approximately 1hour, 5 minutes in total, conducted three times a week for eight weeks. The intervention included 45 minutes of conventional physiotherapy intervention, followed by an additional 20 minutes of engaging, task-oriented virtual reality activities designed to stimulate upper and lower limb motor function, enhance balance and coordination, and improve muscle strength, endurance, and joint flexibility.

3.2.1 Research Design

The pre-test, post-test control group experimental design was used in this study. The design was adopted because it was appropriate for comparing the differences in upper and lower limb's muscle strength, muscle endurance, joint flexibility, coordination and balance of stroke survivors prior to and following an 8-week VR. Baseline measurements was taken, recorded and re-evaluated at the 8th week as the post test result of the intervention programmes. Experimental participants were involved in virtual reality and conventional treatment, while participants in control group were involved in conventional treatment only. The design provided avenue through which differences were checked. The design is illustrated as follows:

R	O_1		O_2
R	O_1	X_1	O_2

Where:

R = Randomization

O_1 = Pre-test

O_2 = Post-test

X_1 = Virtual Reality (Experimental group)

3.2.2 Sampling Technique

Simple random sampling was employed to allocate eligible participants into the two groups using a random draw technique to prevent bias. Participants were coded and randomly assigned to either group.

3.2.3 Sample Size

The sample size for this study was determined using Yamane's (1967) formula for a finite population, which is expressed as:

$$n = \frac{N}{1+N(e)^2}$$

where:

n = required sample size,

N = total population, and

e = level of precision (0.05 at 95% confidence level).

Given a total population (N) of 60 stroke survivors, the calculation was as follows:

$$n = \frac{60}{1+60(0.05)^2}$$

$$n = \frac{60}{1+0.15}$$

$$n = \frac{60}{1.15}$$

$$n = 52.17$$

The computed sample size was approximately 52 stroke survivors. A total of 52 stroke survivors undergoing rehabilitation at UBTH were initially assessed for eligibility. However, 9 stroke survivors did not meet the inclusion criteria and 3 stroke survivors declined participation. This brought the number of eligible stroke survivors to 40. All 40 eligible stroke survivors were randomly allocated equally into two groups: the experimental group, which received virtual reality-based rehabilitation in addition to conventional physiotherapy, and the control group, which received conventional physiotherapy only. A total of 40 participants who completed the study and were included in the final analysis.

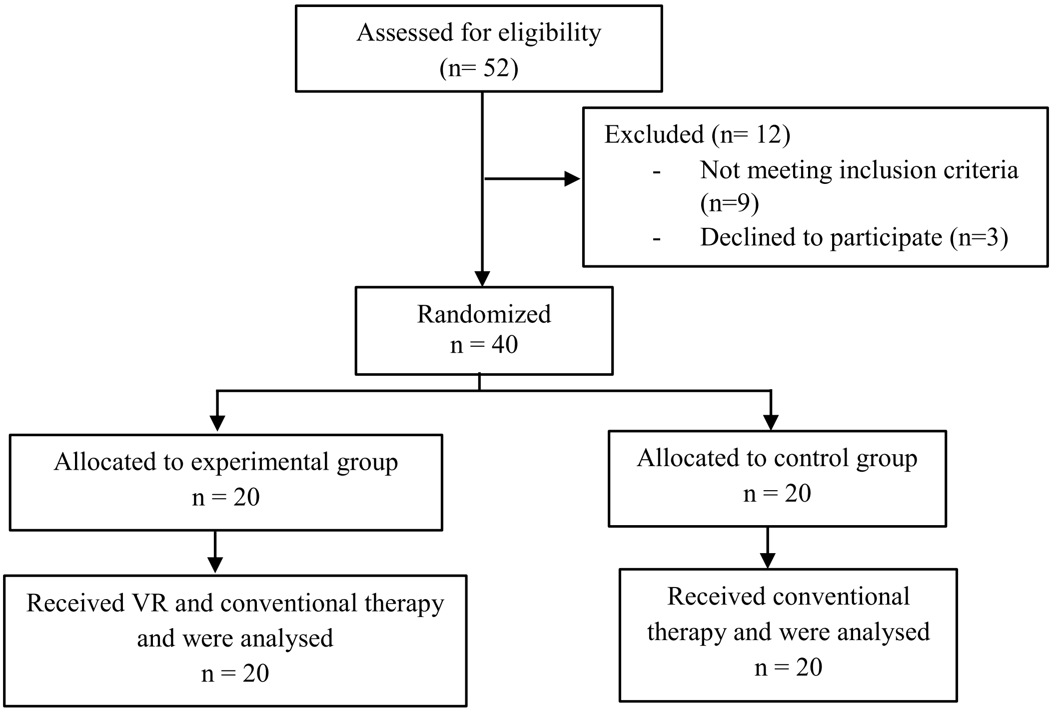


Figure 5: Flowchart Showing the Recruitment and Allocation of Participants in the Study

3.2.4 Ethical Consideration

Ethical approval for this study was obtained from the Health Research Ethics Committee of the University of Benin Teaching Hospital, Benin City, Nigeria, with protocol number: ADM/E22/A/VOL.VII/2025/132.

Before enrolment, each participant received detailed information about the study objectives, procedures, and potential risks, after which informed consent was obtained. Participation was entirely voluntary, and participants were informed of their right to withdraw from the study at any stage without any consequences for their ongoing medical care.

The confidentiality of participant data was strictly maintained by assigning unique identification letters (e.g., A, B, C) and restricting access to study records to the research team only. Data were stored securely and used solely for research purposes. The interventions posed minimal risk to participants, as both virtual reality-based therapy and conventional physiotherapy are established rehabilitation approaches for stroke patients.

3.2.5 Procedure for Data Collection

The data collection process followed a structured sequence of steps to ensure consistency, accuracy, and participant safety throughout the study. The entire procedure was carried out over 8 weeks at the Outpatient Clinic of the Physiotherapy Department at the University of Benin Teaching Hospital.

Recruitment and Screening of Participants: Potential participants were identified from the pool of stroke patients currently undergoing rehabilitation at UBTH. These individuals were approached in the clinic or ward and given a brief explanation of the study. Those who expressed interest were further screened based on the inclusion and exclusion criteria.

Eligibility Assessment: Participants were assessed to ensure they met the eligibility (inclusion and exclusion) criteria.

Informed Consent: Eligible individuals were given a clear explanation of the study's purpose, procedures, duration, and risks. Participants or their legal guardians read and signed the consent forms where necessary.

Baseline (Pre-Test) Assessments: Participants underwent baseline assessments to determine their initial motor function status before the intervention began. These tests were used to measure progress after the 8-week intervention. The following parameters were assessed using standardised and validated tools:

i. Muscle Strength

Instrument: Medical Research Council (MRC) Scale

Description: This is a widely accepted clinical scale to evaluate voluntary muscle contraction against gravity and resistance.

Muscle Groups Assessed – Upper limb (Shoulder flexors/extensors, elbow flexors/extensors, wrist flexors/extensors) and Lower limb (Hip flexors/extensors, knee flexors/extensors, ankle flexors/extensors)

Scoring: Each muscle group was graded on a 0–5 scale:

0 = No contraction

1 = Flicker or trace of contraction

2 = Active movement with gravity eliminated

3 = Active movement against gravity

4 = Active movement against gravity and some resistance

5 = Normal strength

Procedure: The researcher palpated and observed each group's muscle activity during resisted movement. Each muscle group was tested individually, and scores were recorded.

ii. Muscle Endurance: separate field tests were used for both upper and lower limb endurance:

Upper Limb Endurance

- Instrument: Modified Arm Curl Test (30-seconds, weight-free adaptation)
- Procedure: The traditional Arm Curl Test, developed as part of the Senior Fitness Test, requires participants to perform as many arm curls as possible in 30 seconds using a fixed dumbbell weight (2.5 kg for females and 3.5 kg for males). For the present study, the test was adapted to suit stroke survivors with motor impairments by eliminating the external weight. Participants were instructed to perform elbow flexion and extension movements with the affected arm, relying solely on the natural weight of the limb.
- Scoring: The number of complete flexion–extension repetitions achieved within 30 seconds was recorded.

Lower Limb Endurance

- Instrument: 30-Second Chair Stand Test
- Procedure: The participant sat in a standard chair (about 43 cm high) with arms folded across the chest. They were instructed to stand up fully and sit back down as many times as possible in 30 seconds.
- Scoring: The total number of full stands completed was documented.

iii. Joint Flexibility

Instrument: Universal Goniometer

Joints Measured: Upper limb (Shoulder, elbow, wrist) and Lower limb (Hip, knee, ankle)

Procedure: With the participant seated or lying, the researcher aligned the goniometer arms with anatomical landmarks to measure active joint angles.

Scoring: The ROM was recorded in degrees for each joint.

iv. Balance

Instrument: Berg Balance Scale (BBS)

Procedure: This 14-item scale assesses static and dynamic balance through tasks such as standing unsupported, turning, and transferring.

Scoring: Each item is rated from 0 to 4, with a maximum total score of 56. Higher scores reflect better balance.

v. Coordination

Instruments:

Rapid Alternating Movement Test (forearm pronation–supination); number of repetitions completed within 30 seconds.

Heel-to-Shin Test for lower limb coordination (number of repetitions performed within 30 seconds).

Procedure:

- Upper-limb coordination was assessed using the Rapid Alternating Movement (RAM) Test (forearm pronation/supination). Lower-limb coordination was assessed using a timed Heel-to-Shin repetition test. For both tests, participants performed one familiarisation trial, then were instructed to perform as many correct repetitions as possible in 30 seconds with the affected limb. One correct repetition was defined as one full pronation followed by one full supination returning to the start position; Heel-to-Shin: one full slide of the heel from the ankle to the knee and back to the ankle. Only complete and accurate repetitions were counted. Partial, grossly inaccurate, or heavily compensatory movements were not counted.

Scoring: The number of correct repetitions in 30 seconds was recorded as the coordination score.

All assessments were carried out by the researcher and trained assistants, following standardised protocols. To minimise inter-rater variability, the same assessor performed both pre- and post-test evaluations for each participant.

All baseline measurements were documented on data collection forms and later entered into a secure digital database.

Group Allocation: Following pre-test assessment, participants were randomly assigned to one of two groups using simple random sampling (i.e. random paper-draw from a container). The two groups are:

Experimental Group – received Virtual Reality therapy plus conventional therapy

Control Group – received Conventional Physiotherapy only

Intervention Administration: The intervention phase spanned 8 weeks, with participants attending three sessions per week (24 sessions in total).

A. Virtual Reality Therapy (Experimental Group)

Participants in the VR group received conventional physiotherapy and VR therapy, which involved using a fully immersive virtual reality system. The setup consisted of:

i. A head-mounted display (HMD) to project a simulated environment
ii. Motion sensors to track limb movement
iii. Interactive rehabilitation software focused on reaching, grasping, stepping, and balance tasks

Examples of VR activities delivered through Kinesix XR on Meta Quest 3 included:

i. Upper limb tasks: Participants engaged in catching and releasing moving virtual objects, and stacking cubes that required controlled reaching and fine motor coordination.
ii. Lower limb tasks: Activities involved shifting weight from side to side while navigating through virtual hallways, as well as stepping tasks designed to challenge balance and stability.
iii. Coordination tasks: Participants practiced hitting or guiding objects to specific targets, which required accuracy, timing, and smooth alternating movements.

B. Conventional Physiotherapy (Control Group)

Participants in this group underwent rehabilitation following UBTH's standard stroke rehab protocol. Each session included the following amongst others:

i. Strengthening exercises for weak muscles using manual resistance
ii. Range of motion exercises (active and passive stretching of joints)
iii. Balance and gait training, including sit-to-stand drills, supported walking, and weight-shifting
iv. Task-oriented practice, such as reaching, picking objects, and step-ups
v. Coordination drills like clapping patterns, or heel-to-shin sliding

Post-Test Assessments: After 8 weeks, all outcome measures (muscle strength, endurance, joint ROM, balance, and coordination) were reassessed using the same tools and procedures as in the baseline. The post-intervention data allowed comparison of progress made by each group.

Data Management and Preparation for Analysis: All data were entered into a spreadsheet for review and checked for completeness and correctness. Each participant was assigned a unique ID to maintain confidentiality. The compiled data was analysed using appropriate statistical tools, with results presented in tables.

3.2.6 Data Analysis

Descriptive statistics of frequency, percentage, mean and standard deviation were used to analyse the socio-demographic and clinical characteristics of the participants. An inferential statistic of one-way analysis of variance (one-way ANOVA) was adopted to test hypotheses 1 to 9. Tukey's Honestly Significant Difference (HSD) post-hoc test was performed for all outcomes to identify specific pairwise differences between groups. Statistical significance was accepted for p-value of <0.05. All the analyses were performed with the use of Statistical Package for the Social Sciences (SPSS) version 27.

CHAPTER FOUR

RESULTS

4.1 Socio-demographic and Clinical Characteristics of the Participants

The socio-demographic characteristics of the participants are summarised in Table 2. Out of the 40 participants, 18 (45%) were males and 22 (55%) were females. The mean age of the participants was 50.30 ± 11.04 years. Regarding the type of stroke, 26 participants (65%) had an ischaemic stroke, while 14 participants (35%) had a haemorrhagic stroke.

Table 2: Descriptive Statistics of the Demographic Parameters of the Participants

Variables		**Frequency**	**Percentage %**	**Mean**	**Standard Deviation**
Age				50.30	11.044
Gender	Male	18	22.5		
	Female	22	27.5		
Type of Stroke	Ischaemic	26	32.5		
	Haemorrhagic	14	17.5		

4.2 Effects of Intervention on Motor Recovery (Hypotheses Testing)

This section reports the effects of virtual reality combined with conventional physiotherapy versus conventional physiotherapy alone on motor recovery in stroke survivors, across upper and lower limb strength, endurance, joint flexibility, balance and coordination.

Hypothesis 1

There is no significant difference in upper limb muscular strength between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 3: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality Based Rehabilitation on Upper Limb Muscle Strength

Dependent Variable		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
MSsf	Between Groups	16.150	3	5.383	8.933	<.001*
	Within Groups	45.800	76	.603		
	Total	61.950	79			
MSse	Between Groups	13.800	3	4.600	7.874	<.001*
	Within Groups	44.400	76	.584		
	Total	58.200	79			
MSef	Between Groups	18.000	3	6.000	13.412	<.001*
	Within Groups	34.000	76	.447		
	Total	52.000	79			
MSee	Between Groups	17.200	3	5.733	18.463	<.001*
	Within Groups	23.600	76	.311		
	Total	40.800	79			
MSwf	Between Groups	20.950	3	6.983	10.407	<.001*
	Within Groups	51.000	76	.671		
	Total	71.950	79			
MSwe	Between Groups	22.950	3	7.650	10.970	<.001*
	Within Groups	53.000	76	.697		
	Total	75.950	79			

MSsf- muscle strength shoulder flexion, MSse- muscle strength shoulder extension, MSef – muscle strength elbow flexion, MSee- muscle strength elbow extension, MSwf- Muscles strength wrist flexion, MSwe- muscle strength wrist extension

From Table 3, the analysis of variance indicated a statistically significant difference ($p < 0.001$) in the upper limb muscle strength of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. These findings demonstrate that the intervention had a significant impact on improving upper limb muscular strength among stroke survivors. Due to this significant difference, hypothesis 1 is rejected. This outcome warranted further analysis using Tukey’s post-hoc test to determine where the specific differences lie among the intervention groups. The post-hoc results are summarized in Table 4.

Table 4: Tukey's Honestly Significance Difference Post-Hoc Test of Upper Limb Muscle Strength Between Experimental and Control Group

Dependent Variable	**(I) ANOVA**	**(J) ANOVA**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
MSsf	Pre CT	Post CT	-.400	.245	.368
		Pre VR	.001	.245	1.000
		Post VR	-1.100*	.245	<.001
	Post CT	Pre CT	.400	.245	.368
		Pre VR	.400	.245	.368
		Post VR	-.700*	.245	.028
	Pre VR	Pre CT	.001	.245	1.000
		Post CT	-.400	.245	.368
		Post VR	-1.100*	.245	<.001
	Post VR	Pre CT	1.100*	.245	<.001
		Post CT	.700*	.245	.028
		Pre VR	1.100*	.245	<.001
MSse	Pre CT	Post CT	-.600	.242	.071
		Pre VR	.100	.242	.976
		Post VR	-.900*	.242	.002
	Post CT	Pre CT	.600	.242	.071
		Pre VR	.700*	.242	.025
		Post VR	-.300	.242	.603
	Pre VR	Pre CT	-.100	.242	.976
		Post CT	-.700*	.242	.025
		Post VR	-1.000*	.242	<.001
	Post VR	Pre CT	.900*	.242	.002
		Post CT	.300	.242	.603
		Pre VR	1.000*	.242	<.001
MSef	Pre CT	Post CT	-.700*	.212	.008
		Pre VR	-.400	.212	.240
		Post VR	-1.300*	.212	<.001
	Post CT	Pre CT	.700*	.212	.008
		Pre VR	.300	.212	.492
		Post VR	-.600*	.212	.029
	Pre VR	Pre CT	.400	.212	.240
		Post CT	-.300	.212	.492
		Post VR	-.900*	.212	<.001
	Post VR	Pre CT	1.300*	.212	.000
		Post CT	.600*	.212	.029
		Pre VR	.900*	.212	<.001
MSee	Pre CT	Post CT	-.800*	.176	<.001
		Pre VR	-.100	.176	.941
		Post VR	-1.100*	.176	<.001
	Post CT	Pre CT	.800*	.176	<.001
		Pre VR	.700*	.176	<.001
		Post VR	-.300	.176	.330

	Pre VR	Pre CT	.100	.176	.941
		Post CT	-.700*	.176	<.001
		Post VR	-1.000*	.176	<.001
	Post VR	Pre CT	1.100*	.176	<.001
		Post CT	.300	.176	.330
		Pre VR	1.000*	.176	<.001
MSwf	Pre CT	Post CT	-.400	.259	.417
		Pre VR	.800*	.259	.015
		Post VR	-.500	.259	.224
	Post CT	Pre CT	.400	.259	.417
		Pre VR	1.200*	.259	<.001
		Post VR	-.100	.259	.980
	Pre VR	Pre CT	-.800*	.259	.015
		Post CT	-1.200*	.259	<.001
		Post VR	-1.300*	.259	<.001
	Post VR	Pre CT	.500	.259	.224
		Post CT	.100	.259	.980
		Pre VR	1.300*	.259	<.001
MSwe	Pre CT	Post CT	-.300	.264	.669
		Pre VR	.900*	.264	.006
		Post VR	-.500	.264	.240
	Post CT	Pre CT	.300	.264	.669
		Pre VR	1.200*	.264	.000
		Post VR	-.200	.264	.873
	Pre VR	Pre CT	-.900*	.264	.006
		Post CT	-1.200*	.264	<.001
		Post VR	-1.400*	.264	<.001
	Post VR	Pre CT	.500	.264	.240
		Post CT	.200	.264	.873
		Pre VR	1.400*	.264	<.001

Pre CT – pre control, Post CT – post control, Pre VR – pre virtual reality, Post VR – post virtual reality.

Tukey's Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in upper limb muscle strength of the participants. For shoulder flexion (MSsf), all statistically significant pairwise mean differences ($p < 0.05$) were observed between Pre CT versus Post VR (-1.100*), Post CT versus Post VR (-0.700*), Pre VR versus Post VR (-1.100*), Post VR versus Pre CT (1.100*), Post VR versus Post CT (0.700*), and Post VR versus Pre VR (1.100*). For shoulder extension (MSse), significant differences occurred between Pre CT versus Post VR (-0.900*), Post CT versus Pre VR (0.700*), Pre VR versus Post CT (-0.700*), Pre VR versus Post VR (-1.000*), Post VR versus Pre CT (0.900*), and Post VR versus Pre VR (1.000*). For elbow flexion (MSef), significant mean differences were noted between Pre CT versus Post CT (-0.700*), Pre CT versus Post VR (-1.300*), Post

CT versus Pre CT (0.700*), Post CT versus Post VR (-0.600*), Pre VR versus Post VR (-0.900*), Post VR versus Pre CT (1.300*), Post VR versus Post CT (0.600*), and Post VR versus Pre VR (0.900*). For elbow extension (MSee), the significant pairwise differences included Pre CT versus Post CT (-0.800*), Pre CT versus Post VR (-1.100*), Post CT versus Pre VR (0.700*), Pre VR versus Post CT (-0.700*), Pre VR versus Post VR (-1.000*), Post VR versus Pre CT (1.100*), and Post VR versus Pre VR (1.000*). For wrist flexion (MSwf), significant differences were found between Pre CT versus Pre VR (0.800*), Post CT versus Pre VR (1.200*), Pre VR versus Pre CT (-0.800*), Pre VR versus Post CT (-1.200*), Pre VR versus Post VR (-1.300*), and Post VR versus Pre VR (1.300*). Lastly, for wrist extension (MSwe), significant mean differences were recorded between Pre CT versus Pre VR (0.900*), Post CT versus Pre VR (1.200*), Pre VR versus Pre CT (-0.900*), Pre VR versus Post CT (-1.200*), Pre VR versus Post VR (-1.400*), and Post VR versus Pre VR (1.400*). Collectively, the post-hoc analysis revealed that most of the significant mean differences consistently involved the Post VR group, which demonstrated superior performance across all upper limb muscle strength parameters (shoulder, elbow, and wrist flexion and extension). Therefore, virtual reality-based rehabilitation produced significant improvements in upper limb muscle strength among stroke survivors when compared to conventional therapy and pre-intervention conditions.

Hypothesis 2

There is no significant difference in lower limb muscular strength between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 5: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality Based Rehabilitation on Lower Limb Muscle Strength

Dependent Variable		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
MShf	Between Groups	27.200	3	9.067	21.533	<.001*
	Within Groups	32.000	76	.421		
	Total	59.200	79			
MShe	Between Groups	30.400	3	10.133	26.018	<.001*
	Within Groups	29.600	76	.389		
	Total	60.000	79			
MSkf	Between Groups	26.950	3	8.983	17.687	<.001*
	Within Groups	38.600	76	.508		
	Total	65.550	79			
MSke	Between Groups	15.350	3	5.117	13.790	<.001*
	Within Groups	28.200	76	.371		
	Total	43.550	79			
MSaf	Between Groups	18.000	3	6.000	7.972	<.001*
	Within Groups	57.200	76	.753		
	Total	75.200	79			
MSae	Between Groups	26.200	3	8.733	16.268	<.001*
	Within Groups	40.800	76	.537		
	Total	67.000	79			

MShf- muscle strength hip flexion, MShe- muscle strength hip extension, MSkf – muscle strength knee flexion, MSke- muscle strength knee extension, MSaf- Muscles strength ankle flexion, MSae- muscle strength ankle extension

From Table 5, the analysis of variance test indicated a statistically significant difference ($p < 0.001$) in the lower limb muscle strength of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. These findings demonstrate that the intervention had a significant impact on improving lower limb muscular strength among stroke survivors. Due to this significant difference, hypothesis 2 is rejected. This outcome warranted further analysis using Tukey's post-hoc test to determine where the specific differences lie among the intervention groups. The post-hoc results are summarized in Table 6.

Table 6: Tukey's Honestly Significance Difference Post-Hoc Test of Lower Limb Muscle Strength Between Experimental and Control Group

Dependent Variable	(I) ANOVA	(J) ANOVA	Mean Difference (I-J)	Std. Error	Sig.
MShf	Pre CT	Post CT	-1.000*	.205	<.001
		Pre VR	-.600*	.205	.023
		Post VR	-1.600*	.205	<.001
	Post CT	Pre CT	1.000*	.205	<.001
		Pre VR	.400	.205	.217
		Post VR	-.600*	.205	.023
	Pre VR	Pre CT	.600*	.205	.023
		Post CT	-.400	.205	.217
		Post VR	-1.000*	.205	<.001
	Post VR	Pre CT	1.600*	.205	<.001
		Post CT	.600*	.205	.023
		Pre VR	1.000*	.205	<.001
MShe	Pre CT	Post CT	-1.000*	.197	<.001
		Pre VR	.000	.197	1.000
		Post VR	-1.400*	.197	<.001
	Post CT	Pre CT	1.000*	.197	<.001
		Pre VR	1.000*	.197	<.001
		Post VR	-.400	.197	.187
	Pre VR	Pre CT	.000	.197	1.000
		Post CT	-1.000*	.197	<.001
		Post VR	-1.400*	.197	<.001
	Post VR	Pre CT	1.400*	.197	<.001
		Post CT	.400	.197	.187
		Pre VR	1.400*	.197	<.001
MSkf	Pre CT	Post CT	-.700*	.225	.014
		Pre VR	.000	.225	1.000
		Post VR	-1.400*	.225	<.001
	Post CT	Pre CT	.700*	.225	.014
		Pre VR	.700*	.225	.014
		Post VR	-.700*	.225	.014
	Pre VR	Pre CT	.000	.225	1.000
		Post CT	-.700*	.225	.014
		Post VR	-1.400*	.225	<.001
	Post VR	Pre CT	1.400*	.225	<.001
		Post CT	.700*	.225	.014
		Pre VR	1.400*	.225	<.001
MSke	Pre CT	Post CT	-.800*	.193	<.001
		Pre VR	-.500	.193	.054
		Post VR	-1.200*	.193	<.001
	Post CT	Pre CT	.800*	.193	<.001
		Pre VR	.300	.193	.409
		Post VR	-.400	.193	.170
	Pre VR	Pre CT	.500	.193	.054
		Post CT	-.300	.193	.409
		Post VR	-.700*	.193	.003

	Post VR	Pre CT	1.200*	.193	<.001
		Post CT	.400	.193	.170
		Pre VR	.700*	.193	.003
MSaf	Pre CT	Post CT	-.200	.274	.885
		Pre VR	.100	.274	.983
		Post VR	-1.100*	.274	.001
	Post CT	Pre CT	.200	.274	.885
		Pre VR	.300	.274	.695
		Post VR	-.900*	.274	.008
	Pre VR	Pre CT	-.100	.274	.983
		Post CT	-.300	.274	.695
		Post VR	-1.200*	.274	<.001
	Post VR	Pre CT	1.100*	.274	.001
		Post CT	.900*	.274	.008
		Pre VR	1.200*	.274	<.001
MSae	Pre CT	Post CT	-.400	.232	.317
		Pre VR	.000	.232	1.000
		Post VR	-1.400*	.232	<.001
	Post CT	Pre CT	.400	.232	.317
		Pre VR	.400	.232	.317
		Post VR	-1.000*	.232	<.001
	Pre VR	Pre CT	.000	.232	1.000
		Post CT	-.400	.232	.317
		Post VR	-1.400*	.232	<.001
	Post VR	Pre CT	1.400*	.232	<.001
		Post CT	1.000*	.232	<.001
		Pre VR	1.400*	.232	<.001

Tukey’s Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in lower limb muscle strength of the participants. For hip flexion (MShf), all statistically significant pairwise mean differences ($p < 0.05$) were observed between Pre CT versus Post CT (-1.000^{*}), Pre CT versus Pre VR (-0.600^{*}), Pre CT versus Post VR (-1.600^{*}), Post CT versus Post VR (-0.600^{*}), Pre VR versus Pre CT (0.600^{*}), Pre VR versus Post VR (-1.000^{*}), Post VR versus Pre CT (1.600^{*}), Post VR versus Post CT (0.600^{*}), and Post VR versus Pre VR (1.000^{*}). For hip extension (MShe), significant mean differences were noted between Pre CT versus Post CT (-1.000^{*}), Pre CT versus Post VR (-1.400^{*}), Post CT versus Pre CT (1.000^{*}), Post CT versus Pre VR (1.000^{*}), Pre VR versus Post CT (-1.000^{*}), Pre VR versus Post VR (-1.400^{*}), Post VR versus Pre CT (1.400^{*}), and Post VR versus Pre VR (1.400^{*}). For knee flexion (MSkf), significant pairwise mean differences occurred between Pre CT versus

Post CT (-0.700*), Pre CT versus Post VR (-1.400*), Post CT versus Pre CT (0.700*), Post CT versus Pre VR (0.700*), Post CT versus Post VR (-0.700*), Pre VR versus Post CT (-0.700*), Pre VR versus Post VR (-1.400*), Post VR versus Pre CT (1.400*), Post VR versus Post CT (0.700*), and Post VR versus Pre VR (1.400*). For knee extension (MSke), statistically significant differences ($p < 0.05$) were found between Pre CT versus Post CT (-0.800*), Pre CT versus Post VR (-1.200*), Pre VR versus Post VR (-0.700*), Post VR versus Pre CT (1.200*), and Post VR versus Pre VR (0.700*). For ankle flexion (MSaf), significant mean differences were observed between Pre CT versus Post VR (-1.100*), Post CT versus Post VR (-0.900*), Pre VR versus Post VR (-1.200*), Post VR versus Pre CT (1.100*), Post VR versus Post CT (0.900*), and Post VR versus Pre VR (1.200*). Lastly, for ankle extension (MSae), significant pairwise mean differences ($p < 0.05$) were found between Pre CT versus Post VR (-1.400*), Post CT versus Post VR (-1.000*), Pre VR versus Post VR (-1.400*), Post VR versus Pre CT (1.400*), Post VR versus Post CT (1.000*), and Post VR versus Pre VR (1.400*). Collectively, the post-hoc analysis revealed that most of the significant mean differences consistently involved the Post VR group, which demonstrated superior performance across all lower limb muscle strength parameters (hip, knee, and ankle flexion and extension). Therefore, virtual reality-based rehabilitation produced significant improvements in lower limb muscle strength among stroke survivors when compared to conventional therapy and pre-intervention conditions.

Hypothesis 3

There is no significant difference in upper limb muscular endurance between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 7: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality Based Rehabilitation on Upper Limb Muscle Endurance

Dependent Variable	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	597.750	3	199.250	15.582	<.001*
Within Groups	971.800	76	12.787		
Total	1569.550	79			

From Table 7, the analysis of variance revealed a statistically significant difference ($p < 0.001$) in the upper limb muscular endurance of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. This indicates that the intervention had a significant effect on improving upper limb muscular endurance among stroke survivors. Due to this significant difference, Hypothesis 3 is rejected. Consequently, further analysis was carried out using Tukey's post-hoc test to determine the specific pairwise differences among the intervention groups. The post-hoc results are presented in Table 8.

Table 8: Tukey's Honestly Significance Difference Post-Hoc Test of Upper Limb Muscle Endurance Between Experimental and Control Group

(I) ANOVA	**(J) ANOVA**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
Pre CT	Post CT	-3.300*	1.131	.023
	Pre VR	.600	1.131	.951
	Post VR	-6.200*	1.131	<.001
Post CT	Pre CT	3.300*	1.131	.023
	Pre VR	3.900*	1.131	.005
	Post VR	-2.900	1.131	.058
Pre VR	Pre CT	-.600	1.131	.951
	Post CT	-3.900*	1.131	.005
	Post VR	-6.800*	1.131	<.001
Post VR	Pre CT	6.200*	1.131	<.001
	Post CT	2.900	1.131	.058
	Pre VR	6.800*	1.131	<.001

Tukey's Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in upper limb muscle endurance of the participants.

Statistically significant mean differences ($p < 0.05$) were observed between Pre CT and Post CT (-3.300*), Pre CT and Post VR (-6.200*), Post CT and Pre CT (3.300*), Post CT and Pre VR (3.900*), Pre VR and Post CT (-3.900*), Pre VR and Post VR (-6.800*), Post VR and Pre CT (6.200*), and Post VR and Pre VR (6.800*). These findings indicate that the Post VR group consistently showed higher endurance values compared to both Pre VR and all control conditions, reflecting a marked improvement following virtual reality-based rehabilitation. Overall, the post-hoc results confirm that virtual reality-based rehabilitation significantly enhanced upper limb muscular endurance among stroke survivors compared to conventional physiotherapy and pre-intervention levels.

Hypothesis 4

There is no significant difference in lower limb muscular endurance between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 9: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality-Based Rehabilitation on Lower Limb Muscle Endurance

Dependent Variable	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	239.350	3	79.783	7.955	<.001*
Within Groups	762.200	76	10.029		
Total	1001.550	79			

From Table 9, the analysis of variance revealed a statistically significant difference ($p < 0.001$) in the lower limb muscular endurance of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. This indicates that the intervention had a significant effect on improving lower limb muscular endurance among stroke survivors. Due to this significant difference, Hypothesis 4 is rejected. Consequently, further analysis was carried out using Tukey's post-hoc test to determine the specific pairwise differences among the intervention groups. The post-hoc results are presented in Table 10.

Table 10: Tukey's Honestly Significance Difference Post-Hoc Test of Lower Limb Muscle Endurance Between Experimental and Control Group

(I) ANOVA	(J) ANOVA	Mean Difference (I-J)	Std. Error	Sig.
Pre CT	Post CT	-2.300	1.001	.108
	Pre VR	-.300	1.001	.991
	Post VR	-4.300^{*}	1.001	<.001
Post CT	Pre CT	2.300	1.001	.108
	Pre VR	2.000	1.001	.198
	Post VR	-2.000	1.001	.198
Pre VR	Pre CT	.300	1.001	.991
	Post CT	-2.000	1.001	.198
	Post VR	-4.000^{*}	1.001	.001
Post VR	Pre CT	4.300^{*}	1.001	<.001
	Post CT	2.000	1.001	.198
	Pre VR	4.000^{*}	1.001	.001

Tukey's Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in lower limb muscle endurance of the participants. Statistically significant mean differences ($p < 0.05$) were observed between Pre CT and Post VR (-4.300^{*}), Pre VR and Post VR (-4.000^{*}), Post VR and Pre CT (4.300^{*}), and Post VR and Pre VR (4.000^{*}). These findings indicate that the Post VR group consistently demonstrated higher endurance values compared to both Pre VR and all control conditions, reflecting substantial improvement following virtual reality-based rehabilitation. Overall, the post-hoc results confirm that virtual reality-based rehabilitation significantly enhanced lower limb muscular endurance among stroke survivors compared to conventional physiotherapy and pre-intervention levels.

Hypothesis 5

There is no significant difference in upper limb joint flexibility (range of motion) between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 11: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality-Based Rehabilitation on Upper Limb Joint Flexibility

Depedent Variable		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
JFsf	Between Groups	19285.000	3	6428.333	4.053	.010*
	Within Groups	120546.800	76	1586.142		
	Total	139831.800	79			
JFse	Between Groups	1622.600	3	540.867	1.778	.159
	Within Groups	23121.200	76	304.226		
	Total	24743.800	79			
JFef	Between Groups	7767.000	3	2589.000	6.308	<.001*
	Within Groups	31191.200	76	410.411		
	Total	38958.200	79			
JFwf	Between Groups	3727.200	3	1242.400	6.002	.001*
	Within Groups	15732.000	76	207.000		
	Total	19459.200	79			
JFwe	Between Groups	1720.000	3	573.333	3.700	.015*
	Within Groups	11775.200	76	154.937		
	Total	13495.200	79			

JFsf- joint flexibility shoulder flexion, JSse- joint flexibility shoulder extension, JSef- joint flexibility elbow flexion, JSwf- Joint flexibility wrist flexion, JSwe- Joint flexibility wrist extension.

From Table 11, the analysis of variance revealed statistically significant differences ($p < 0.05$) in upper limb joint flexibility for shoulder flexion (JFsf: $p = 0.010$), elbow flexion (JFef: p = <0.001), wrist flexion (JFwf: $p = 0.001$), and wrist extension (JFwe: $p = 0.015$) among stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. However, there was no significant difference observed for shoulder extension (JFse: $p = 0.159$). This indicates that virtual reality-based rehabilitation had a significant positive effect on improving upper limb joint flexibility in most movement parameters, except for shoulder extension. Due to these significant differences, Hypothesis 5 is rejected. Consequently, further analysis was conducted using Tukey's post-hoc test to determine the specific pairwise differences among the intervention groups. The post-hoc results are presented in Table 12.

Table 12: Tukey's Honestly Significance Difference Post-Hoc Test of Upper Limb Joint Flexibility Between Experimental and Control Group

Dependent Variable	**(I) ANOVA**	**(J) ANOVA**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
JFsf	Pre CT	Post CT	-9.500	12.594	.875
		Pre VR	12.500	12.594	.754
		Post VR	-30.000	12.594	.089
	Post CT	Pre CT	9.500	12.594	.875
		Pre VR	22.000	12.594	.307
		Post VR	-20.500	12.594	.369
	Pre VR	Pre CT	-12.500	12.594	.754
		Post CT	-22.000	12.594	.307
		Post VR	-42.500*	12.594	.006
	Post VR	Pre CT	30.000	12.594	.089
		Post CT	20.500	12.594	.369
		Pre VR	42.500*	12.594	.006
JFse	Pre CT	Post CT	-3.300	5.516	.932
		Pre VR	4.300	5.516	.863
		Post VR	-8.000	5.516	.472
	Post CT	Pre CT	3.300	5.516	.932
		Pre VR	7.600	5.516	.517
		Post VR	-4.700	5.516	.829
	Pre VR	Pre CT	-4.300	5.516	.863
		Post CT	-7.600	5.516	.517
		Post VR	-12.300	5.516	.124
	Post VR	Pre CT	8.000	5.516	.472
		Post CT	4.700	5.516	.829
		Pre VR	12.300	5.516	.124
JFef	Pre CT	Post CT	-8.200	6.406	.578
		Pre VR	6.600	6.406	.732
		Post VR	-19.800*	6.406	.015
	Post CT	Pre CT	8.200	6.406	.578
		Pre VR	14.800	6.406	.105
		Post VR	-11.600	6.406	.276
	Pre VR	Pre CT	-6.600	6.406	.732
		Post CT	-14.800	6.406	.105
		Post VR	-26.400*	6.406	.001
	Post VR	Pre CT	19.800*	6.406	.015
		Post CT	11.600	6.406	.276
		Pre VR	26.400*	6.406	.001
JFwf	Pre CT	Post CT	-2.400	4.550	.952
		Pre VR	-2.400	4.550	.952
		Post VR	-17.200*	4.550	.002
	Post CT	Pre CT	2.400	4.550	.952
		Pre VR	.000	4.550	1.000
		Post VR	-14.800*	4.550	.009
	Pre VR	Pre CT	2.400	4.550	.952
		Post CT	.000	4.550	1.000
		Post VR	-14.800*	4.550	.009

	Post VR	Pre CT	17.200^{*}	4.550	.002
		Post CT	14.800^{*}	4.550	.009
		Pre VR	14.800^{*}	4.550	.009
JFwe	Pre CT	Post CT	-2.800	3.936	.892
		Pre VR	4.600	3.936	.648
		Post VR	-8.200	3.936	.168
	Post CT	Pre CT	2.800	3.936	.892
		Pre VR	7.400	3.936	.245
		Post VR	-5.400	3.936	.521
	Pre VR	Pre CT	-4.600	3.936	.648
		Post CT	-7.400	3.936	.245
		Post VR	-12.800^{*}	3.936	.009
	Post VR	Pre CT	8.200	3.936	.168
		Post CT	5.400	3.936	.521
		Pre VR	12.800^{*}	3.936	.009

Tukey's Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in upper limb joint flexibility of the participants. Statistically significant mean differences ($p < 0.05$) for shoulder flexion (JFsf) were observed between Pre VR and Post VR (-42.500^{*}), and Post VR and Pre VR (42.500^{*}). For shoulder extension (JFse), no pairwise comparisons reached statistical significance ($p > 0.05$). For elbow flexion (JFef), significant differences were recorded between Pre CT and Post VR (-19.800^{*}), Pre VR and Post VR (-26.400^{*}), Post VR and Pre CT (19.800^{*}), and Post VR and Pre VR (26.400^{*}). For wrist flexion (JFwf), significant pairwise mean differences included Pre CT versus Post VR (-17.200^{*}), Post CT versus Post VR (-14.800^{*}), Pre VR versus Post VR (-14.800^{*}), Post VR versus Pre CT (17.200^{*}), Post VR versus Post CT (14.800^{*}), and Post VR versus Pre VR (14.800^{*}). For wrist extension (JFwe), significant mean differences were observed between Pre VR and Post VR (-12.800^{*}) and Post VR and Pre VR (12.800^{*}). Collectively, the post-hoc analysis showed that most significant pairwise comparisons involved the Post VR condition, indicating that participants in the Post VR group demonstrated substantially greater improvements in joint flexibility (notably shoulder flexion, elbow flexion, wrist flexion and wrist extension) compared with pre-intervention and control conditions;

therefore, virtual reality–based rehabilitation produced significant enhancements in upper limb joint flexibility relative to conventional physiotherapy.

Hypothesis 6

There is no significant difference in lower limb joint flexibility (range of motion) between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 13: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality Based Rehabilitation on Lower Limb Joint Flexibility

Dependent Variable		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
JFhf	Between Groups	13569.800	3	4523.267	7.403	<.001*
	Within Groups	46436.400	76	611.005		
	Total	60006.200	79			
JFhe	Between Groups	400.950	3	133.650	1.435	.239
	Within Groups	7079.800	76	93.155		
	Total	7480.750	79			
JFkf	Between Groups	12920.550	3	4306.850	11.896	<.001*
	Within Groups	27515.400	76	362.045		
	Total	40435.950	79			
JFaf	Between Groups	426.200	3	142.067	3.460	.020*
	Within Groups	3120.800	76	41.063		
	Total	3547.000	79			
JFae	Between Groups	696.600	3	232.200	2.545	.062
	Within Groups	6935.200	76	91.253		
	Total	7631.800	79			

JFhf- joint flexibility hip flexion, JShe- joint flexibility hip extension, JSkf- joint flexibility knee flexion, JSaf- Joint flexibility ankle flexion, JSae- Joint flexibility ankle extension.

From Table 13, the analysis of variance revealed statistically significant differences ($p < 0.05$) in the lower limb joint flexibility of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. Specifically, significant differences were observed in hip flexion ($p < 0.001$), knee flexion ($p < 0.001$), and ankle flexion ($p = 0.020$), while no significant differences were noted in hip extension ($p = 0.239$) and ankle extension ($p = 0.062$). This indicates that the intervention had a notable effect on enhancing lower limb joint flexibility among stroke survivors. Due to this significant difference, Hypothesis 6 is rejected. Consequently, further analysis was carried out using

Tukey's post-hoc test to determine the specific pairwise differences among the intervention groups. The post-hoc results are presented in Table 14.

Table 14: Tukey's Honestly Significance Difference Post-Hoc Test of Lower Limb Joint Flexibility Between Experimental and Control Group

Dependent Variable	**(I) ANOVA**	**(J) ANOVA**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
JFhf	Pre CT	Post CT	-10.700	7.817	.523
		Pre VR	-3.600	7.817	.967
		Post VR	-33.500^{*}	7.817	<.001
	Post CT	Pre CT	10.700	7.817	.523
		Pre VR	7.100	7.817	.800
		Post VR	-22.800^{*}	7.817	.024
	Pre VR	Pre CT	3.600	7.817	.967
		Post CT	-7.100	7.817	.800
		Post VR	-29.900^{*}	7.817	.001
	Post VR	Pre CT	33.500^{*}	7.817	<.001
		Post CT	22.800^{*}	7.817	.024
		Pre VR	29.900^{*}	7.817	.001
JFhe	Pre CT	Post CT	-3.000	3.052	.760
		Pre VR	-2.600	3.052	.829
		Post VR	-6.300	3.052	.174
	Post CT	Pre CT	3.000	3.052	.760
		Pre VR	.400	3.052	.999
		Post VR	-3.300	3.052	.702
	Pre VR	Pre CT	2.600	3.052	.829
		Post CT	-.400	3.052	.999
		Post VR	-3.700	3.052	.621
	Post VR	Pre CT	6.300	3.052	.174
		Post CT	3.300	3.052	.702
		Pre VR	3.700	3.052	.621
JFkf	Pre CT	Post CT	-9.400	6.017	.406
		Pre VR	-1.500	6.017	.995
		Post VR	-31.800^{*}	6.017	<.001
	Post CT	Pre CT	9.400	6.017	.406
		Pre VR	7.900	6.017	.558
		Post VR	-22.400^{*}	6.017	.002
	Pre VR	Pre CT	1.500	6.017	.995
		Post CT	-7.900	6.017	.558
		Post VR	-30.300^{*}	6.017	<.001

	Post VR	Pre CT	31.800*	6.017	<.001
		Post CT	22.400*	6.017	.002
		Pre VR	30.300*	6.017	.000
JFaf	Pre CT	Post CT	-2.200	2.026	.699
		Pre VR	-2.400	2.026	.639
		Post VR	-6.400*	2.026	.012
	Post CT	Pre CT	2.200	2.026	.699
		Pre VR	-.200	2.026	1.000
		Post VR	-4.200	2.026	.171
	Pre VR	Pre CT	2.400	2.026	.639
		Post CT	.200	2.026	1.000
		Post VR	-4.000	2.026	.207
	Post VR	Pre CT	6.400*	2.026	.012
		Post CT	4.200	2.026	.171
		Pre VR	4.000	2.026	.207
JFae	Pre CT	Post CT	-4.000	3.021	.551
		Pre VR	-2.800	3.021	.791
		Post VR	-8.200*	3.021	.040
	Post CT	Pre CT	4.000	3.021	.551
		Pre VR	1.200	3.021	.979
		Post VR	-4.200	3.021	.509
	Pre VR	Pre CT	2.800	3.021	.791
		Post CT	-1.200	3.021	.979
		Post VR	-5.400	3.021	.287
	Post VR	Pre CT	8.200*	3.021	.040
		Post CT	4.200	3.021	.509
		Pre VR	5.400	3.021	.287

Tukey’s Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in lower limb joint flexibility of the participants. Statistically significant mean differences ($p < 0.05$) for hip flexion (JFhf) were observed between Pre CT and Post VR (-33.500*), Post CT and Post VR (-22.800*), Pre VR and Post VR (-29.900*), and reciprocally between Post VR and Pre CT (33.500*), Post VR and Post CT (22.800*), and Post VR and Pre VR (29.900*). For hip extension (JFhe), no pairwise comparisons reached statistical significance ($p > 0.05$). For knee flexion (JFkf), significant mean differences were found between Pre CT and Post VR (-31.800*), Post CT and Post VR (-22.400*), Pre VR and Post VR (-30.300*), and reciprocally between Post VR and Pre CT

(31.800*), Post VR and Post CT (22.400*), and Post VR and Pre VR (30.300*). For ankle flexion (JFaf), significant pairwise mean differences occurred between Pre CT and Post VR (-6.400*) and Post VR and Pre CT (6.400*). For ankle extension (JFae), significant mean differences were recorded between Pre CT and Post VR (-8.200*) and Post VR and Pre CT (8.200*). Collectively, the post-hoc analysis revealed that most significant pairwise differences involved the Post VR condition, indicating that participants in the Post VR group demonstrated markedly greater improvements in lower limb joint flexibility (particularly hip flexion, knee flexion, ankle flexion, and ankle extension) compared with pre-intervention and control conditions. Therefore, virtual reality–based rehabilitation significantly enhanced lower limb joint flexibility relative to conventional physiotherapy.

Hypothesis 7

There is no significant difference in balance between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 15: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality Based Rehabilitation on Balance

Dependent Variable	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	1656.200	3	552.067	10.077	<0.001*
Within Groups	4163.600	76	54.784		
Total	5819.800	79			

From Table 15, the analysis of variance revealed a statistically significant difference ($p < 0.001$) in the balance of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. This indicates that the intervention had a significant effect on improving balance among stroke survivors. Due to this significant difference, Hypothesis 7 is rejected. Consequently, further analysis was carried out using Tukey’s Honestly Significant Difference (HSD) Post-Hoc Test to determine the specific pairwise group differences among the intervention groups. The post-hoc results are presented in Table 16.

Table 16: Tukey's Honestly Significance Difference Post-Hoc Test of Balance Between Experimental and Control Group

(I) ANOVA	(J) ANOVA	Mean Difference (I-J)	Std. Error	Sig.
Pre CT	Post CT	-6.300*	2.341	.043
	Pre VR	-.700	2.341	.991
	Post VR	-11.200*	2.341	<.001
Post CT	Pre CT	6.300*	2.341	.043
	Pre VR	5.600	2.341	.087
	Post VR	-4.900	2.341	.165
Pre VR	Pre CT	.700	2.341	.991
	Post CT	-5.600	2.341	.087
	Post VR	-10.500*	2.341	<.001
Post VR	Pre CT	11.200*	2.341	<.001
	Post CT	4.900	2.341	.165
	Pre VR	10.500*	2.341	<.001

Tukey's Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in balance among the participants. Statistically significant mean differences ($p < 0.05$) were observed between Pre CT and Post CT (-6.300*), Pre CT and Post VR (-11.200*), Pre VR and Post VR (-10.500*), Post CT and Pre CT (6.300*), Post VR and Pre CT (11.200*), and Post VR and Pre VR (10.500*). These findings indicate that the Post VR group consistently demonstrated higher mean balance scores compared to both pre-intervention and control conditions. Collectively, the post-hoc analysis suggests that virtual reality-based rehabilitation significantly improved balance performance in stroke survivors relative to conventional physiotherapy.

Hypothesis 8

There is no significant difference in upper limb coordination between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 17: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality-Based Rehabilitation on Upper Limb Coordination

Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	762.550	3	254.183	7.692	<.001*
Within Groups	2511.400	76	33.045		
Total	3273.950	79			

From Table 17, the analysis of variance revealed a statistically significant difference ($p < 0.001$) in the upper limb coordination of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. This indicates that the intervention had a significant effect on improving upper limb coordination among stroke survivors. Due to this significant difference, Hypothesis 8 is rejected. Consequently, further analysis was conducted using Tukey's Honestly Significant Difference (HSD) Post-Hoc Test to determine the specific pairwise differences among the intervention groups. The post-hoc results are presented in Table 18.

Table 18: Tukey's Honestly Significance Difference Post-Hoc Test of Upper Limb Coordination Between Experimental and Control Group

(I) ANOVA	**(J) ANOVA**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
Pre CT	Post CT	-2.900	1.818	.387
	Pre VR	3.200	1.818	.300
	Post VR	-5.000^{*}	1.818	.037
Post CT	Pre CT	2.900	1.818	.387
	Pre VR	6.100^{*}	1.818	.007
	Post VR	-2.100	1.818	.657
Pre VR	Pre CT	-3.200	1.818	.300
	Post CT	-6.100^{*}	1.818	.007
	Post VR	-8.200^{*}	1.818	<.001
Post VR	Pre CT	5.000^{*}	1.818	.037
	Post CT	2.100	1.818	.657
	Pre VR	8.200^{*}	1.818	<.001

Tukey's Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in upper limb coordination of the participants. Statistically significant mean differences ($p < 0.05$) were observed between Pre CT and Post VR (-5.000^{*}), Post CT and Pre VR (6.100^{*}), Pre VR and Post CT (-6.100^{*}), Pre VR and Post VR (-8.200^{*}), Post VR and Pre CT (5.000^{*}), and Post VR and Pre VR (8.200^{*}). These findings indicate that the Post VR group consistently demonstrated superior coordination compared to both Pre VR and all control conditions, reflecting substantial improvement following virtual reality-based rehabilitation. Overall, the post-hoc results confirm that virtual reality-based rehabilitation significantly enhanced upper limb coordination among stroke survivors compared to conventional physiotherapy and pre-intervention levels.

Hypothesis 9

There is no significant difference in lower limb coordination between stroke survivors who receive virtual reality-based rehabilitation and those who do not receive virtual reality-based rehabilitation.

Table 19: One-Way ANOVA Showing the Main and Interaction Effects of Virtual Reality-Based Rehabilitation on Lower Limb Coordination

Dependent Variable	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	501.400	3	167.133	23.592	<.001*
Within Groups	538.400	76	7.084		
Total	1039.800	79			

From Table 19, the analysis of variance revealed a statistically significant difference ($p < 0.001$) in the lower limb coordination of stroke survivors who received virtual reality-based rehabilitation compared to those who underwent conventional physiotherapy. This indicates that the intervention had a significant effect on improving lower limb coordination among stroke survivors. Due to this significant difference, Hypothesis 9 is rejected. Consequently, further analysis was conducted using Tukey's post-hoc test to determine the specific pairwise differences among the intervention groups. The post-hoc results are presented in table 20.

Table 20: Tukey's Honestly Significance Difference Post-Hoc Test of Lower Limb Coordination Between Experimental and Control Group

(I) ANOVA	**(J) ANOVA**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
Pre CT	Post CT	-2.600^*	.842	.015
	Pre VR	.800	.842	.778
	Post VR	-5.600^*	.842	<.001
Post CT	Pre CT	2.600^*	.842	.015
	Pre VR	3.400^*	.842	.001
	Post VR	-3.000^*	.842	.003
Pre VR	Pre CT	-.800	.842	.778
	Post CT	-3.400^*	.842	.001
	Post VR	-6.400^*	.842	<.001
Post VR	Pre CT	5.600^*	.842	<.001
	Post CT	3.000^*	.842	.003
	Pre VR	6.400^*	.842	<.001

Tukey’s Honestly Significant Difference (HSD) Post-Hoc Test was conducted to determine the specific pairwise group differences in lower limb coordination of the participants. Statistically significant mean differences ($p < 0.05$) were observed between Pre CT and Post CT (-2.600^*), Pre CT and Post VR (-5.600^*), Post CT and Pre CT (2.600^*), Post CT and Pre VR (3.400^*), Post CT and Post VR (-3.000^*), Pre VR and Post CT (-3.400^*), Pre VR and Post VR (-6.400^*), Post VR and Pre CT (5.600^*), Post VR and Post CT (3.000^*), and Post VR and Pre VR (6.400^*). These findings indicate that the Post VR group consistently demonstrated higher coordination values compared to both Pre VR and all control conditions, reflecting marked improvement following virtual reality-based rehabilitation. Overall, the post-hoc results confirm that virtual reality-based rehabilitation significantly enhanced lower limb coordination among stroke survivors relative to conventional physiotherapy and pre-intervention levels.

CHAPTER FIVE

5.1 DISCUSSION

This study evaluated the effectiveness of virtual reality combined with conventional physiotherapy on motor recovery among stroke survivors at the University of Benin Teaching Hospital. The findings demonstrated that participants in the experimental group exhibited significant improvements in upper and lower limb muscle strength, endurance, joint flexibility, balance, and coordination when compared to those in the control group. These results further support the growing agreement that virtual reality rehabilitation enhances recovery outcomes by promoting higher engagement, task repetition, and neural reorganisation processes that underpin motor recovery after stroke.

Upper Limb Muscle Strength and Function

This study revealed significant gains in upper limb muscle strength (shoulder, elbow, and wrist flexors and extensors) among participants in the experimental group. These improvements suggest that virtual reality tasks, which typically involve repetitive reaching, grasping, and lifting movements, may effectively stimulate motor pathways and encourage neuroplastic changes. The results of this study are consistent with Rodríguez-Hernández et al. (2023), who reported that conventional rehabilitation combined with specific VR systems improved hand motor function, voluntary movement, and normalized muscle tone in post-stroke patients. Similarly, the systematic review and meta-analysis by Soleimani et al. (2024) demonstrated that VR-based interventions significantly enhance upper limb motor recovery, dexterity, and spasticity management when compared to conventional occupational therapy alone. Although Khan et al. (2021) found no significant differences in motor outcomes when the intervention dosage was matched, their study still highlighted the motivational and engaging qualities of VR, which may indirectly improve patient adherence, participation, and overall rehabilitation outcomes. Likewise, Aderinto et al. (2023) underscored the feasibility of implementing virtual reality-based rehabilitation in Nigeria despite limitations such as cost, power supply, and infrastructure. The consistency between the present findings and those of previous studies reinforces the growing agreement that VR offers additional sensory and cognitive stimuli that promote motor relearning. This is likely achieved through mechanisms such as repetitive task-specific training, enhanced feedback, and immersive visual-motor engagement, which together encourage cortical reorganisation and functional restoration of the affected upper limb.

Lower Limb Muscle Strength, Endurance, and Joint Flexibility

According to this study, participants who were in the experimental group demonstrated significant improvements in lower limb outcomes, including muscular strength, endurance, and joint flexibility. These results are in line with Ghai et al. (2020), who reported moderate improvements in gait speed, stride length, and cadence among post-stroke patients following VR interventions. The use of virtual environments to simulate walking and balance tasks allows patients to practice complex motor skills safely and repetitively, which enhances coordination between the lower limb muscle groups and supports gait retraining. Hammed et al. (2018) similarly reported that structured and repetitive therapeutic exercises lead to improvements in gait velocity and lower limb strength, further validating the importance of motor practice intensity in stroke rehabilitation. Although the study by Cai et al. (2021) was a protocol, it emphasized the global shift toward incorporating immersive VR for gait and mobility rehabilitation. Collectively, these findings indicate that VR can effectively complement conventional physiotherapy by creating enriched training environments that challenge postural control, endurance, and joint flexibility.

Balance and Coordination

This study also recorded significant improvements in balance and coordination among participants who were in the experimental group. This observation supports the findings of

Khan et al. (2021), who reported that VR promotes better motor outcomes like balance by offering interactive and engaging exercises that require dynamic postural adjustments. Virtual reality-based balance training encourages participants to maintain stability during simulated movements, thereby enhancing sensory integration and proprioceptive feedback. Additionally, improvements in upper limb control and lower limb strength, as noted earlier, may have contributed to enhanced postural stability. Rodríguez-Hernández et al. (2023) observed that improvements in arm and trunk coordination following VR interventions also facilitate better balance control. Thus, the gains in balance and coordination observed in this study suggest that virtual reality-based exercises not only improve isolated joint function but also enhance the overall integration of motor systems necessary for coordinated movement.

5.2 CONCLUSION

The findings of this study indicate that virtual reality-based rehabilitation, when combined with conventional physiotherapy, significantly improves motor recovery in stroke survivors compared to conventional therapy alone. Specifically, experimental group demonstrated superior outcomes in upper and lower limb muscle strength, endurance, joint flexibility, balance, and coordination. These results underscore the efficacy of VR as a cornerstone in stroke rehabilitation, providing task-specific, repetitive, and engaging interventions that facilitate neuroplasticity and functional recovery.

5.3 RECOMMENDATION

Based on the findings of this study, the following recommendations are proposed:

i. Integration of VR in Stroke Rehabilitation: Physiotherapy departments should consider incorporating virtual reality-based rehabilitation alongside conventional therapy to enhance motor recovery outcomes in stroke survivors.

ii. Training and Capacity Building: Physiotherapists should receive training on the use of VR technology to optimize its therapeutic potential.

iii. Policy Support: Health institutions and policymakers should provide infrastructure support and resources for the implementation of virtual reality based rehabilitation in tertiary health facilities.

iv. Patient Engagement: Stroke survivors should be encouraged to participate in virtual reality based interventions as an engaging adjunct to standard physiotherapy programs.

5.4 IMPLICATIONS FOR PHYSIOTHERAPY

The study has several implications for physiotherapy practice:

i. Enhanced Rehabilitation Outcomes: virtual reality-based rehabilitation can significantly accelerate recovery in both upper and lower limbs, as well as improve balance and coordination.

ii. Patient-Centered Therapy: VR interventions provide interactive, immersive, and motivating exercises that can improve patient adherence and engagement.

iii. Resource Optimization: Combining VR with conventional therapy may allow physiotherapists to deliver more efficient, goal-directed rehabilitation within the same clinical timeframe.

iv. Evidence-Based Practice: The findings provide empirical support for physiotherapists to integrate technology-driven interventions into standard stroke rehabilitation protocols.

5.5 CONTRIBUTIONS TO KNOWLEDGE

This study makes the following contributions to knowledge:

i. Provides evidence that virtual reality combined with conventional physiotherapy produces superior motor recovery outcomes compared to conventional therapy alone in stroke survivors.
ii. Confirms the feasibility and effectiveness of VR interventions within the Nigerian clinical context, addressing a gap in local empirical evidence.
iii. Adds to global literature on VR rehabilitation by showing that even relatively short-term interventions (20-minute sessions over 8 weeks) can produce measurable functional gains.

5.6 SUGGESTIONS FOR FURTHER STUDIES

Future research could consider the following:

i. Larger Sample Sizes: Conduct studies with larger, more diverse populations to enhance generalizability.
ii. Longer Intervention Duration: Investigate the long-term effects of virtual reality-based rehabilitation on motor recovery and functional independence.
iii. Cognitive and Functional Outcomes: Include assessments of cognitive function, quality of life, and activities of daily living to evaluate broader impacts of VR interventions.
iv. Different VR Systems: Compare various VR platforms (immersive vs non-immersive) to determine the most effective modalities for stroke rehabilitation.

REFERENCES

Aderinto, N. *et al.* (2023) *Exploring the efficacy of virtual reality-based rehabilitation in stroke: A narrative review of current evidence*. Annals of Medicine. https://pmc.ncbi.nlm.nih.gov/articles/PMC10836287/

American Stroke Association (2022). *Stroke Symptoms – Act F.A.S.T.* Available at: https://www.stroke.org/en/about-stroke/stroke-symptoms

Annongu, I.T. *et al.* (2022) *Clinical and brain computed tomographic profile of stroke patients in a Tertiary Hospital, North Central Nigeria*. SCIRP. https://www.scirp.org/journal/paperinformation?paperid=121285

Bersano, A. & Gatti, L. (2023). *Pathophysiology and treatment of stroke: present status and future perspectives*. International Journal of Molecular Sciences, 24(19), 14848. https://doi.org/10.3390/ijms241914848

Bui, J., Luauté, J. & Farnè, A. (2024) *Enhancing upper limb rehabilitation of stroke patients with virtual reality: A mini review*. Frontiers in Virtual Reality. https://dumas.ccsd.cnrs.fr/IMPACT_TEAM/hal-04776453v1

Cai, H., Lin, T., Chen, L., et al. (2021). *Evaluating the effect of immersive virtual reality technology on gait rehabilitation in stroke patients: a study protocol for a randomized controlled trial.* Trials, 22, p.91. https://doi.org/10.1186/s13063-021-05031-z

Carr, J.H. & Shepherd, R.B. (1987). *A Motor Relearning Programme for Stroke*. 2nd ed. Baltimore: Aspen Publishers.

Feigin V. L. *et al.* (2024) 'Global, regional, and national burden of stroke and its risk factors, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021,' *The Lancet Neurology*, 23(10), pp. 973–1003. https://doi.org/10.1016/s1474-4422(24)00369-7

Feigin V., Brainin M., Norrving B., et al. World Stroke Organization (WSO): Global Stroke Fact Sheet 2022. International Journal of Stroke. 2022;17(1):18-29. https://doi.org/10.1177/17474930211065917

GBD 2019 Stroke Collaborators (2021). *Global, regional, and national burden of stroke and its risk factors, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019*. The Lancet Neurology, 20(10), pp. 795–820. https://www.thelancet.com/journals/laneur/article/PIIS1474-4422(21)00252-0/fulltext

Gelineau, A., Perrochon, A., Robin, L., et al. (2022). *Measured and perceived effects of upper limb home-based exergaming interventions on activity after stroke: A systematic review and meta-analysis*. International Journal of Environmental Research and Public Health, 19(15), p.9112. https://www.mdpi.com/1660-4601/19/15/9112

Ghai, S., Ghai, I. & Lamontagne, A. (2020). *Virtual reality training enhances gait poststroke: a systematic review and meta-analysis*. Annals of the New York Academy of Sciences, 1478: 18–42. https://doi.org/10.1111/nyas.14420

Hammed I. A., Monikhe, A.S, & Okey, A.E. (2018). *Alterations in gait velocity and grip strength of stroke survivors following a 12-week structured therapeutic exercise programme.* Biomedical Human Kinetics, Sciendo, Vol. 10 (Issue 1), pp. 76–80. https://doi.org/10.1515/bhk-2018-0012

Intercollegiate Stroke Working Party, (2023). *National Clinical Guideline for Stroke: Rehabilitation after stroke*. London: Royal College of Physicians. Available at: https://www.strokeguideline.org

Jeon, B.-J., Kim, W.-H. and Park, E.-Y. (2015) 'Effect of task-oriented training for people with stroke: a meta-analysis focused on repetitive or circuit training,' *Topics in Stroke Rehabilitation*, 22(1), pp. 34–43. https://doi.org/10.1179/1074935714z.0000000035

Khan, A., Podlasek, A., & Somaa, F. (2021). *Virtual reality in post-stroke neurorehabilitation – a systematic review and meta-analysis.* Topics in Stroke Rehabilitation, 30(1), 53–72.

https://doi.org/10.1080/10749357.2021.1990468

Khan, A., Imam, Y. Z., Muneer, M., et al. K. (2024). *Virtual reality in stroke recovery: a meta-review of systematic reviews.* Bioelectronic Medicine, 10, 23. https://doi.org/10.1186/s42234-024-00150-9

Kumar, S., Selim, M. H., & Caplan, L. R. (2010). *Medical complications after stroke.* The Lancet Neurology, 9(1), 105–118. https://doi.org/10.1016/S1474-4422(09)70266-2

Kvernland, A. *et al.* (2022) 'Borderzone infarction and recurrent stroke in intracranial atherosclerosis,' *Journal of Stroke and Cerebrovascular Diseases*, 32(1), p. 106897.

https://doi.org/10.1016/j.jstrokecerebrovasdis.2022.106897

Langhorne, P., Bernhardt, J., & Kwakkel, G. (2011). *Stroke rehabilitation*. Lancet (London, England), 377(9778), 1693–1702. https://doi.org/10.1016/S0140-6736(11)60325-5

Laver, K. E., Lange, B., George, S., et. al. (2017). *Virtual reality for stroke rehabilitation.* Cochrane Database of Systematic Reviews, (11), CD008349. https://doi.org/10.1002/14651858.CD008349.pub4

Lee, C.D., Folsom, A.R. and Blair, S.N. (2003) 'Physical activity and stroke risk,' *Stroke*, 34(10), pp. 2475–2481. https://doi.org/10.1161/01.str.0000091843.02517.9d

Li, S. (2023). *Stroke recovery is a journey: prediction and potentials of motor recovery after a stroke from a practical perspective*. Life, 13(10), 2061. https://doi.org/10.3390/life13102061

Mekbib, D.B., Han, J., Zhang, L., et al. (2020). *Virtual reality therapy for upper limb rehabilitation in patients with stroke: A meta-analysis of randomized clinical trials*. Brain Injury, 34(4), pp.456–465. https://doi.org/10.1080/02699052.2020.1725126

Michos, E.D., McEvoy, J.W. and Blumenthal, R.S. (2019). *Lipid management for the prevention of atherosclerotic cardiovascular disease*. New England Journal of Medicine, 381(16), pp. 1557–1567. https://doi.org/10.1056/nejmra1806939

Moan, M. E., Vonstad, E. K., Su, X., et. al. (2021). *Experiences of Stroke Survivors and Clinicians with a Fully Immersive Virtual Reality Treadmill Exergame for Stroke Rehabilitation: A Qualitative Pilot Study.* Frontiers in Aging Neuroscience, 13, 735251

https://doi.org/10.3389/fnagi.2021.735251

Murphy, S. J., & Werring, D. J. (2020). *Stroke: causes and clinical features.* Medicine (Abingdon, England : UK ed.), 48(9), 561–566. https://doi.org/10.1016/j.mpmed.2020.06.002

National Clinical Guideline for Stroke (2023) *Motor recovery and physical effects of stroke*. https://www.strokeguideline.org/chapter/motor-recovery-and-physical-effects-of-stroke/

National Heart, Lung, and Blood Institute. (2023). Stroke. Retrieved from https://www.nhlbi.nih.gov/health/stroke

Nguyen P. T., Chou LW., Hsieh YL. (2022) *Proprioceptive Neuromuscular Facilitation-Based Physical Therapy on the Improvement of Balance and Gait in Patients with Chronic Stroke: A Systematic Review and Meta-Analysis.* Life (Basel);12(6):882. doi:10.3390/life12060882

Noguchi, K. S., Moncion, K., Wiley, E., et al. (2025). *Prescribing strength training for stroke recovery: a systematic review and meta-analysis of randomised controlled trials.* British journal of sports medicine, 59(3), 185–197. https://doi.org/10.1136/bjsports-2024-108476

Ogah, O.S., Naidoo, P., Damasceno, A., et al. (2021). *Stroke in Africa: profile, progress, prospects and priorities.* Nature Reviews Neurology, 17(10), pp. 634–656. https://doi.org/10.1038/s41582-021-00542-4

Okekunle, A.P., Jones, S., Adeniji, O., et al. (2023). *Stroke in Africa: a systematic review and meta-analysis of the incidence and case-fatality rates*. International Journal of Stroke, 18(6), pp. 634–644. https://doi.org/10.1177/17474930221147164

Owolabi, M.O., Akarolo-Anthony, S., Akinyemi, R., et al. (2015). *The burden of stroke in Africa: a glance at the present and a glimpse into the future*. Cardiovascular Journal of Africa, 26(2), pp. 27–38. https://doi.org/10.5830/CVJA-2015-038

Rodríguez-Hernández, M., Polonio-López, B., Corregidor-Sánchez, AI., et al. (2023) *Can specific virtual reality combined with conventional rehabilitation improve poststroke hand* *motor function? A randomized clinical trial.* J NeuroEngineering and Rehabilitation 20, 38. https://doi.org/10.1186/s12984-023-01170-3

Sacco, R.L., Kasner, S.E., Broderick, J.P., et al. (2013). *An updated definition of stroke for the 21st century: A statement for healthcare professionals from the American Heart Association/American Stroke Association.* Stroke, 44(7), pp. 2064–2089. https://doi.org/10.1161/STR.0b013e318296aeca

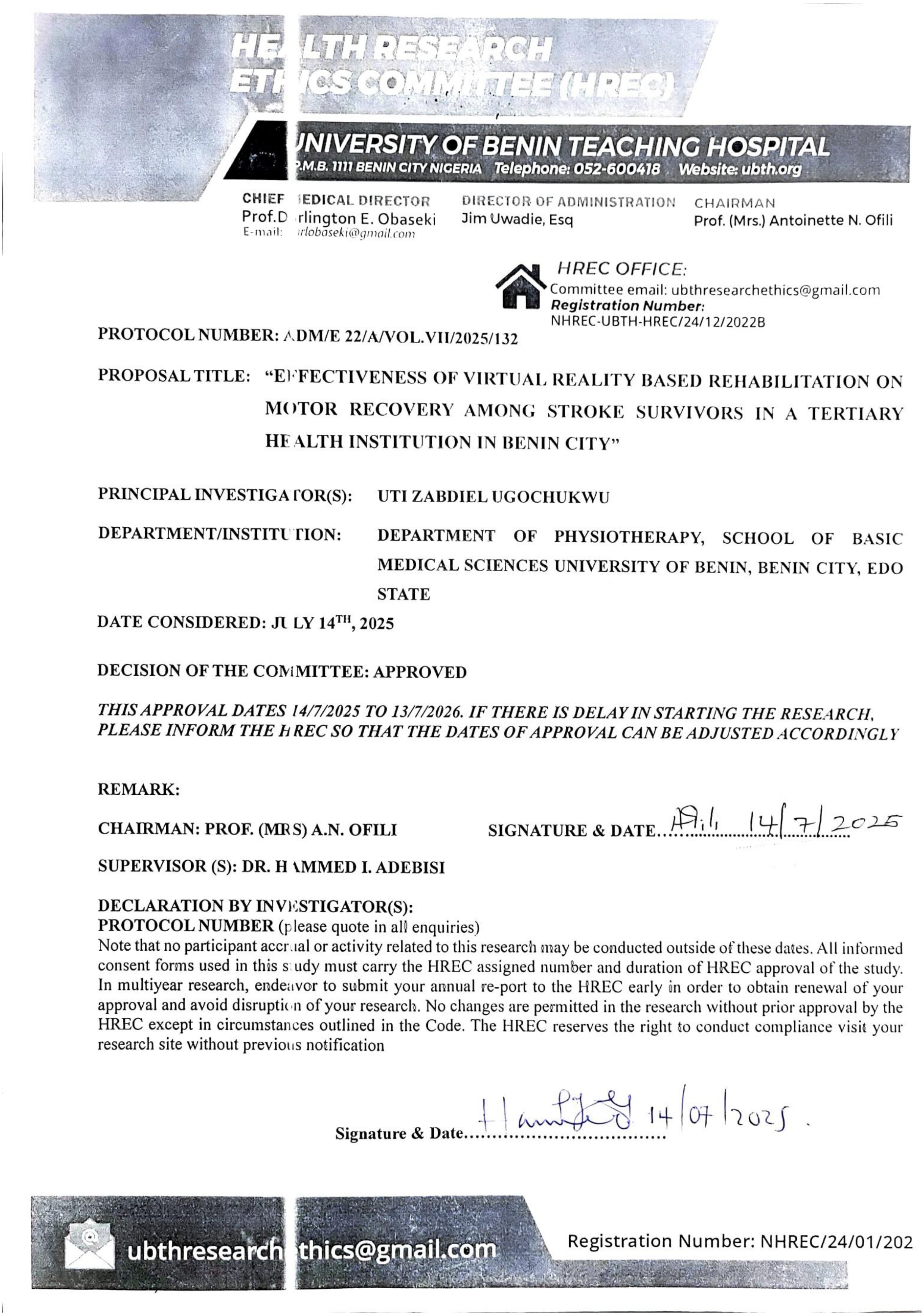
Scrivener, K. *et al.* (2020). *Bobath therapy is inferior to task-specific training and not superior to other interventions in improving lower limb activities after stroke: a systematic review*. Journal of Physiotherapy, 66(4), pp. 225–235. https://doi.org/10.1016/j.jphys.2020.09.008

Soleimani, M., Ghazisaeedi, M. & Heydari, S. (2024). *The efficacy of virtual reality for upper limb rehabilitation in stroke patients: a systematic review and meta-analysis.* BMC Medical Informatics and Decision Making, 24(1). https://doi.org/10.1186/s12911-024-02534-y

Tsai, Y. et al. (2024). *Virtual reality skateboarding training for balance and functional performance in degenerative lumbar spine disease* - journal of Neuroengineering and Rehabilitation, BioMed Central. Available at: https://jneuroengrehab.biomedcentral.com/articles/10.1186/s12984-024-01357-2

APPENDIX I

ETHICAL APPROVAL



HEALTH RESEARCH ETHICS COMMITTEE (HREC)

UNIVERSITY OF BENIN TEACHING HOSPITAL
P.M.B. 1111 BENIN CITY NIGERIA Telephone: 052-600418 Website: ubth.org

CHIEF MEDICAL DIRECTOR	DIRECTOR OF ADMINISTRATION	CHAIRMAN
Prof.D rlington E. Obaseki E-mail: rlobaseki@gmail.com	Jim Uwadie, Esq	Prof. (Mrs.) Antoinette N. Ofili

HREC OFFICE:
Committee email: ubthresearchethics@gmail.com
Registration Number:
NHREC-UBTH-HREC/24/12/2022B

PROTOCOL NUMBER: ADM/E 22/A/VOL.VII/2025/132

PROPOSAL TITLE: "EFFECTIVENESS OF VIRTUAL REALITY BASED REHABILITATION ON MOTOR RECOVERY AMONG STROKE SURVIVORS IN A TERTIARY HEALTH INSTITUTION IN BENIN CITY"

PRINCIPAL INVESTIGATOR(S): UTI ZABDIEL UGOCHUKWU

DEPARTMENT/INSTITUTION: DEPARTMENT OF PHYSIOTHERAPY, SCHOOL OF BASIC MEDICAL SCIENCES UNIVERSITY OF BENIN, BENIN CITY, EDO STATE

DATE CONSIDERED: JULY 14TH, 2025

DECISION OF THE COMMITTEE: APPROVED

THIS APPROVAL DATES 14/7/2025 TO 13/7/2026. IF THERE IS DELAY IN STARTING THE RESEARCH, PLEASE INFORM THE HREC SO THAT THE DATES OF APPROVAL CAN BE ADJUSTED ACCORDINGLY

REMARK:

CHAIRMAN: PROF. (MRS) A.N. OFILI **SIGNATURE & DATE**......14/7/2025

SUPERVISOR (S): DR. H MMED I. ADEBISI

DECLARATION BY INVESTIGATOR(S):
PROTOCOL NUMBER (please quote in all enquiries)
Note that no participant accrual or activity related to this research may be conducted outside of these dates. All informed consent forms used in this study must carry the HREC assigned number and duration of HREC approval of the study. In multiyear research, endeavor to submit your annual re-port to the HREC early in order to obtain renewal of your approval and avoid disruption of your research. No changes are permitted in the research without prior approval by the HREC except in circumstances outlined in the Code. The HREC reserves the right to conduct compliance visit your research site without previous notification

Signature & Date...................... 14/07/2025 .

ubthresearchethics@gmail.com Registration Number: NHREC/24/01/202

APPENDIX II

INFORMED CONSENT FORM

Project Title:

Effectiveness of Virtual Reality on Motor Recovery Among Stroke Survivors in a Tertiary Health Institution in Benin City

Researcher:

Zabdiel Uti
Department of Physiotherapy,
School of Basic Medical Sciences,
College of Medical Sciences,
University of Benin, Benin City.
Phone: 08136497282
Email: utizabdiel@gmail.com

Supervisor:

Dr. Hammed I. Adebisi
Department of Physiotherapy,
School of Basic Medical Sciences,
College of Medical Sciences,
University of Benin, Benin City.

Dear Participant,

You are invited to take part in a research study being conducted as part of the requirements for the award of a Bachelor of Physiotherapy degree. Please read this form carefully and feel free to ask any questions before deciding whether to participate.

Purpose of the Study:

This study aims to evaluate the effectiveness of virtual reality therapy on motor recovery, specifically muscular strength, muscular endurance, joint flexibility, balance, and coordination in stroke survivors undergoing rehabilitation at the University of Benin Teaching Hospital.

Procedures:

If you agree to participate, you will be randomly assigned to either a group that receives virtual reality therapy or a group that receives conventional physiotherapy. The sessions will occur three times a week for a period of eight weeks, and assessments will be carried out before and after the intervention using standard instruments.

Voluntary Participation and Withdrawal:

Your participation in this study is entirely voluntary. You may choose to withdraw from the study at any time without penalty.

Risks and Benefits:

The exercises will be supervised by a trained physiotherapist, and all safety precautions will be taken. Participation may help improve your motor function and contribute to the advancement of stroke rehabilitation practices.

Confidentiality:

All personal and medical information will be kept strictly confidential. Your data will be used solely for the purpose of this research and may be published in academic settings, but your identity will never be revealed.

Consent Statement:

By signing below, you are agreeing that you have read and understood the information provided above and voluntarily consent to participate in this study. You understand that you may withdraw at any point and that your information will be kept confidential.

Participant's Name: ____

Participant's Signature: ______________________________

Date: _______________________

Researcher's Signature: ____

Date: _______________________

APPENDIX III

FIGURES

Figure 6: Front view of the Meta Quest 3 Virtual Reality Headset used for the intervention.
(Researcher's Photograph, 2025)

Figure 7: Top view of the Meta Quest 3 Virtual Reality Headset inside its box showing headset placement and packaging.
(Researcher's Photograph, 2025)

Figure 8: The researcher guiding a participant during a VR-based rehab session
(Researcher's Field Photograph, 2025)

Figure 9: A participant performing a VR rehab task
(Researcher's Photograph, 2025)

Figure 10: A participant interacting with a VR environment aimed at improving motor function
(Researcher's Photograph, 2025)

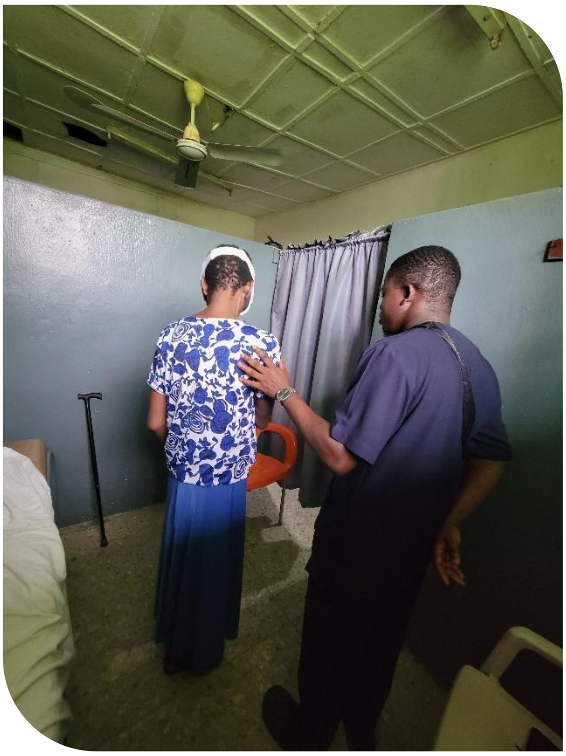


Figure 11: A researcher guiding a participant during a VR rehab aimed at improving balance
(Researcher's Photograph, 2025)

Figure 12: A participant independently performing a VR rehab task aimed at improving balance
(Researcher's Photograph, 2025)

Figure 13: A participant independently performing a VR rehab task
(Researcher's Photograph, 2025)