The Impact of Oculus MR-Based Exercise in Comparison to Conventional Physical Therapy Approaches on Lower Limb Rehabilitation in Healthy Adults: A Randomized Controlled Trial

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Purpose This study aims to compare the effectiveness of a MR-based exercise device with traditional physiotherapy methods and assess how these approaches impact lower limb strength, muscular endurance, cardiorespiratory endurance, flexibility, and balance. ***Methods*** The study involved 24 healthy adults divided into two groups: an MR-based exercise device group and a traditional physiotherapy group, each performing exercises for four weeks. Assessment parameters included strength, muscular endurance, cardiorespiratory endurance, flexibility, and balance, with pre- and post-intervention measurements. Strength was evaluated using one-repetition maximum (1RM), muscular endurance by the number of repetitions at a set weight, cardiorespiratory endurance via a two-minute step test, flexibility with the Sit and Reach test, and balance through the Timed Up and Go (TUG) test. ***Results*** Both groups showed significant improvements in strength, muscular endurance, and cardiorespiratory endurance from pre- to post-intervention ($p < 0.05$). However, there were no significant changes in flexibility and balance ($p > 0.05$). No significant differences were observed in post-intervention results between the MR-based exercise device group and the traditional physiotherapy group across all parameters. ***Conclusion*** This study suggests that both MR-based exercise devices and traditional physiotherapy methods are similarly effective in improving lower limb strength, muscular endurance, and cardiorespiratory endurance. However, the improvements in flexibility and balance were limited, possibly due to the characteristics of the participants and the assessment tools. MR-based exercise devices have the potential to serve as an alternative in physiotherapy, though future studies should include more diverse populations and evaluate long-term effects for more comprehensive findings.

Key words DTx, Digital healthcare, gamification, mixed reality,

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Received date 27 January 2025
Revised date 16 February 2025
Accept date 17 February 2025

I. Introduction

Technological advances in recent years have revolutionized healthcare and rehabilitation. In particular, Mixed Reality (MR) technology integrates physical and digital environments to allow users to have an immersive experience, which represents a new paradigm for rehabilitation therapy.[1)] Mixed reality technologies integrate virtual reality (VR) and augmented reality (AR) technologies, providing a new form of interaction that combines the real and virtual worlds.[2)] MR technology offers innovative applications in a variety of fields and has the potential to maximize patient engagement and motivation, especially in rehabilitation.[3)] MR technology can increase the accuracy and effectiveness of exercises through visual feedback. This can contribute significantly to maximizing patient engagement and treatment outcomes in areas such as neurorehabilitation.[4)]

The Oculus MR glasses-based exercise device utilizes this MR technology and has the potential to revolutionize the approach to rehabilitation therapy.[5)] MR technology can be used in various aspects of rehabilitation therapy and can be applied to a variety of exercise programs, for example, to train balance, increase strength, and improve flexibility.[6)] In balance

http:dx.doi.org/10.17817/JCMSH.2025.29.1.6

training programs, patients can perform various balancing activities in a virtual environment and receive real-time feedback.[7] This can help patients to modify their posture and movements on the fly and improve their balance more effectively.

Additionally, in strength training programs, MR technology can be used to perform a variety of virtual resistance training. Virtual resistance helps strengthen muscles by allowing patients to experience resistance in a virtual environment, even if they don't feel the actual physical resistance.[8] Flexibility improvement programs follow different stretching movements in a virtual environment and offer a variety of ways to improve flexibility. These technological advancements will increase the efficiency of rehabilitation therapy and help patients become more engaged in their treatment.[9] In particular, gamified MR environments can provide patients with a more fun and engaging therapeutic experience, which can significantly contribute to increased treatment persistence and engagement. This will play an important role in increasing the long-term success rate of rehabilitation treatment.[10]

Traditional physical therapy includes a variety of techniques aimed at increasing strength, improving balance, increasing flexibility, and improving cardiorespiratory endurance.[11] These methods have a long history and have been proven effective by many studies.[12,13] However, traditional physical therapy can have limitations in maintaining patient motivation and engagement, which can negatively impact treatment effectiveness.[14]

The Oculus MR glass-based exercise device provides users with an immersive exercise experience, which can increase the fun and motivation of exercise. The devices allow exercises to be performed in a virtual environment, encouraging patients to be more active and engaged.[5] Recent studies suggest that MR-based exercise devices can improve the effectiveness of physical therapy.[4,15] However, studies that systematically evaluate the effectiveness of MR technology are still lacking, and studies that compare it to traditional physical therapy methods are even rarer.

Therefore, this study aims to analyze the effects of Oculus MR glasses-based exercise devices on muscle strength, muscular endurance, flexibility, balance, and cardiorespiratory endurance compared to traditional physical therapy methods. Such a comparative study will provide an important basis for evaluating the usefulness of MR technology in rehabilitation. The study aims to (a) Compare and analyze the effects of Oculus MR glass-based exercise devices and traditional physical therapy methods on strength, muscular endurance, flexibility, balance, and cardiorespiratory endurance. (b) evaluate the benefits and limitations of the MR device from a clinical and patient perspective, and (c) provide practical recommendations for integrating MR technology into existing rehabilitation treatment methods.

II. Materials and Methods

The subjects were randomized into two groups: an experimental group (MRG) using an MR-based exercise device and a control group (PTG) receiving traditional physical therapy methods. All subjects underwent a pre-study medical examination, gave informed consent, and participated in the study. Twelve subjects were assigned to the experimental group (using the Oculus MR glasses-based exercise device) and 12 to the control group (using traditional physical therapy).

This study included 24 adult men and women who met the following criteria. Inclusion criteria were adults aged between 20 and 50 years old, who were deemed able to perform rehabilitation exercises in a pre-study medical examination, and who fully understood the purpose and methods of the study and voluntarily provided informed consent. Exclusion criteria included severe cardiovascular disease (heart disease, high blood pressure, etc.), psychiatric illness (mental illness or cognitive decline), pregnant women (pregnancy limits exercise performance), and any other health condition that, in the opinion of the researcher, would make participation in the study unsuitable. Study participant characteristics include the following (Table 1).

Table 1. General characteristics of participants (N = 24)

	MRG (n=12)	PTG (n=12)
Age (years)	22.06±1.56	21.79±1.58
Height(cm)	169.42±6.70	169.22±7.80
Weight (Kg)	66.55±10.69	66.33±13.82

Note. Values indicated as mean ± standard deviation, MRG: mixed-reality exercise group, PTG: physical therapist exercise group

Figure 1. Mixed reality exercise group

All participants completed a questionnaire about their health status, physical activity level, and past medical history before the start of the study to ensure homogeneity between groups. Participants were continuously monitored by the research team for any side effects or discomfort that may occur during the study.

The intervention in this study was group-assigned. The experimental group used the Oculus MR glasses-based exercise device, while the control group received traditional physical therapy exercises performed by a physical therapist without MR equipment. In all groups, the intervention program was 4 weeks, 3 times per week, 30 minutes per session, and included stationary indoor bikes, steppers, and twists (Figure 1).

Muscle strength was measured in the bilateral knee flexors with digital MMT.[16] The subject sits in a chair or lies on a bed, the knee is flexed to a 90-degree angle, and the subject extends the knee with maximum effort, recording the force measured by the machine. This process is repeated for both knees and the measurement is repeated three times, and the average of each measurement is recorded.

Muscular endurance was measured using a 30-second sit-to-stand test.[17] The subject was seated in a chair with knees and feet parallel to the floor, the researcher set a timer, and the subject repeated the sit-to-stand motion as many times as possible in 30 seconds. The total number of repetitions performed by the subject was recorded, and the posture was such that when standing up, the subject should be fully upright, and when sitting down, the buttocks should touch the chair, and the test was repeated twice, and the total number of repetitions for each repetition was averaged and recorded.

In this study, flexibility was assessed with the Sit and Reach test,[18] where the subject sat on the floor with both legs straight and toes pointed upward, and the subject reached as far as possible on the tips of their toes, measuring the distance reached or the position reached. Subjects performed three repetitions and recorded their maximum reach, with the longest dis-

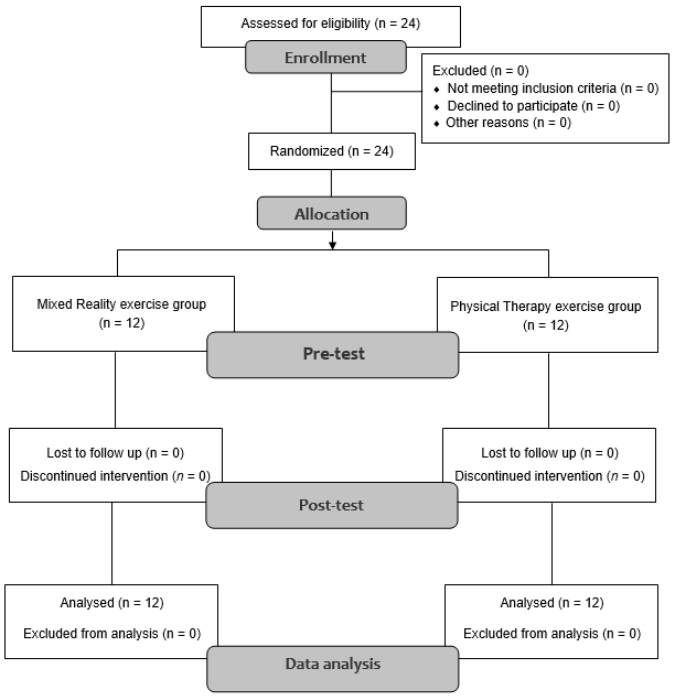


Figure 2. Study flow diagram

tance value recorded as the final measurement.

In this study, the Timed Up and Go (TUG) test was used to assess the subjects' balance.[19] The subject sits in a chair and receives a start signal as instructed by the researcher. At the start signal, the subject gets up from the chair, walks a distance of 3 meters, turns around at a marked point, and sits back down in the chair. The total time taken was measured and recorded by a timer. The test was repeated twice, and the time for each test was recorded and the average value was used as the final measure.

The 2-minute step test assesses cardiorespiratory endurance and requires subjects to stand on a flat surface and alternately raise their feet high.[20] Once the feet were raised to knee height, the researcher started the timer and the subject repeated the steps as many times as possible for two minutes. The total number of steps performed by the subject was recorded, and the subject's feet were kept at a constant height for accurate measurement. The test was performed only once, and the total number of steps was recorded and used as the final measurement.

All data analysis in this study was performed using IBM SPSS ver.26. Independent t-test was used to analyze the effect between MR-based exercise devices and traditional physical therapy methods, and paired sample t-test was used for before-and-after comparisons within groups. The significance level of statistics was set at $p < 0.05$.

III. Results

The pre-measurements of this study showed no significant differences between the two groups on any of the variables ($p > 0.05$)(Table 2). In the within-group comparison, both groups showed significant differences in strength ($p < 0.001$), muscular endurance ($p < 0.05$), and cardiorespiratory endurance ($p < 0.001$), but not in flexibility and balance ($p > 0.05$)(Table 2)(Figure 3). Post hoc measurements showed that the two groups did not differ significantly ($p > 0.05$) on any variable (Table 2).

Table 2. Comparison between groups after intervention. (N = 24)

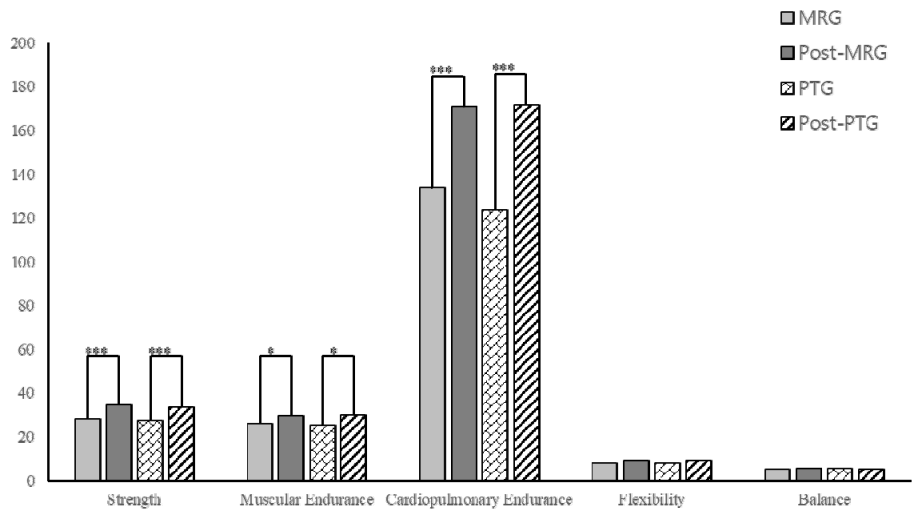
	Pre-test			Post-test		
	MRG (n = 12)	PTG (n = 12)	t	MRG (n = 12)	PTG (n =12)	t
Strength	28.01±8.07	27.49±7.87	1.707	34.38±6.80	33.40±6.86	0.561
Muscular Endurance	25.97±6.20	25.24±7.43	0.432	29.45±5.30	29.82±7.33	0.818
Cardiopulmonary Endurance	133.76±31.59	123.52±31.72	1.314	171.09±51.91	171.67±51.73	0.964
Flexibility	8.10±10.12	8.11±11.65	-0.005	9.02±11.07	9.11±10.40	0.973
Balance	5.34±0.92	5.56±1.05	-0.916	5.42±0.88	5.23±0.59	0.382

Note. mean ± standard deviation, MRG: mixed-reality exercise group, PTG: physical therapy exercise group.

Table 3. Comparison within a group after intervention. (N = 24)

	MRG (n =12)			PTG (n = 12)		
	Pre-test	Post-test	t	Pre-test	Post-test	T
Strength	28.01±8.07	34.38±6.80	-3.897***	27.49±7.87	33.40±6.86	-3.801***
Muscular Endurance	25.97±6.20	29.45±5.30	-2.434*	25.24±7.43	29.82±7.33	-2.632*
Cardiopulmonary Endurance	133.76±31.59	171.09±51.91	-4.960***	123.52±31.72	171.67±51.73	-6.004***
Flexibility	8.10±10.12	9.02±11.07	-0.408	8.11±11.65	9.11±10.40	-0.407
Balance	5.34±0.92	5.42±0.88	-0.380	5.56±1.05	5.23±0.59	1.574

Note. *p<.05, **p<.01, ***p<.001, mean ± standard deviation, MRG: mixed-reality exercise group, PTG: physical therapy exercise group.



Note. *p<.05, **p<.01, ***p<.001, MRG: mixed-reality exercise group, PTG: physical therapy exercise group.

Figure 3. Comparison between group and within a group after intervention.

Ⅳ. Discussion

The results of this study showed that the two groups did not differ significantly from pre to post ($p > 0.05$), and in the within-group comparison, both groups showed significant differences in muscle strength ($p < 0.001$), muscular endurance ($p < 0.05$), and cardiorespiratory endurance ($p < 0.001$). However, there was no significant difference in balance and flexibility ($p > 0.05$).

The stationary cycle (SC) exercise used in this study is commonly used as an alternative to walking

or running for people with lower extremity injuries or to reduce loading rates on the hip and knee joints[21] and is an effective exercise for lower extremity strength, power, and postural control by improving reciprocal muscle activity to facilitate lower extremity coordination.[22] In particular, it has been shown to result in higher quadriceps and hamstring loading and lower vertical reaction force compared to walking, making it an effective exercise for strength training.[23] Stepper exercises are also effective in improving knee and hip extensor strength.[24] For standing, the hamstrings, quadriceps, gastrocnemius, and tibialis anterior are particularly important, and strengthening these muscles is crucial for supporting more weight.[23] These muscles are all activated during bicycle and stepper exercises, which require reciprocal flexion and extension of the hip, knee, and ankle joints, and the study found significant differences in lower extremity strength between the two groups. A meta-analysis based on 22 previous studies found that virtual reality-based strengthening exercises had a medium-sized effect, which is consistent with the results of this study.[25]

However, unlike previous studies that have shown positive effects on TUG (dynamic balance), which is closely related to increased lower limb strength and improved control in standing, this study did not find significant differences in balance in either group. This may be due to the fact that the TUG was originally used to assess frail elderly people's balance, gait speed, and ability to perform activities of daily living tasks necessary for autonomy, which may not have been appropriate for the population of this study, and unlike previous studies in stroke, this study was conducted in healthy adults.[26,27] In addition, above a certain level, such as in healthy adults, explosive force rather than mere lower extremity strength affects gait speed, which may not have affected TUG because the present exercise maintained an elliptical motion with constant speed.[28] In addition, a previous meta-analysis showed that VR-based exercises had very small effect sizes on balance, and gait was not dependent on VR-based training.[25] In contrast, elliptical exercise set at a constant speed and progressive exercise program showed significant differences in muscular endurance and cardiorespiratory endurance in both groups. The 2 mins step test (2MST) is an aerobic exercise capacity test often used to assess cardiopulmonary function, like the 6 mins walk test (6MWT), which is suitable for measuring cardiopulmonary capacity in a shorter time and can cause more cardiopulmonary stress. In addition, the number of steps in the 2MST is positively correlated with the distance in the 6MWT and leg strength.[29] In this study, both groups strengthened their lower extremity strength through SC and stepper exercises, which may have had an effect on their cardiorespiratory endurance. Furthermore, we can confirm that the SC and stepper exercises had an effect on the muscular endurance in this study because according to The American College of Sports Medicine (ACSM) guidelines, only exercise sessions lasting longer than 10 minutes can accumulate as exercise duration, which can improve muscular endurance and cardiorespiratory endurance.[30]

The sit and reach test is an assessment to estimate the extensibility of the hamstrings and lumbar and can be a useful field test alternative when tests such as the straight leg raise or knee extension tests are not available. However, this test has a moderate level of validity for assessing the hamstring, but a low mean validity for the lumbar, making it less suitable[31]. This is likely due to the fact that the twist machine used in this study rotates the waist from side to side in the transverse plane, which has little effect on the elongation of the hamstring and calf muscles, which have the most influence on the assessment results.

The aim of this study was to analyze the effectiveness of MR-based exercise devices versus traditional physical therapy methods. In conclusion, this study found similar effects between MR-based exercise devices and traditional physical therapy methods and demonstrated that both approaches are effective in improving strength and endurance. There were limited effects on improving balance and flexibility, but this may be a result of the short study duration and limitations in subject characteristics. Future studies should include a wider range of subjects, assess long-term effects, and use different exercise methods and assess-

ment tools to generate more comprehensive results. These studies suggest that MR-based exercise devices may contribute to the development of personalized exercise therapy.

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