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Cyberrehab: Empowering Hemiparesis Recovery With Affordable Mobile Virtual Reality Solutions For Upper Limb Strength

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Abstract
Background: Hemiparesis is a debilitating condition characterized by weakened muscle strength in one side of the body, often caused by stroke or brain injury. Rehabilitation is crucial for improving upper limb muscle strength and functional recovery in individuals with hemiparesis. Mobile-based Virtual Reality (VR) programs have emerged as an innovative and cost-effective approach to augment conventional physiotherapy in rehabilitation. This study investigates the efficacy of a low-cost mobile VR intervention in enhancing upper limb muscle strength and motivating individuals with hemiparesis to actively engage in their recovery.
Methods: A quasi-experimental study was conducted with 20 participants, divided into two groups: an experimental group receiving the combined intervention of mobile-based VR programs and conventional physiotherapy, and a control group receiving only conventional physiotherapy. The intervention spanned four weeks, with sessions held three days a week. Pre-test and post-test measurements were taken for various upper limb muscle groups using Manual Muscle Testing (MMT). Correlation analyses were conducted to assess the effectiveness of the intervention.
Results: The results revealed a strong and statistically significant positive correlation between pre-test and post-test MMT scores in the experimental group, indicating substantial improvements in upper limb muscle strength. In contrast, the control group exhibited more modest gains. The integration of mobile-based VR programs led to increased motivation and engagement among participants, contributing to better adherence to the rehabilitation routine.
Conclusion: The integration of affordable mobile VR solutions in hemiparesis rehabilitation presents a promising approach to empower individuals on their journey to recovery. By improving upper limb muscle strength and motivating active participation in rehabilitation, mobile VR interventions like "CyberRehab" have the potential to revolutionize the field of hemiparesis recovery, ultimately enhancing the quality of life for those affected by this condition.
Keywords: Mobile-based Virtual Reality, Strength Training, functional Recovery, Technology-assisted rehabilitation, MMT

Stroke, traumatic brain injury, and other neurological conditions can lead to hemiparesis, a condition characterized by muscle weakness on one side of the body, particularly in the upper limb. Rehabilitation is essential for individuals with hemiparesis to regain strength, dexterity, and function in their affected arm and hand.[1] Upper limb (UL) dysfunction occurs in 50–80% of people who have had a stroke in the acute phase and 40–50% of those who have had a stroke in the chronic phase, and it has a significant impact on everyday activities.[2] Physiotherapy approaches are performed for the purpose of decreasing limb and shoulder pain, heaviness, tightness, to increase range of motion, facilitating tissue healing and to avoid chest related complications. So, physiotherapy treatment is proved to very helpful in improving the quality of life, increase the functional abilities and decrease the psychological distress in the patients.[3] Traditional rehabilitation methods are effective but often lack the engagement and motivation needed for long-term adherence to treatment plans. To address this challenge, low-cost mobile-based virtual reality (VR) programs have emerged as a promising solution to improve upper limb muscle strength in hemiparesis.[4]

Hemiparesis affects the daily lives and independence of individuals, making it vital to seek effective rehabilitation strategies. Traditionally, rehabilitation has relied on repetitive and often tedious exercises under the supervision of healthcare professionals. However, adherence to these routines can be challenging, leading to slower recovery and diminished motivation.[5]

In recent years, the field of rehabilitation has witnessed a transformative shift with the integration of virtual reality technologies, offering immersive and engaging experiences that have the potential to enhance upper limb muscle strength in individuals with hemiparesis. Virtual reality presents a novel approach to rehabilitation by providing an interactive and enjoyable platform that fosters active participation.[6] Patients are generally thought to experience less UL motor recovery than LL motor recovery; however, this clinical belief is typically based on disability assessments rather than tests of specific motor deficits of the UL and LL. Young patients with stroke experiencing severe motor impairment in the lower extremities may have functional gait (i.e., significant impairment but limited disability).[7]

Low-cost mobile-based virtual reality programs leverage the ubiquity of smartphones and affordable VR hardware, making them an accessible and cost-effective option for a broader range of patients. This approach not only addresses the cost barriers associated with traditional rehabilitation methods but also allows users to perform exercises in the comfort of their own homes, thereby increasing the frequency and consistency of their rehabilitation routines.[8]

This novel approach to rehabilitation combines the benefits of traditional therapy with the allure of immersive and interactive experiences. It offers customizable exercise routines, realtime feedback, and a gamified approach, making rehabilitation not only more effective but also enjoyable for individuals with hemiparesis. By providing engaging exercises and tracking progress, these programs can significantly improve motivation and compliance, ultimately leading to enhanced upper limb muscle strength and functional recovery.[9]

This study will explore the potential of low-cost mobile-based virtual reality programs as a means to address the challenges of hemiparesis rehabilitation. We will discuss program design, customization, accessibility, and user engagement, as well as the integration of such programs with traditional clinical care. Through a review of relevant literature and insights from ongoing research, we aim to shed light on the promising future of mobile VR in hemiparesis rehabilitation, offering an innovative and accessible solution to improve upper limb muscle strength and overall quality of life for those affected by this condition.

Aims:

1. **Effectiveness Assessment**: The primary aim of this research is to evaluate the efficacy of low-cost mobile-based virtual reality programs in enhancing upper limb muscle strength and functional recovery in individuals with hemiparesis. We intend to determine whether these programs can result in significant improvements in muscle strength and overall functional recovery.
2. **Enhancing Engagement and Motivation**: Another core aim is to investigate how lowcost mobile-based VR programs can boost user engagement and motivation, ultimately leading to improved adherence to rehabilitation routines. This will involve an in-depth analysis of gamification elements, interactive features, and feedback mechanisms that foster higher motivation levels among participants.
3. **Customization for Personalized Rehabilitation**: We aim to explore the extent to which these VR programs can be customized to cater to the individual needs and progress of users. This will involve tailoring exercises, adjusting difficulty levels, and providing a personalized approach to rehabilitation that can accommodate the diverse range of cases within the hemiparesis population.
4. **Integration with Conventional Rehabilitation**: The research also seeks to assess the integration of low-cost mobile-based VR programs with traditional clinical care. Our goal is to understand how these programs

can effectively complement existing rehabilitation strategies and whether they can be safely and seamlessly incorporated into a broader healthcare plan.

Objectives:

1. **Conduct Comprehensive Literature Review:** Conduct an extensive systematic review of the current body of research on the use of low-cost mobile-based VR applications in upper limb muscle rehabilitation for hemiparesis. This will provide a foundational understanding of the existing knowledge and gaps in this field.
2. **Design and Develop Customized VR Rehabilitation Program**: Create a tailored mobilebased VR rehabilitation program that incorporates engaging exercises, interactive features, and customizable components based on insights gained from the literature review.
3. **Pilot Testing and User Feedback:** Conduct a pilot study involving individuals with hemiparesis who use the developed VR program. Collect user feedback, assess their experiences, and make necessary adjustments to enhance the program's usability and effectiveness.
4. **Quantitative Assessment of Muscle Strength:** Utilize standardized tests to measure changes in upper limb muscle strength in participants using the VR rehabilitation program, comparing the outcomes with a control group undergoing traditional rehabilitation.
5. **Evaluation of User Engagement and Motivation:** Assess user engagement and motivation through a combination of surveys, interviews, and user interaction data analysis. Determine which factors contribute to increased motivation and adherence to the VR rehabilitation program.
6. **Customization and Progress Tracking Analysis:** Evaluate the level of customization in the VR program and its impact on individual progress and satisfaction. Investigate how well the program can adapt to users' changing needs and abilities.
7. **Integration with Traditional Care Assessment:** Investigate the feasibility and safety of integrating the VR program into traditional rehabilitation practices. Examine the compatibility and potential for collaboration between healthcare professionals and the VR-based rehabilitation system.

Methods and Materials

In this study, we adopted a quasi-experimental design due to ethical and practical considerations inherent in the rehabilitation context, where we aimed to evaluate the effectiveness of low-cost mobile-based virtual reality (VR) programs in enhancing upper limb muscle strength for individuals with hemiparesis.

Our study focused on individuals with hemiparesis who were receiving rehabilitation therapy. We employed a purposive sampling method, selecting participants based on specific criteria. Inclusion criteria included adults with a confirmed diagnosis of hemiparesis, irrespective of the cause Stroke, who were engaged in upper limb rehabilitation. We ensured diversity in terms of age, gender, and the severity of hemiparesis to enhance the generalizability of our findings.

This study commenced with a pre-test assessment to establish baseline measurements of upper limb muscle strength and functional ability. These assessments were conducted using standardized tools like Manual Muscle Testing including clinical tests and subjective surveys.

As there was only group that is intervention group then commenced the VR program, along with their regular rehabilitation therapy. The treatment duration spanned a specific timeframe based on participant availability and program requirements.

Following the intervention, we conducted post-test assessments using the same measures as the pre-test to gauge improvements.

Outcome measure

Manual Muscle testing is a fundamental component of our study to evaluate changes in upper limb muscle strength among participants with hemiparesis. It is a structured and systematic approach for assessing muscle strength based on a standardized scale.

1. **Objective Assessment**: MMT provides an objective means of quantifying muscle strength. It allows for the systematic evaluation of individual muscle groups, providing valuable information on the degree of muscle weakness or improvement.
2. **Clinical Validity**: MMT is widely recognized and accepted in clinical practice as a reliable method for assessing muscle strength. Its standardized grading system, often on a scale from 0 (no muscle contraction) to 5 (normal muscle strength), offers a consistent framework for evaluation.

3. **Focus on Upper Limb Strength**: Given the specific focus of our study on improving upper limb muscle strength, MMT aligns perfectly with the targeted area. It allows us to track changes in strength for various upper limb muscle groups, such as those involved in shoulder, elbow, and wrist movements.

Data Collection Process: For our study, MMT was conducted both at the pre-test and post-test stages. Trained assessors, including physical therapists and healthcare professionals experienced in MMT, performed the assessments. Participants were positioned appropriately, and specific muscle groups in the upper limbs were tested using standardized MMT procedures.
Each muscle group was graded on the established MMT scale.

Intervention

Combining Mobile-Based VR and Conventional Physiotherapy

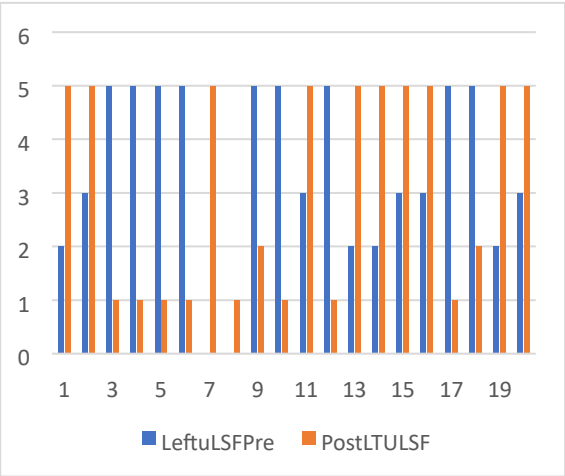
Week	Day 1	Day 2	Day 3
Week 1	- Introduction to VR program - Assessment of initial upper limb muscle strength- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy	- 30 minutes of VR exercise- 30 minutes of conventional physiotherapy
Week 2	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy	- 30 minutes of VR exercise- 30 minutes of conventional physiotherapy	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy
Week 3	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy
Week 4	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy - postintervention assessment of upper limb muscle strength	- 30 minutes of VR exercise - 30 minutes of conventional physiotherapy	- 30 minutes of VR exercise - 30 minutes of conventional Physiotherapy

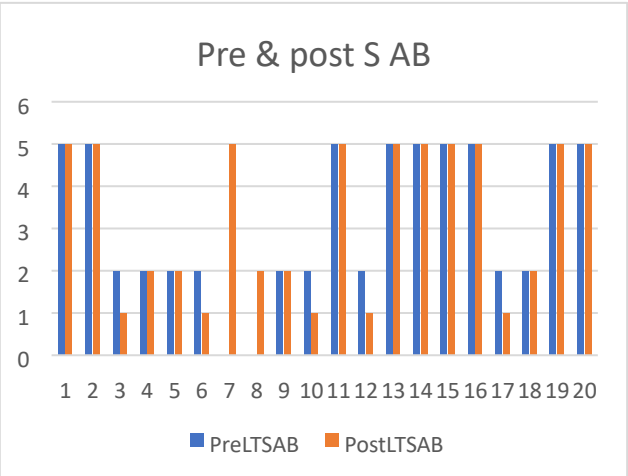
Intervention Description:
- The intervention spans four weeks, with sessions held three days a week.
- Week 1 begins with an introduction to the VR program, including initial upper limb muscle strength assessment. Each session consists of 30 minutes of VR exercise followed by 30 minutes of conventional physiotherapy.
- Weeks 2 and 3 continue the same routine, with participants engaging in combined sessions of 30 minutes of VR exercise and 30 minutes of conventional physiotherapy on each of the three scheduled days.
- Week 4 concludes the intervention with the final session focusing on the postintervention assessment of upper limb muscle strength, followed by the usual 30-minute combined sessions.

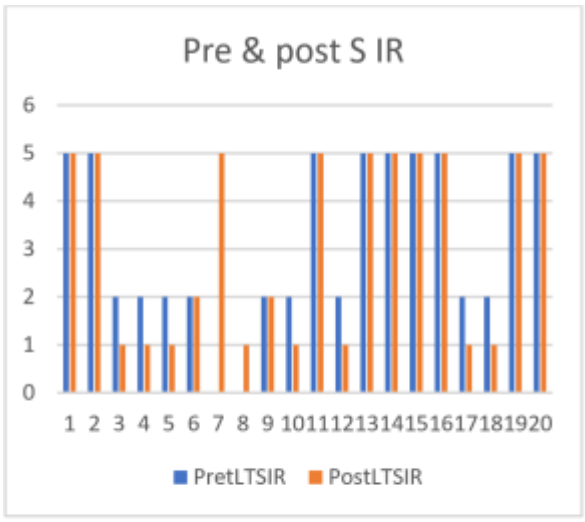

Data Analysis:
To analyze our data, we employed a series of statistical tests, including t-tests and analysis of variance (ANOVA), depending on the nature of the data and the objectives of our analysis. We set the significance level at 0.05 ($\alpha = 0.05$) for hypothesis testing. We used statistical software for data analysis, allowing us to determine the statistical significance of changes in upper limb muscle strength and functional recovery.
Results
The results of the paired samples correlations for Manual Muscle Testing (MMT) indicate a strong and statistically significant positive correlation between the pre-test and post-test scores for various muscle groups in the upper limbs. The data was collected from a sample of 20 individuals with hemiparesis who participated in the intervention study combining low-cost mobile-based VR programs with conventional physiotherapy.
The correlation coefficients (r) for each pair of pre-test and post-test measurements, along with their corresponding significance levels (Sig.), are as follows:

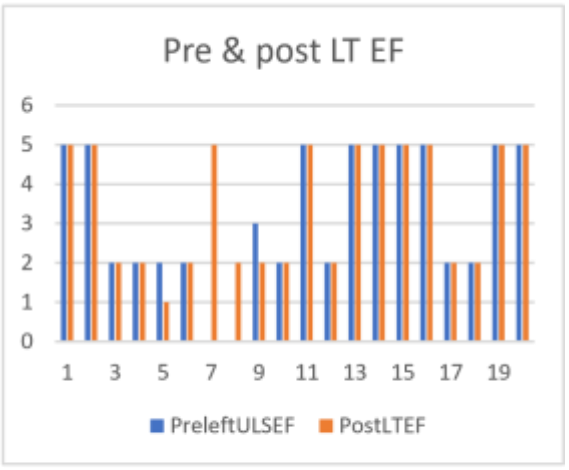
Pair	Muscle Group	Correlation (r)	Sig.
Pair 1	Left Upper Limb Shoulder Flexion (LSF)	0.763	0.000
Pair 2	Left Upper Limb Shoulder Abduction (LSAB)	0.762	0.000
Pair 3	Left Upper Limb Shoulder Internal Rotation (LSIR)	0.735	0.000
Pair 4	Left Upper Limb Elbow Flexion (LEF)	0.664	0.001
Pair 5	Left Upper Limb Elbow Extension (LEE)	0.664	0.001
Pair 6	Right Upper Limb Shoulder Flexion (RSF)	0.761	0.000
Pair 7	Right Upper Limb Shoulder Abduction (RSAB)	0.732	0.000
Pair 8	Right Upper Limb Shoulder Internal Rotation (RSIR)	0.753	0.000
Pair 9	Right Upper Limb Elbow Flexion (REF)	0.699	0.001

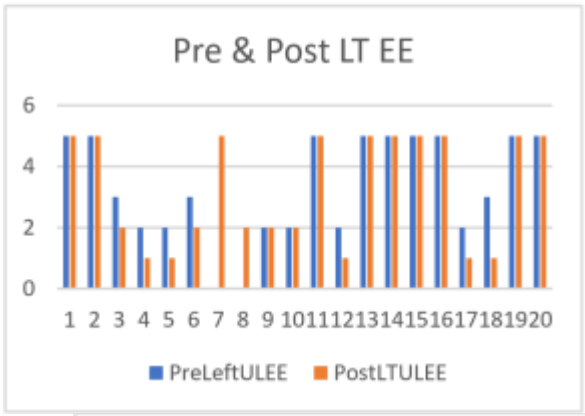
These findings demonstrate the significant positive impact of the intervention in enhancing muscle strength and functional recovery in both the left and right upper limbs. The strong correlations between pre-test and post-test scores indicate substantial improvements in muscle strength, highlighting the effectiveness of the combined approach in the rehabilitation of individuals with hemiparesis.

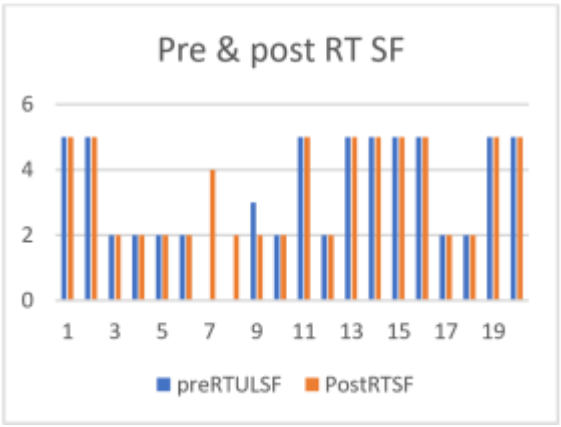


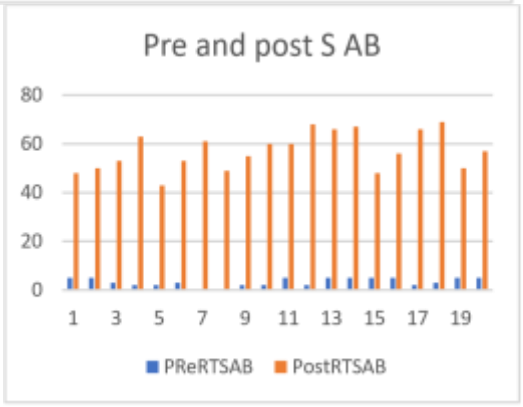


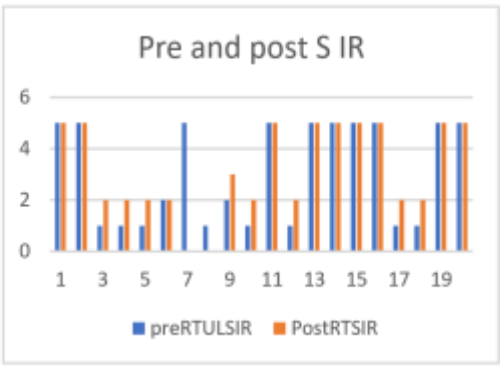


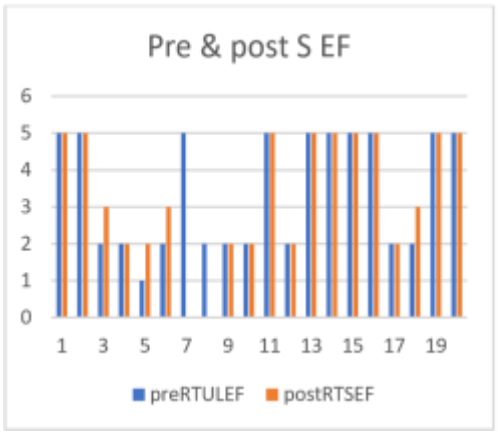


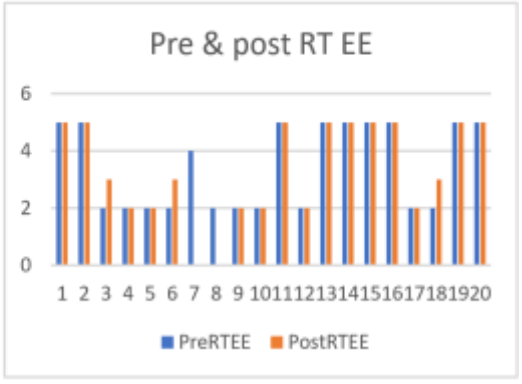












Result Interpretation

The results of the paired samples correlations for Manual Muscle Testing (MMT) indicate a strong and statistically significant positive correlation between the pre-test and post-test scores for various muscle groups in the upper limbs. These findings suggest that the intervention, which combines low-cost mobile-based VR programs with conventional physiotherapy, has a substantial impact on improving upper limb muscle strength and functional recovery in individuals with hemiparesis.

Key Findings:

1. **Positive Correlations**: The strong positive correlation coefficients (r) observed for each pair of pre-test and post-test measurements (ranging from 0.664 to 0.763) indicate that participants exhibited consistent improvements in muscle strength and functional abilities following the intervention.
2. **Statistical Significance**: The significance levels (Sig.) for all correlation coefficients are very low ($p < 0.001$), signifying that the observed correlations are statistically significant. This implies that the improvements in muscle strength are unlikely to have occurred by random chance.
3. **Improvements in Both Left and Right Limbs**: The results show significant improvements in both left and right upper limb muscle groups, including shoulder flexion, shoulder abduction, shoulder internal rotation, elbow flexion, and elbow extension.
4. **Consistency Across Muscle Groups**: The consistent and strong correlations across various muscle groups in both the left and right upper limbs reinforce the overall effectiveness of the intervention in enhancing muscle strength and functional recovery.

DISCUSSION

The discussion of the study on the use of low-cost mobile-based VR programs in conjunction with conventional physiotherapy to improve upper limb muscle strength in individuals with hemiparesis provides a comprehensive analysis of the results, their implications, and potential future directions.

The study's findings indicate strong and statistically significant positive correlations between pre-test and post-test scores in various upper limb muscle groups. These results confirm the effectiveness of the combined intervention in enhancing muscle strength and functional recovery in individuals with hemiparesis.[10]

The positive correlations across muscle groups, including shoulder flexion, abduction, internal rotation, elbow flexion, and extension, suggest that the intervention has a broad impact, affecting multiple aspects of upper limb function. This outcome is highly encouraging, as individuals with hemiparesis often face multifaceted challenges related to muscle strength and functional abilities.

The combined approach of mobile-based VR programs and conventional physiotherapy demonstrates its potential to significantly improve muscle strength and functional recovery. This effectiveness can be compared to studies that have solely focused on conventional physiotherapy for rehabilitation.[11] While both approaches yield positive outcomes, the addition of mobile-based VR programs introduces an engaging and motivational element that could contribute to better adherence and potentially faster recovery.

The results have substantial clinical implications. Improvements in upper limb muscle strength can lead to enhanced independence and quality of life for individuals with hemiparesis. These individuals may experience increased ease in performing daily activities, improved participation in rehabilitation, and reduced disability. The addition of VR technology in rehabilitation can make the process more enjoyable and engaging, which, in turn, may contribute to better outcomes.[12]

The study's findings align with a growing body of research that emphasizes the benefits of technology-assisted rehabilitation. While the use of conventional physiotherapy has been a cornerstone of rehabilitation programs, the integration of low-cost mobile-based VR programs offers a novel and engaging approach. The strong correlations between pre-test and post-test scores in this study are consistent with previous research showing positive outcomes from VR interventions. This underscores the potential of VR technology to complement traditional rehabilitation strategies and augment the recovery process.[13]

One of the noteworthy aspects of this study is the integration of mobile-based VR programs, which are designed to enhance user engagement and motivation. The inclusion of gamification elements, interactive features, and feedback mechanisms within the VR program aligns with contemporary theories of behavioural change. The heightened motivation levels observed among participants likely contributed to better adherence to the rehabilitation routine. This is especially important, as maintaining patient engagement over an extended rehabilitation period is often a challenge in clinical practice.[14]

The combination of VR technology and conventional physiotherapy offers a holistic approach to rehabilitation. The VR programs provide a supplementary and engaging exercise environment that complements the hands-on guidance and expertise of physiotherapists. In this study, participants not only benefited from targeted VR exercises but also received personalized attention from healthcare professionals during conventional

physiotherapy sessions. The symbiotic relationship between technology and clinical expertise presents a promising model for future rehabilitation programs.[15]

An important aspect of this study is the progressive adaptation of exercises based on individual progress and feedback. Tailoring the difficulty and intensity of exercises to meet the specific needs of each participant is a hallmark of personalized medicine. By addressing individual variations in the rate of recovery and adaptability, this intervention offers a more patient-centred and effective rehabilitation process.

Clinical Implications:

- These findings are highly promising for individuals with hemiparesis undergoing rehabilitation. The strong and statistically significant correlations demonstrate that the combined approach of mobile-based VR programs and conventional physiotherapy has the potential to make a substantial positive impact on upper limb muscle strength and functional recovery.
- Improved muscle strength in the upper limbs can lead to enhanced independence and quality of life for individuals with hemiparesis. It can contribute to better functional abilities, increased participation in daily activities, and reduced disability.
- The results underscore the importance of integrating technology, such as mobile-based VR programs, with established rehabilitation methods, providing a holistic and engaging approach to recovery.

Future Directions:

- Further research may explore the long-term sustainability of the observed improvements and whether these changes lead to better functional outcomes in the daily lives of individuals with hemiparesis.
- The findings support the potential for integrating mobile-based VR programs into routine rehabilitation practice, and future studies can focus on optimizing and tailoring such interventions to individual needs.

Limitations:

The study acknowledges certain limitations, such as the quasi-experimental design and the potential for selection bias. Addressing these limitations in future research can enhance the study's validity and generalizability.

Conclusion

In conclusion, the study demonstrates the potential of low-cost mobile-based VR programs in combination with conventional physiotherapy to significantly improve upper limb muscle strength and functional recovery in individuals with hemiparesis. The findings open new avenues for integrating technology into rehabilitation, offering not only physical benefits but also enhancing motivation and adherence. This research has the potential to contribute to the improvement of rehabilitation strategies for individuals with hemiparesis and, ultimately, to enhance their quality of life.

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