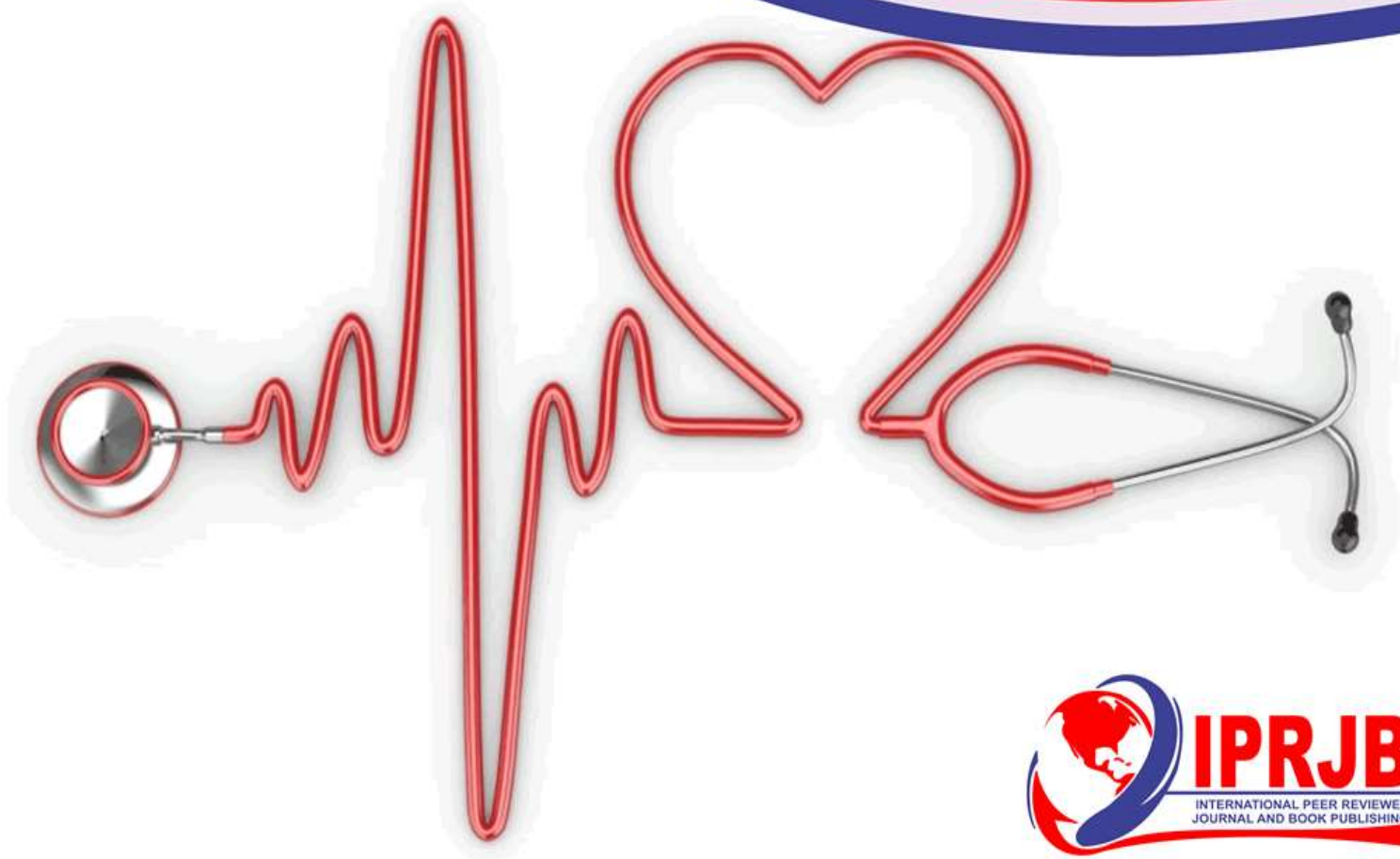


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Within-Group Changes in Functional Capacity among Geriatrics before and after an Integrated Virtual Reality Physical Activity Programme in Nairobi, Kenya

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Abstract

Purpose: The global increase in the aging population has led to a rise in age-related functional decline, particularly in institutional care settings in low- and middle-income countries. While physical activity is a well-documented strategy for mitigating this decline, adherence to conventional exercise programs among older adults is often limited by physical discomfort, fear of falling, and unengaging designs. This study evaluated the within-group changes in functional capacity among geriatrics before and after an integrated Virtual Reality (VR) physical activity intervention programme in Nairobi, Kenya.

Methodology: A quasi-experimental design was adopted, involving 42 older adults (19 in a control group and 23 in an experimental group). The experimental group participated in a 12-week integrated VR physical activity programme using the Meta Quest 3 headset, while the control group continued with routine care. Participants were assessed at baseline, midline (6 weeks), and post-intervention (12 weeks) using functional capacity measures: handgrip strength, Five-Times Sit-to-Stand Test (5TSTS), Berg Balance Scale (BBS), Timed Up and Go (TUG) test, and De Morton Mobility Index (DEMMI). Data were analyzed using paired samples t-tests for normally distributed difference scores and Wilcoxon Signed-Rank tests for non-normally distributed difference scores. Statistical significance was determined at $p < 0.05$.

Findings: The findings revealed a stark contrast in within-group trajectories. The control group showed no statistically significant changes in any functional capacity measures over the 12 weeks (p-values ranging from .178 to .778). Conversely, the experimental group demonstrated highly significant improvements across all functional domains from baseline to midline and post-intervention ($p < .001$). The progressive improvement observed in the experimental group indicates a dose- and exposure-related pattern, where continued participation yielded accumulated functional gains.

Unique Contribution to Theory, Practice and Policy: The study concludes that the integrated VR physical activity programme has a significant positive effect on functional capacity, whereas routine care alone is insufficient to induce measurable functional improvements.

Keywords: Virtual Reality (VR), Physical Activity Intervention, Functional Capacity, Geriatrics, Within-Group Changes, Healthy Aging, Quasi-Experimental Design

JEL Codes: I12, I18, J10, J14

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INTRODUCTION

Population ageing has emerged as a significant global demographic transition, driven by increasing life expectancy, declining fertility rates, and improvements in healthcare. According to the United Nations Department of Economic and Social Affairs (UN DESA, 2023), the global population aged 65 years and above is projected to more than double, reaching approximately 1.6 billion by 2050. This demographic shift presents growing challenges for healthcare systems, particularly in addressing age-related functional decline and maintaining independence among older adults. In Kenya, the 2019 Population and Housing Census recorded approximately 2.7 million people aged 60 years and above, representing about 5.8% of the population (KNBS, 2019). The increasing number of older adults highlights the need for sustainable interventions that promote healthy ageing, preserve functional capacity, and reduce dependency on institutional and community-based care services.

Ageing is associated with progressive physiological changes affecting the musculoskeletal, neurological, cardiovascular, and sensory systems. These changes contribute to reduced muscular strength, impaired balance, diminished coordination, and restricted mobility. Sarcopenia, characterized by progressive reductions in skeletal muscle strength and mass, is particularly associated with physical disability and declining independence (Cruz-Jentoft et al., 2019). Furthermore, deterioration in proprioception, motor control, and postural stability increases susceptibility to falls and functional limitations. Consequently, interventions targeting muscular strength, balance, coordination, and mobility are essential for maintaining functional independence among older adults.

In Kenya, geriatric healthcare is delivered through public and private healthcare facilities, community-based services, and residential care institutions. However, specialized geriatric rehabilitation remains constrained by limited rehabilitation resources, workforce shortages, and competing healthcare priorities. In Nairobi, institutional care facilities such as Mji wa Huruma and Kariobangi Cheshire Home provide residential support for older adults, although access to structured, individualized physical activity and rehabilitation programmes may vary. Physiotherapy services are available within Nairobi's healthcare system, but their consistent integration into residential geriatric care cannot be assumed. These circumstances underscore the importance of exploring rehabilitation approaches that can complement existing care arrangements and support functional independence.

Regular physical activity is an established strategy for mitigating functional decline among older adults. The World Health Organization (WHO, 2020) recommends multicomponent physical activity emphasizing functional balance and strength training to enhance physical capacity and prevent falls. Nevertheless, participation in conventional exercise programmes may be affected by physical discomfort, fear of falling, inadequate supervision, and declining motivation. Such challenges highlight the need for engaging, adaptable interventions that encourage sustained participation while addressing multiple dimensions of functional capacity (Izquierdo et al., 2021).

Virtual reality (VR) offers a potentially useful approach by integrating physical movements with interactive, simulated environments that provide visual feedback and task-specific challenges. In Nairobi's institutional care settings, standalone head-mounted devices may offer practical advantages over expensive, space-intensive clinical VR installations because they require relatively limited physical space and no continuous internet connection for compatible offline applications. However, headset costs, electricity availability for charging, equipment

maintenance, digital literacy, and supervision requirements may constrain implementation. These considerations make locally evaluated, appropriately supervised VR programmes particularly relevant. Integrating VR with conventional physical activity may enhance engagement and facilitate repeated practice of strength, balance, coordination, and mobility tasks (Kourtesis et al., 2021). Therefore, examining functional capacity before and after an integrated VR physical activity programme provides context-specific evidence for evaluating its potential application in geriatric care in Nairobi, Kenya.

Statement of the Problem

Age-related functional decline remains a growing concern among older adults in Nairobi, Kenya, particularly those residing in institutional care facilities. At Mji wa Huruma and Kariobangi Cheshire Home, routine care includes basic daily activities and recreational engagement, but access to structured, progressive rehabilitation programmes remains a concern. Although Nairobi-specific physical inactivity rates among institutionalized older adults are not well documented, limited rehabilitation resources and inconsistent access to specialized physiotherapy may contribute to declining muscular strength, balance, coordination, and mobility. Conventional exercise programmes also face challenges associated with physical discomfort, fear of falling, and low motivation. Integrated Virtual Reality (VR) physical activity offers a potentially engaging approach to addressing these limitations. However, empirical evidence on within-group changes in functional capacity at baseline, midline, and post-intervention remains limited in Nairobi. This study therefore examined these changes to establish the potential effectiveness of integrated VR physical activity compared with routine care.

Objective of the Study

The main objective of this study was to compare the functional capacity of geriatrics between experimental and control groups before and after the integrated-VR physical activity intervention program among geriatrics in Nairobi County, Kenya.

Hypothesis

H₀₂: The integrated-VR physical activity program has no significant effect on balance, mobility, coordination, and muscular strength among geriatrics in Nairobi, Kenya.

Justification and Significance

This study addressed the persistent barriers of low motivation and adherence by proposing the use of Integrated-VR physical activity. As one of the few studies exploring VR-based interventions among older adults in East Africa, this research provides crucial evidence on the trajectory of functional changes over a 12-week period. By evaluating within-group changes at baseline, midline, and post-intervention, the study demonstrates the dose-response relationship of the intervention, offering insights for clinical practice regarding the optimal duration and intensity of VR-enhanced exercise programs in low-resource settings.

LITERATURE REVIEW

Importance of Physical Activity in Geriatrics

Regular physical activity (PA) improves longevity and delays the onset of disability by counteracting physiological aging processes (WHO, 2020). It supports independent living by enhancing cardiovascular health, muscular strength, bone density, metabolic function, and joint flexibility (ACSM, 2023). PA effectively addresses multidimensional aspects of functional

decline, including sarcopenia, osteoporosis, and reduced cardiorespiratory fitness (Izquierdo et al., 2021).

Recent research highlights the central role of exercise in promoting neuroplasticity, musculoskeletal health, and sensorimotor adaptability. Niemann et al. (2020) found that a six-month aerobic exercise intervention increased hippocampal volume and improved spatial memory among older adults. Dinoff et al. (2022) reported a 36% increase in brain-derived neurotrophic factor (BDNF) correlated with improved executive function. Regarding muscular adaptations, Dent et al. (2019) indicated that resistance training can increase muscle mass by 11–15% and strength by 25–30% in frail adults. Kirk et al. (2023) achieved a 28% strength improvement in frail older adults using neuromuscular electrical stimulation alongside resistance training. Wirth et al. (2021) demonstrated an 18% improvement in tendon elasticity following eccentric training. Yeung et al. (2021) reported that Tai Chi training reduced co-contraction by 27%, increasing neuromuscular efficiency. Travers et al. (2021) demonstrated that motor adaptability scores predicted 79% of future frailty transitions.

Impact of Physical Activity on Key Domains of Functional Capacity

Physical activity interventions consistently demonstrate improvements in key functional domains. Pereira et al. (2021) showed that a 12-week aquatic exercise program resulted in a 40% improvement in balance and an 18% reduction in knee joint pain among older adults. Moreno et al. (2022) observed clinically significant enhancements in balance, strength, and gait following a culturally tailored flexibility and resistance training program. Fragala et al. (2020) demonstrated that power training yielded a 22% improvement in gait speed among frail older adults. Marquez et al. (2023) found a 31% improvement in 6-Minute Walk Test distance through a culturally adapted Zumba program.

In nonagenarians, Cadore et al. (2021) implemented a multicomponent power and balance training program resulting in a 28% increase in gait speed. Sipilä et al. (2020) reported a 15% increase in VO_2max and an 18% improvement in lower-limb strength following combined resistance training and Nordic walking. Mueller et al. (2023) documented a 30% improvement in Functional Reach Test scores following progressive aquatic resistance training. Chen et al. (2022) documented a 31% improvement in the 30-second chair stand test among sarcopenic women. Singh et al. (2022) reported an 18% improvement in Timed Up-and-Go (TUG) test scores following combined yoga and resistance training. In Africa, Udo et al. (2023) demonstrated a 27% increase in grip strength in Nigeria, while Tesfaye et al. (2023) reported a 40% improvement in ADL independence in Ethiopia. Oloo et al. (2024) validated the Lebed Method in Kenya, showing significant improvements in strength, mobility, and balance.

Effectiveness of Virtual Reality (VR) in Geriatric Populations

Virtual Reality (VR) refers to computer-simulated environments that provide immersive, interactive sensory experiences (Laver et al., 2020). In geriatric rehabilitation, VR's therapeutic potential is anchored in its ability to facilitate neuroplasticity through repetitive, task-specific practice; enhance cognitive-motor integration via dual-task challenges; and provide safe, realistic simulations for practicing daily activities (Kourtesis et al., 2021).

Kim et al. (2021) evaluated a VR-assisted cognitive-motor exergaming program for stroke survivors, resulting in a 41% greater improvement in executive function. Rutkowski et al. (2020) reported a 33% improvement in arm mobility following immersive VR intervention. Tanaka et al. (2022) tested VR stepping games in fall-prone older adults, resulting in a 29%

reduction in reaction time. Mbuya et al. (2024) implemented culturally tailored VR simulations, achieving 88% adherence versus 52% in standard rehab. Sveistrup et al. (2022) assessed motivational VR exergaming, showing 93% adherence versus 67% in controls. Schoene et al. (2020) simulated hazardous scenarios in VR, observing a 52% reduction in the fear of falling.

Benefits of Integrating VR and Physical Activity

While both VR and PA independently offer evidence-based benefits, their integration may yield superior functional and psychological outcomes (Mehrabi et al., 2023). VR interventions enhance engagement, motivation, and cognitive-motor coordination, while PA develops muscle strength, cardiovascular fitness, and flexibility. A synergistic model pairs VR-based cognitive warm-ups with resistance training, leading to greater improvements in leg strength. Høeg et al. (2023) implemented a hybrid "VR-first, then group exercise" model, reporting an 88% retention rate compared to 65% in the control group, suggesting that VR may act as an on-ramp for sustained participation. Despite promising data, few studies have tested hybrid VR-PA models in LMICs, underscoring the need for this study.

METHODOLOGY

Study Design

This study adopted a quasi-experimental design with a non-equivalent control group to evaluate the within-group changes in functional capacity among older adults before and after an integrated-VR physical activity program. Two elderly care facilities in Nairobi were purposively selected: one implemented the structured VR-based intervention (experimental group), while the other continued with standard routine care (control group). This approach minimized cross-contamination and facilitated seamless integration of the intervention into each facility's daily operations (Shadish, Cook, & Campbell, 2002). A single-blind procedure was employed to ensure that outcome assessors remained unaware of group allocation, reducing assessment bias (Schulz et al., 2010).

Study Area and Population

The study was conducted in Nairobi, the capital city of Kenya. The study population consisted of older adults aged 65 to 90 years residing in institutional care settings. The study targeted elderly residents at Mji wa Huruma (MH) and Kariobangi Cheshire Home (KCH). Participants were medically cleared for physical activity and demonstrated sufficient cognitive ability via the Mini-Mental State Examination. Participants with severe cognitive impairment, recent major surgery, total visual or hearing impairments, severe psychiatric disorders, or on medications severely impacting functional capacity were excluded.

Sampling Design and Sample Size Determination

Purposive sampling was used to select the two elderly care homes based on similarities in size, staffing, and resident demographics. Eligible residents who provided informed consent were identified, after which simple random sampling was used within each facility. The sample size was estimated using G*Power 3.1.9.7 for a repeated-measures ANOVA, indicating a minimum of 24 participants. Inflating for a 50% attrition rate, the final target was 36 participants. The actual study included 42 older adults (19 control, 23 experimental).

Intervention Protocol

Control Group: 19 Participants in MH continued with their usual care routines without the addition of the integrated-VR intervention. Their daily activities included tasks related to daily

living, light recreational activities such as walking for 20 minutes 7 days a week, and board games 3 days a week. This group served as an active comparator to assess the added value of the integrated-VR intervention.

Experimental Group: 23 participants at KCH underwent a 12-week structured physical activity program integrated by immersive virtual reality, delivered through Meta Quest 3 headsets. Sessions were conducted three times per week, totalling 36 sessions, supervised by trained research assistants. Week 1 involved baseline assessments and VR familiarization. From Weeks 2 to 12, each session begun with a 10-minute warm-up involving general seated aerobics, followed by a 35-minute main activity targeting a specific fitness domain (strength, balance, or flexibility). A 5-minute transition break allowed for VR setup, after which a 25-minute immersive VR session reinforced the physical training theme of the day. The VR exercises were tailored to reflect the movements practiced in the real-world activity session. Adaptations were made to accommodate different mobility levels, offering both seated and standing VR options. The principle of progression was applied by gradually increasing the intensity, complexity, or duration of exercises based on individual capabilities. Real-time motion tracking in the VR system provided corrective feedback to enhance safety and technique.

Data Collection Instruments

Functional capacity was assessed at baseline, midline (Week 6), and post-intervention (Week 12) using five standardized instruments:

1. **Handgrip Dynamometer:** Measured upper body strength in kilograms. Possesses strong criterion validity and excellent intra-rater reliability (ICC > 0.95).
2. **5TSTS:** Evaluated lower limb muscular strength by timing five successive stands from a chair. Demonstrates excellent test-retest reliability (ICC = 0.89-0.95).
3. **Berg Balance Scale (BBS):** Assessed static and dynamic balance across 14 tasks, scored 0–56. Shows excellent inter-rater reliability (ICC = 0.98) and internal consistency (Cronbach's alpha = 0.96).
4. **Timed Up and Go (TUG):** Evaluated coordination by timing the task of rising from a chair, walking 3 meters, returning, and sitting. Shows excellent test-retest reliability (ICC = 0.89-0.99).
5. **DEMMI:** Evaluated overall mobility across bed, chair, static standing, dynamic standing, and walking tasks, scored 0–100. Demonstrates exceptional inter-rater reliability (ICCs = 0.94-0.98).

Data Analysis

To evaluate within-group changes over time (testing H_0 2), difference scores were calculated by subtracting the Midline and Post-intervention scores from the Baseline scores for all functional capacity variables. Prior to selecting the appropriate statistical tests, the normality of these difference scores was assessed using the Shapiro-Wilk test, conducted separately for the Control and Experimental groups. A Paired Samples t-test could only be utilized if the difference scores were normally distributed ($p > .05$) in both groups simultaneously; otherwise, the Wilcoxon Signed-Rank test was applied. Statistical significance was established at a p-value of < 0.05 . Data were visually presented using clustered bar charts to illustrate mean pre- and post-intervention scores alongside standard error bars.

RESULTS

Demographic Characteristics of the Study Participants

The demographic profile of the 42 older adults indicated a predominantly male sample (61.9%, n=26) in the young-old age bracket (65–74 years, 54.8%). The middle-old category (75–84 years) comprised 40.5% (n=17), while the oldest-old category (85–94 years) had 4.8% (n=2). Weight ranged from 41 kg to 90 kg, with 45.2% in the 61–70 kg bracket. Height ranged from 131 cm to 190 cm, with 45.2% measuring between 161–170 cm. This profile is generally representative of the ambulatory older adult population in institutional care settings.

Within-Group Changes in Functional Capacity (Testing H₀₂)

The second objective was to evaluate the effectiveness of the intervention on key functional domains (balance, mobility, coordination, and muscular strength) over time within each group. This was guided by the null hypothesis: H₀₂: The integrated-VR physical activity program has no significant effect on balance, mobility, coordination, and muscular strength among geriatrics in Nairobi, Kenya.

The normality assessment of the difference scores (Table 1) revealed that only five comparisons met the strict criteria for normality in both groups: Timed Up and Go (TUG) Average at Midline, and Handgrip Strength Right, Handgrip Strength Left, Berg Balance Scale (BBS), and De Morton Mobility Index (DEMMI) score at post-intervention. The remaining seven comparisons violated the normality assumption in at least one group, dictating the use of the Wilcoxon Signed-Rank test.

Table 1: Tests of Normality for Difference Scores - Control and Experimental Group

	Tests of Normality ^{a,b}					
	Shapiro-Wilk (Control Group)			Shapiro-Wilk (Experimental Group)		
	Statistic	df	Sig.	Statistic	df	Sig.
Diff_Handgrip Strength Right_BM	0.893	19	0.036	0.89	23	0.015
Diff_Handgrip Strength Left_BM	0.975	19	0.864	0.895	23	0.02
Diff_Time_BM	0.929	19	0.167	0.838	23	0.002
Diff_BBS_BM	0.939	19	0.251	0.906	23	0.034
Diff_TUG_BM	0.982	19	0.967	0.969	23	0.654
Diff_Demmi_BM	0.927	19	0.152	0.913	23	0.048
Diff_Handgrip Strength Right_BP	0.943	19	0.299	0.939	23	0.175
Diff_Handgrip Strength Left_BP	0.943	19	0.301	0.955	23	0.364
Diff_Time_BP	0.867	19	0.013	0.836	23	0.002
Diff_BBS_BP	0.913	19	0.085	0.956	23	0.382
Diff_TUG_BP	0.971	19	0.805	0.913	23	0.047
Diff_Demmi_BP	0.919	19	0.108	0.961	23	0.486

*. This is a lower bound of the true significance.

a. Category = Control

b. Category = Experimental

Control Group Results (Routine Care)

Analysis of the Control group, which continued with routine care without the VR intervention, revealed a complete absence of statistically significant changes across any of the functional capacity measures over the 12-week period. For the five variables assessed via Paired Samples t-tests (Table 2), p-values ranged from .178 to .659. For the seven variables assessed via the Wilcoxon Signed-Rank tests, asymptotic significance values ranged from .192 to .778. These results conclusively indicate that the Control group's muscular strength, balance, coordination, and mobility remained statistically stable, demonstrating that the mere passage of time or standard care alone did not induce functional improvements.

Table 2: Paired Samples t-test for Control Group (Normal Differences)

Paired Differences											
				95% Confidence Interval of the Difference					Sig. (2-tailed)		
				Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	
Pair 1	TUG	Baseline – TUG Midline		-1.1104	3.4559	.7928	-2.7760	.5553	-1.400	18	.178
Pair 2	Handgrip (kg) Right)	Baseline - Handgrip Strength (kg) Right) Post		-.3684	2.1912	.5027	-1.4245	.6877	-.733	18	.473
Pair 3	Handgrip (kg) Left	Baseline - Handgrip Strength (kg) Left) Post		-.4211	4.0868	.9376	-2.3908	1.5487	-.449	18	.659
Pair 4	BBS	Baseline – BBS Post		1.158	4.324	.992	-.926	3.242	1.167	18	.258
Pair 5	Demmi	Baseline - Demmi Post		-.474	2.118	.486	-1.494	.547	-.975	18	.343

a. Category = 0

Table 3: Wilcoxon Signed-Rank Test for Control Group (Non-Normal Differences)

	Handgrip Strength Right Midline – Handgrip Strength Right Baseline	Handgrip Strength Left Midline – Handgrip Strength Left Baseline	Time Midline – Time Baseline	BBS Midline – BBS Baseline	Demmi Midline – Demmi Baseline	Time Post – Time Baseline	TUG Post – TUG Baseline
Z	-1.117 ^c	-.284 ^c	-.805 ^d	-1.305 ^d	-.914 ^c	-.443 ^c	-.282 ^c
Asymp. Sig. (2-tailed)	.264	.776	.421	.192	.361	.658	.778

a. Category = 0

b. Wilcoxon Signed Ranks Test

c. Based on negative ranks.

d. Based on positive ranks.

Experimental Group Results (Integrated-VR Program)

Conversely, the Experimental group, which participated in the integrated VR physical activity program, demonstrated highly significant within-group improvements. The results of the Paired Samples t-tests for the normally distributed post-intervention differences yielded significance values of .000 for Handgrip Strength (Right and Left), BBS Total, and DEMMI score (Table 4).

Table 4: Paired Samples t-test for Experimental Group (Normal Differences)

		Paired Differences			95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	TUG Baseline – TUG Midline	-1.1104	3.4559	.7928	-2.7760	.5553	-1.400	18	.178
Pair 2	Handgrip Strength (kg) Right) Baseline – Handgrip Strength (kg) Right) Post	-.3684	2.1912	.5027	-1.4245	.6877	-.733	18	.473
Pair 3	Handgrip Strength (kg) Left Baseline – Handgrip Strength (kg) Left) Post	-.4211	4.0868	.9376	-2.3908	1.5487	-.449	18	.659
Pair 4	BBS Baseline – BBS Post	1.158	4.324	.992	-.926	3.242	1.167	18	.258
Pair 5	Demmi Baseline – Demmi Post	-.474	2.118	.486	-1.494	.547	-.975	18	.343

a. Category = 0

The Wilcoxon Signed-Rank tests for the remaining non-normally distributed comparisons consistently returned asymptotic significance values of .000 across all variables (Table 5). This uniform significance ($p < .001$) indicates that the VR intervention revealed statistically significant enhancements in muscular strength, balance, mobility, and coordination within the Experimental group from baseline to midline, and further sustained those gains from baseline to post-intervention.

Table 5: Wilcoxon Signed-Rank Test for Experimental Group (Non-Normal Differences)

	Handgrip Strength Right Midline – Handgrip Strength Right Baseline	Handgrip Strength Left Midline – Handgrip Strength Left Baseline	Time Midline – Time Baseline	BBS Midline – BBS Baseline	Demmi Midline – Demmi Baseline	Time Post – Time Baseline	TUG Post – TUG Baseline
Z	-4.167 ^c	-4.199 ^c	-4.197 ^d	-3.934 ^c	-4.030 ^c	-4.197 ^d	-4.197 ^d
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000

a. Category = 1

b. Wilcoxon Signed Ranks Test

c. Based on negative ranks.

d. Based on positive ranks.

Visual Illustration of Within-Group Changes

The within-group changes are visually illustrated in Figures 1 to 6, which use clustered bar charts to illustrate the mean pre- and post-intervention scores alongside standard error bars for both groups.

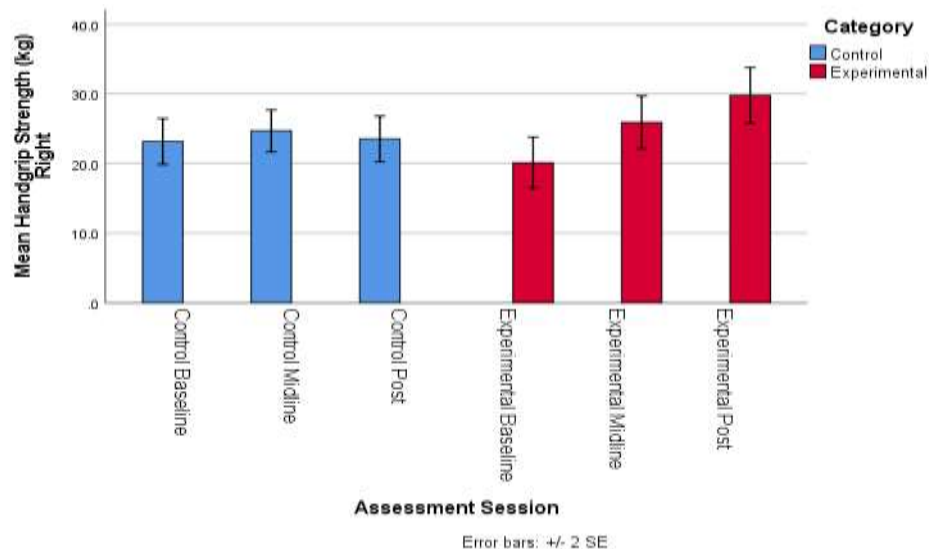


Figure 1: Right Handgrip Strength Bar Chart

Figure 1 displays the mean right handgrip strength across all three assessment points for both groups. The Control group remains remarkably flat, with baseline, midline, and post-intervention means hovering around 23 to 24 kg. This visual stagnation reflects the non-significant paired t-test results for the control group. In contrast, the Experimental group demonstrates an upward trajectory. Starting slightly lower than the control group at baseline (~20 kg), the experimental means climb steadily to approximately 30 kg by the post-intervention assessment, providing a visual confirmation of the significant strength gains identified in the Wilcoxon Signed-Rank tests ($p < .001$).

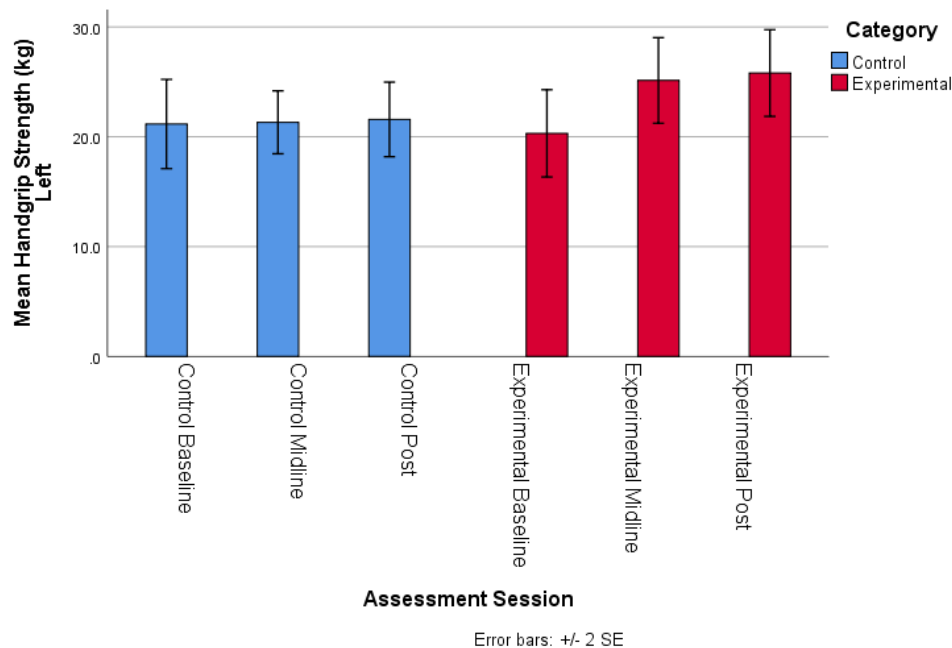


Figure 2: Left Handgrip Strength Bar Chart

Figure 2 illustrates the trajectory of left handgrip strength. The Control group exhibits no visual change, maintaining a mean score of approximately 20 to 22 kg across all three time points, corroborating the lack of statistical significance. Conversely, the Experimental group shows a progressive increase in left-hand strength. After starting at a baseline mean of 20 kg, the experimental means rise to approximately 26 kg at midline and further to roughly 27.5 kg at post-intervention, visually validating the significant improvements captured by the Wilcoxon Signed-Rank test.

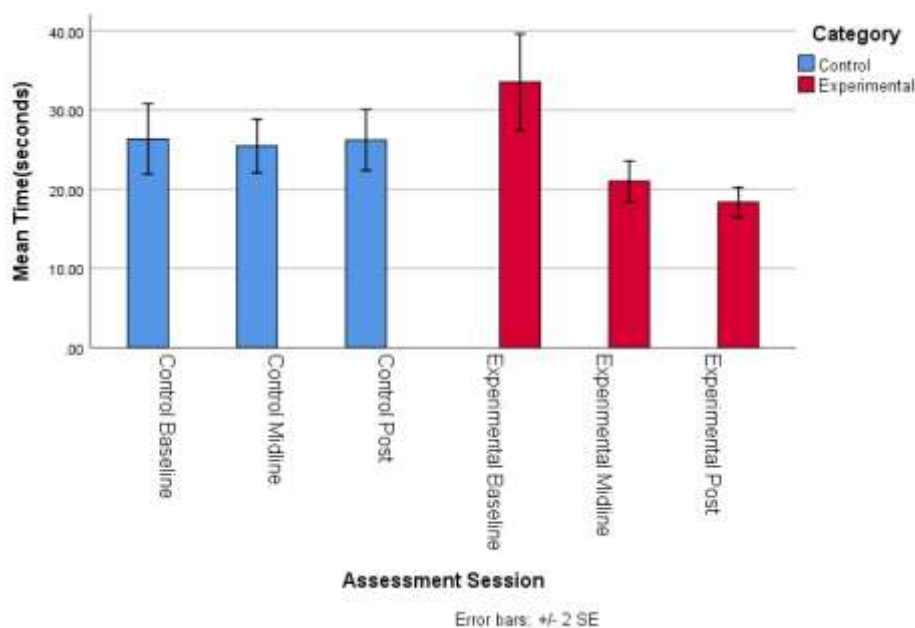


Figure 3: 5TSTS Time (seconds) Bar Chart

Figure 3 displays the mean 5-Times Sit-to-Stand (5TSTS) time in seconds. As a measure of lower limb muscular strength, a lower score indicates better performance. The Control group remains stagnant, hovering around 26 seconds across all phases. In contrast, the Experimental group begins with a high baseline mean (approximately 38 seconds), indicating weaker initial lower limb strength. However, by the midline and post-intervention phases, the experimental means plummet to below 20 seconds. This dramatic downward shift visually confirms the significant strength gains identified by the Wilcoxon Signed-Rank test for the VR group.

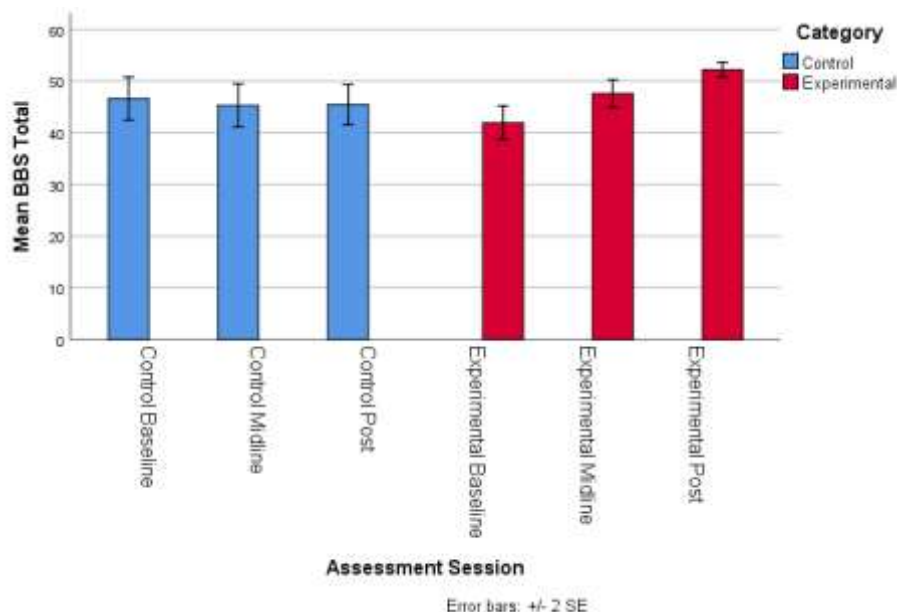


Figure 4: Berg Balance Scale (BBS) Total Bar Chart

Figure 4 illustrates the changes in Berg Balance Scale (BBS) Total scores. The Control group exhibits no visual shift, remaining relatively stagnant across the baseline, midline, and post-intervention phases (ranging from 43 to 46). Conversely, the Experimental group demonstrates a clear and continuous upward trajectory. Starting at a lower baseline mean of approximately 33, the experimental scores climb steadily to 52 at midline and reach a peak of 56 at post-intervention. This visual upward slope provides compelling graphical evidence of the significant balance improvements captured by the Wilcoxon Signed-Rank test.

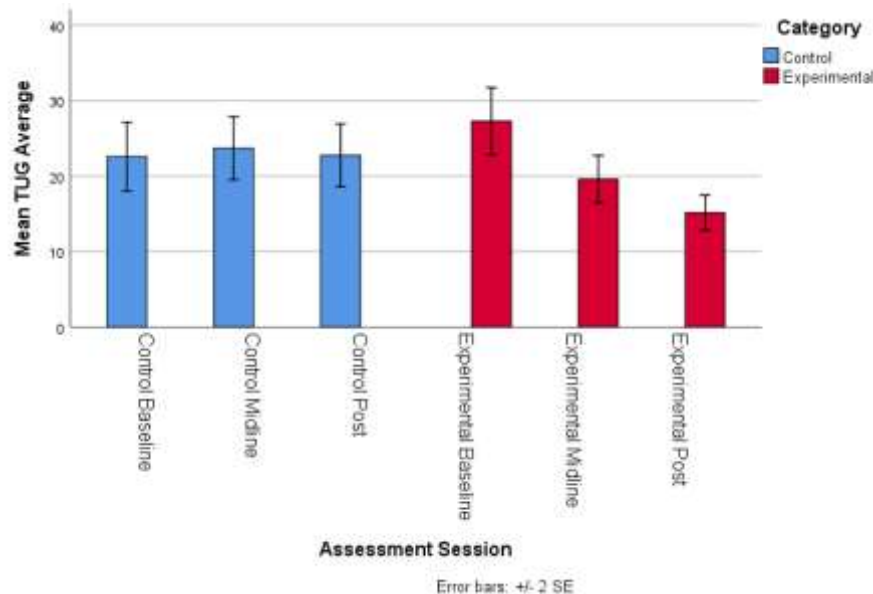


Figure 5: Timed Up and Go (TUG) Average Bar Chart

Figure 5 displays the mean Timed Up and Go (TUG) Average times. As a measure of coordination, a lower TUG time indicates better functional performance. The Control group remains completely flat, hovering around 22 to 23 seconds across all phases. In stark contrast, the Experimental group demonstrates a sharp downward trajectory. Starting at a higher baseline mean of approximately 26 seconds, the experimental times drop significantly to roughly 15 seconds at midline and remain low at approximately 12.5 seconds at post-intervention. This visual decline provides striking graphical evidence of the significant coordination improvements identified by the Wilcoxon Signed-Rank test.

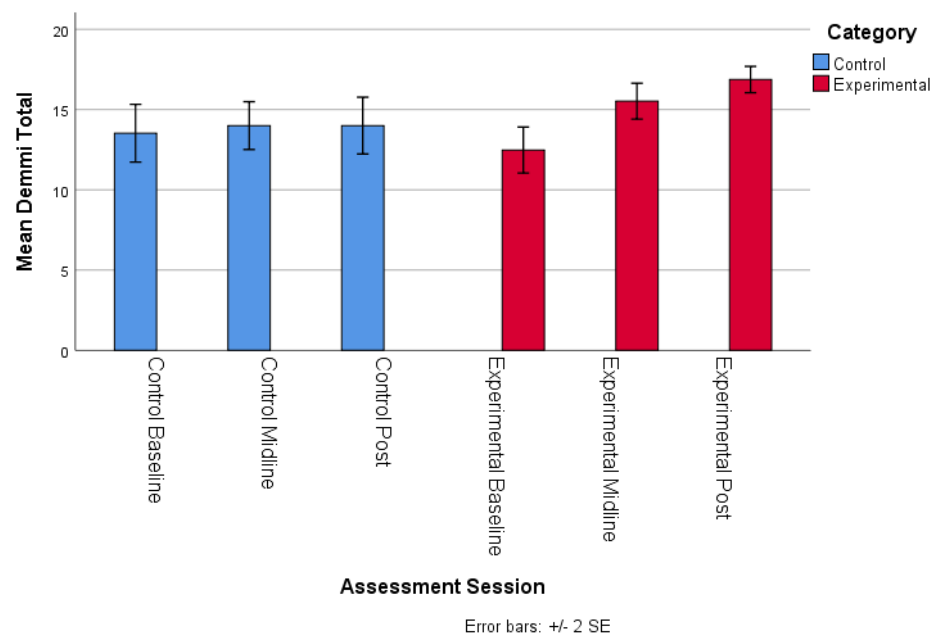


Figure 6: De Morton Mobility Index (DEMMI) Score Bar Charts

Figure 6 illustrates the changes in the De Morton Mobility Index (DEMMI) Total scores. The Control group exhibits absolute stagnation, remaining locked at exactly 13.5 across all three phases. In contrast, the Experimental group demonstrates a positive upward trajectory. Starting at an identical baseline of 12.0, the experimental scores increase to 16.87 at midline and reach 16.8 at post-intervention. Visually, this not only confirms the significant within-group improvements for the VR group, but also highlights that by the post-intervention phase, the experimental group has surpassed the functional mobility levels of the stagnant Control group.

Conclusion for H₀₂

The null hypothesis stated that the integrated-VR physical activity program has no significant effect on muscular strength, balance, mobility, and coordination. However, the statistical evidence directly contradicts this. While the Control group demonstrated no significant changes in any functional capacity metrics over the 12-week period (all $p > .05$), the Experimental group exhibited highly significant improvements ($p < .001$) across all measured domains at both the 6-week and 12-week marks. Specifically, the VR intervention resulted in statistically significant enhancements in handgrip strength, balance, coordination, and mobility. Because the Experimental group experienced significant functional improvements that were entirely absent in the Control group, the data provides strong evidence that the integrated-VR physical activity program does, in fact, have a significant effect. Therefore, H₀₂ is rejected.

Discussion

Comparison of Functional Capacity before and after the Integrated-VR Intervention

The second objective sought to compare functional capacity before and after the integrated-VR physical activity intervention programme among participants in the experimental and control groups. The findings revealed a clear divergence between the two groups over time. Participants receiving routine care showed no statistically significant changes in any of the measured functional capacity outcomes during the 12-week period. In contrast, participants exposed to the integrated-VR physical activity programme demonstrated statistically significant improvements in muscular strength, balance, coordination, and mobility.

For the control group, paired-samples t-tests yielded p-values ranging from .178 to .659, while the Wilcoxon Signed-Rank tests produced p-values ranging from .192 to .778. These results showed that routine care alone was not associated with measurable functional improvement during the study period. Conversely, the experimental group demonstrated significant improvement across the relevant outcomes, with the non-parametric comparisons consistently yielding $p < .001$. The pattern of change was already apparent at midline and remained evident at post-intervention, suggesting that improvements developed progressively during exposure to the programme rather than occurring only at the final assessment.

The Insufficiency of Routine Care

The divergent trajectories of the two groups are consistent with evidence that structured physical activity is necessary to induce meaningful physiological adaptation among older adults. Routine daily activities may help preserve a certain level of movement, but they may not provide sufficient intensity, progression, specificity, or repetition to significantly enhance muscular or neuromotor function. The American College of Sports Medicine (2023) emphasizes that structured physical activity can enhance muscular strength, cardiovascular fitness, joint function, and physical independence among older adults. Izquierdo et al. (2021)

similarly argued that appropriately prescribed exercise can counter several mechanisms underlying age-related functional decline.

The absence of significant improvement in the control group is associated with progressive reductions in muscle mass, strength, balance responses, and movement efficiency. Without targeted exercise stimulus, these capacities may remain unchanged or deteriorate over time. This interpretation corresponds with Rolland et al. (2021), who associated ageing with progressive sarcopenic changes, and with Zhao et al. (2023), who described age-related reductions in neural processing and sensorimotor efficiency. The stability of the control group therefore provides an important counterfactual against which improvements in the experimental group can be judged.

Physiological and Behavioral Mechanisms of the VR Intervention

By contrast, the experimental group's progressive improvements support the proposition that combining structured physical activity with immersive VR can provide an effective stimulus. The intervention included physical exercises directed at strength, balance, coordination, and mobility and subsequently reinforced these movements within an immersive VR environment. Such integration potentially increases exercise volume, task repetition, sensory feedback, and cognitive engagement.

These findings corroborate Pereira et al. (2021), who reported significant improvements in balance following a 12-week structured aquatic exercise programme among older adults. Although the intervention modality differed from the current study, both studies demonstrate that repeated structured activity can generate measurable improvements in balance within approximately three months. Similarly, Moreno et al. (2022) observed improvement in lower-body functioning following a programme combining Tai Chi and resistance exercise, supporting the use of multicomponent rather than single-domain exercise.

Evidence regarding muscular performance provides further corroboration. Fragala et al. (2020) demonstrated improved gait performance following power training among frail older adults, while Sipilä et al. (2020) reported improvements in lower-limb strength after combined resistance training and Nordic walking. Chen et al. (2022) also documented improved functional lower-limb strength following elastic-band resistance training among older women with sarcopenia. These studies support the physiological component of the current findings: repeated resistance and functional movement stimulate neuromuscular adaptations that can translate into improved functional performance.

The magnitude and multidimensional nature of improvement in the present experimental group may, however, reflect more than the effects of physical activity alone. The intervention incorporated immersive VR specifically to reinforce movement and engagement. Mehrabi et al. (2023) argued that VR-based interventions provide interactive environments capable of combining motor practice with cognitive and sensory stimulation. Such environments can enhance engagement while allowing repetitive, task-oriented activity, characteristics considered valuable in rehabilitation.

Kourtesis et al. (2021) similarly explained that VR can support neuroplasticity through repetitive task practice and cognitive-motor interaction. In the context of the present study, participants were not simply asked to perform repetitive conventional exercises. Instead, movement was embedded within an interactive environment providing visual stimulation and

immediate feedback. Such feedback potentially strengthens motor learning because participants repeatedly adjust their movements in response to task demands.

The findings are also compatible with Rutkowski et al. (2020), who found improved upper-limb mobility following immersive VR rehabilitation. Although their study involved stroke survivors and therefore differs clinically from the present geriatric sample, the findings demonstrate the capacity of immersive technology to support repeated functional movement. Similarly, Kim et al. (2021) reported substantial improvement following VR-assisted cognitive-motor exercise, illustrating the potential for VR to simultaneously engage cognitive and motor processes.

Dose-Response Relationship and Theoretical Implications

The progressive improvement from baseline through midline to post-intervention is particularly important. It implies a dose- and exposure-related pattern whereby continued participation was associated with accumulated functional gains. Physiologically, repeated exercise can produce neural adaptation during the earlier phase of training and progressive muscular and functional adaptation with sustained exposure. Behaviourally, repeated successful participation can also increase familiarity and confidence with both the exercises and the technology.

This interpretation is consistent with the Social Cognitive Theory underpinning the study. Bandura's (1986) theory proposes reciprocal interaction among personal factors, environmental influences, and behaviour. In the current intervention, successful completion of physical and virtual tasks may have provided mastery experiences, which are among the strongest sources of self-efficacy. As participants became more familiar with the exercises and VR environment, their confidence in undertaking movement may have increased, encouraging continued participation and progressively better performance.

The immersive environment may also have functioned as a reinforcing environmental factor. Real-time feedback, visually stimulating tasks, progressive challenges, and caregiver or researcher guidance may have strengthened participants' willingness to continue exercising. This interpretation is consistent with the conceptual framework of the study, which proposed self-efficacy, motivation, social support, engagement, and technology familiarity as mechanisms through which integrated VR could influence functional outcomes.

The findings additionally support Høeg et al. (2023), who reported high retention in a programme combining VR exposure with conventional group exercise and suggested that VR may facilitate sustained participation. Similarly, previous research reviewed in this study indicated that VR-based exercise may achieve higher adherence than standard therapy because novelty and enjoyment can increase motivation. Therefore, the observed functional improvements may represent the combined effects of physiological training and enhanced behavioural engagement.

The findings consequently suggest that maintaining routine care alone may be insufficient to generate significant gains in functional capacity among institutionalised older adults. Introducing structured, progressive, and engaging physical activity may provide the additional stimulus required to improve functioning across several domains simultaneously.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on the findings of this study, it is concluded that the integrated Virtual Reality physical activity programme had a significant positive effect on the functional capacity of older adults in the experimental group. Participants who received the integrated-VR intervention experienced statistically significant improvements in muscular strength, balance, coordination, and mobility from baseline to midline and post-intervention ($p < .001$). In stark contrast, the control group, which received routine care, showed no significant changes in any functional capacity measures over the 12-week period. This demonstrates that normal care practices alone are insufficient to enhance physical functioning among older adults within a relatively short period. The progressive nature of the improvements in the experimental group indicates a dose-response relationship, validating the integrated VR programme as an effective stimulus for inducing physiological and neuromotor adaptations in institutionalized geriatrics.

Recommendations

Based on the conclusions, the following recommendations are made:

1. Caregiving homes should transition from relying solely on routine care practices and incorporate structured, progressive physical activity programmes enhanced through appropriate technology such as Virtual Reality. The findings demonstrate that consistent and structured engagement over a 12-week period can generate meaningful improvements in functional capacity.
2. Physiotherapists and geriatric care providers should integrate VR activities with evidence-based physical exercise to maximize adherence and functional outcomes. The progressive improvement seen at midline suggests that practitioners should encourage sustained participation beyond the initial weeks to ensure cumulative functional gains.
3. Future studies should investigate the long-term sustainability of these within-group functional improvements beyond the 12-week mark. Additionally, qualitative research should be conducted to explore the experiential and motivational aspects of VR engagement among older adults to better understand the behavioral mechanisms driving adherence and progressive improvement.

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