Article

Not peer-reviewed version

Psychometric and Physiological Assessment of the Effects of Virtual Reality in Cardiovascular Rehabilitation: A Randomized Controlled Trial

Roberto De Giorgi , Rossana Cuscito , Alessandra Piccionetti , Federico Gentili , Silvia Casolani , Cristiano Rubeca , Claudia Salera , Marco Iosa * , Daniela De Bartolo , Simone Barbato , Gaetano Tieri

Posted Date: 30 June 2025

doi: 10.20944/preprints202506.2518.v1

Keywords: virtual environment; digital rehabilitation; heart; cardiology; gamification

Article

Psychometric and Physiological Assessment of the Effects of Virtual Reality in Cardiovascular Rehabilitation: A Randomized Controlled trial

Roberto De Giorgi [1], Rossana Cuscito [1], Alessandra Piccionetti [1], Federico Gentili [1], Silvia Casolani [1], Cristiano Rubeca [1], Claudia Salera [2], Marco Iosa [2,3], Daniela De Bartolo [4], Simone Barbato [5] and Gaetano Tieri [2,6]

[1] Casa di Cura Nomentana Hospital, Fonte Nuova, Rome, Italy
[2] IRCCS Santa Lucia Foundation, Rome, Italy
[3] Department of Psychology, University Sapienza of Rome, Italy
[4] Department of Social and Developmental Psychology, University Sapienza of Rome, Rome, Italy
[5] Idego Psicologia Digitale, srl, Rome, Italy
[6] Virtual Reality Lab, Department of Law and Digital Society, Unitelma Sapienza University, Rome, Italy
* Correspondence: marco.iosa@uniroma1.it

Abstract: Background: Virtual reality (VR) is a promising tool for cardiac rehabilitation, but conflicting results have been reported in the literature. **Methods**: A Randomized Controlled Trial was conducted on 60 subjects undergoing a cardiac rehabilitation program. The experimental group replaced 20 daily minutes of the therapy with virtual car driving simulation sessions. Both groups received the same amount of therapy time. Hospital Anxiety and Depression Scale (HADS), the Short Form 12 questionnaire for quality of life, and other clinical scales were administered to assess the efficacy of integrating VR into the rehabilitative intervention. **Results**: HADS-score ($p<0.001$) and quality of life ($p<0.02$) significantly improved only in the VR group, whereas other parameters such as pain, perceived exertion and oxygen saturation improved in both groups. **Conclusions**: VR resulted effective in improving patients' conditions, likely due to its high level of engagement. When assessing the effects of a VR system, it is important to consider the specific software with the exergame and the tasks administered: in this study, we selected a car driving simulation, which yielded positive effects.

Keywords: virtual environment; digital rehabilitation; heart; cardiology; gamification

1. Introduction

Virtual reality (VR) is a high-end user-computer interface involving real-time stimulation and interaction of an embedded subject through visual and auditory sensorial channels, based on a synthetic environment in which the subject feels to be present [1]. Over the past few decades, virtual reality (VR) has been extensively used in psychological and neuroscientific research, as well as clinical applications [2], yielding promising results for diverse clinical conditions [3,4]. Furthermore, VR has also been employed in the cardiovascular field across various settings, including cardiac rehabilitation, interventional cardiology, and cardiac surgery, to assess both physiological and psychological outcomes [5,6]. A recent meta-analysis conducted on almost one thousand patients showed that VR-based cardiac rehabilitation significantly reduced symptoms such as anxiety and depression in patients with cardiovascular diseases compared to standard rehabilitation; however, the effects on cardiorespiratory functions were not significantly different between the two approaches [6]. Another meta-analysis confirmed that VR may reduce negative emotions in cardiac rehabilitation, and also added that VR can be effective in improving patients' exercise capacity [7].

VR does not seem to be less effective than conventional cardiac rehabilitation when tested in a longitudinal randomized controlled trial [8].

However, the advantages of using VR could be related to the fact that it is a customizable intervention that may enhance the rehabilitation experience by providing cognitive, emotional, and physical benefits to patients, improving their motivation and engagement, reducing anxiety, but at the same time may provide discomfort [9]. The evidence of this assumption has already been demonstrated for neurological therapy [10,11], but not yet for cardiac rehabilitation.

In general, the effect of VR in cardiac rehabilitation seems more related to mental health improvements, and hence to psychological aspects, despite its superiority not being proven on other factors such as adherence, satisfaction, and quality of life [12].

The aim of this study was to test the efficacy of integrating the use of a VR system based on driving simulation in cardiac rehabilitation through a randomized controlled trial. Cardiovascular disease has been linked to decreases in driving performance, and rehabilitation may also aim at the recovery of driving ability [13]. The use of driving simulators has already been tested in neurological [14] and orthopedic [15] patients. We tested this approach in a virtual reality system for cardiac patients. The objective was not only to facilitate the recovery of driving ability, but also to improve psychological and physiological outcomes of cardiac rehabilitation.

2. Materials and Methods

2.1. Study design and Participants

The study is a randomized controlled trial (RCT) conducted at an Italian clinic that provides intensive inpatient cardiac rehabilitation. Patients were enrolled according to the following inclusion/exclusion criteria and randomized into two possible groups.

The inclusion criteria were: diagnosis of cardiovascular disease and need for intensive inpatient cardiac rehabilitation after cardiac surgery, age over 18 years, absence of comorbidities, ability to understand and follow instructions provided by physiotherapists. The exclusion criteria were: presence of cognitive impairments (Mini Mental State Evaluation score < 24), presence of altered consciousness, psychotic symptoms, bipolar disorder, or other severe psychiatric conditions, conditions contraindicating physical training (e.g., bone fractures), conditions contraindicating the use of VR (e.g., blindness or deafness), refusal to participate in any phase of the research project, or failure to provide informed consent.

2.2. Rehabilitative inteventions

The control group (CG) of this study performed a conventional cardiac rehabilitation protocol that consisted of 1.5-hour group calisthenics sessions with a 10-minute break, held six times per week. This was accompanied by aerobic reconditioning exercises on a stationary bike or treadmill, depending on medical prescription and the patient's health status.

Patients were randomly allocated to the experimental virtual reality group (VRG) and underwent the standard cardiac rehabilitation program, but some sessions were substituted by the virtual reality rehabilitation protocol. The VR intervention consisted of a simulated driving experience delivered over nine sessions, three times per week, each lasting 20 minutes, over a three-week period. Participants observed the virtual scenario through Meta Quest 2 head-mounted display (HMD), offering an approximate 90-100° field of view (FOV) and a resolution of 3840 x 1920 pixels per eye. The virtual reality (VR) therapy employed a full immersion approach, delivering intense multisensory visual-auditory stimulation. Patients were exposed to diverse driving scenarios, specifically: urban streets (featuring intersections, traffic lights, and pedestrians to simulate complex urban environments), ring roads (designed for practicing smooth and confident high-speed driving in dense traffic), and tunnels (sections aimed at gradually desensitizing users to claustrophobic responses during driving). The virtual environment was designed by combining 3D objects and 360° VR videos using Unity 60000.0.33f1 game software environment (https://unity.com/). The 3D

 doi:10.20944/preprints202506.2518.v1

environment consisted of a realistic 3D model of a car's interior, simulating the driver's perspective (1:1 scale). The virtual cockpit incorporated an interactive steering wheel, controlled by participants from their perspective using Meta Controllers. This interaction, however, did not alter the vehicle's movement path. To optimize immersion, the Meta Controllers were rendered as hands, integrated with a 3D avatar model. Real-time arm movements of the avatar were achieved using inverse kinematics (IK), precisely mirroring the participants' physical actions. The 3D cabin was fully enveloped by 360° VR video showcasing the driving scenarios detailed previously. The VR 360° videos were taken with a GoPro Max® 360° camera (GoPro Inc., San Mateo, CA, USA), with a spherical resolution of 5376 × 2688 at 30 fps and 3D spatial audio with an external Zoom H1 microphone. The spherical 360° videos were processed with Adobe Premier Pro® 2021 (Version 15) (Adobe, San Jose, CA, USA). The various scenarios the patient encountered corresponded to a progressively increasing level of difficulty as the rehabiltative sessions proceeded. Examples of challenging elements included narrow roads, urban traffic, tunnel driving, and high-speed roads. Each session lasted approximately 20 minutes, which was the time required to complete the driving route. However, the session might end earlier if the patient was unable to continue.

2.3. Assessment

All patients were assessed at baseline after enrollment (Pre) and again three weeks later at the end of the rehabilitation protocol (Post).

The outcome measures assessed not only functional status, endurance capacity, and mental state, but also quality of life and patient engagement in daily activities. In particular, we measured: Hospital Anxiety and Depression Scale (HADS): A 14-item scale used to assess anxiety (7 items) and depression (7 items) levels related to illness [16,17]; Quality of life (SF-12): A 12-item health survey generating physical and mental health summary scores [18]; Pain Visual Analogue Scale (VAS): A psychometric scale for pain intensity ranging from 0 (no pain) to 10 (worst possible pain) [19]; Borg Scale: A self-assessment tool for perceived exertion, ranging from 0 ("no exertion") to 10 ("maximum exertion") [20]; Upper limb Range of Motion (ROM): Assessment of changes in upper limb range of motion: shoulder flexion/extension, elbow flexion/extension; Manual Muscle Test (MMT): Evaluation of upper limb strength (MMT score from 0 to 5 for shoulder abduction, elbow flexion, and grip strength; total score ranges from 0 = no strength to 15 = normal strength) [21,22].

Additionally, during each session, the following clinical parameters were monitored and recorded: heart rate (HR), arterial oxygen saturation (SpO_2), and the maximum and minimum blood pressure (BP max, min).

2.4. Statistical Analysis

Data are reported in terms of mean ± standard deviation for clarity, but given the ordinal scales used, non-parametric tests were used within subjects (Wilcoxon test) and between subjects (Mann-Whitney u-test). Sample size was computed on the basis of previous data related to the use of VR in cardiac rehabilitation [23], setting an alpha level at 5%, power of the test (1-beta) at 80% and with an effect size of 0.9, obtaining a minimum number of participants of 58. The alpha level of statistical significance for all the analyses was set at 0.05.

3. Results

Sixty patients were enrolled in this study. Their mean age was 70±9 years old, with 77% men and 23% women. All of them needed cardiac rehabilitation. Ninety-seven percent of them had a surgical intervention: 40% for the replacement of mitral and/or aortic valve, 33% after bypass surgery, 24% after other kinds of cardiac surgeries. The mean time between surgery and beginning of rehabilitation was 16±11 days. Only 3% of patients had a heart failure without any surgical intervention. These patients were randomly allocated in the two groups, each consisting of 30 patients.

 doi:10.20944/preprints202506.2518.v1

Table 1 shows the clinical variables assessed pre- and post-rehabilitation, revealing significant improvements in terms of pain and Borg-score in both groups, and HADS-total score, physical and mental health only in Virtual Reality Group. Borg-score resulted significantly lower in VRG than in CG ($p<0.01$). The analysis of upper limb ROM and MMT-score did not show any significant differences between groups before rehabilitation, except for left elbow flexion (CG: 143±15°, VRG: 137±8°, p=0.006). After rehabilitation, significant differences in ROM were observed for left (CG: 123±9°, EG: 129±14°, p=0.020) and right (CG: 121±13°, VRG: 129±15°, p=0.042) shoulder flexion, without differences at left elbow flexion (CG: 147±12°, EG: 146±8°, p=0.187). In terms of MMT-scores, after rehabilitation significant differences were observed for right shoulder flexion (CG: 4.8±0.5; VRG: 5.0±0, p=0.042) and right elbow flexion (CG: 4.9±0.4, VRG: 5.0±0, p=0.042).

Physiological parameters were also assessed before the 1st session of therapy, immediately after it, and before the last session. Data are reported in Table 2. Both groups showed an increase in SpO_2 after rehabilitation. The maximum blood pressure resulted slightly but significantly increased in patients in the control group.

Table 1. Mean ± standard deviation of the clinical variables assessed in Virtual Reality (VR) group and control group, pre- and post- rehabilitation. The p-values refer to the within group comparison performed with Wilcoxon test.

Clinical variables	VR Group			Control Group		
	Pre	Post	p-value	Pre	Post	p-value
HADS	37.0±2.6	34.2±1.9	<0.001	36.6±2.6	34.±2.2	0.187
HADS-A	20.9±2.3	20.9±2.3	0.919	20.1±2.5	21.4±1.8	0.209
HADS-D	16.0±1.8	16.7±1.7	0.097	16.5±2.2	16.0±2.1	0.092
SF-12-PH	38.0±7.4	41.9±7.5	0.012	33.0±5.7	39.2±6.1	0.153
SF-12-MH	46.0±9.3	51.8±8.7	0.002	43.0±12.0	51.6±11.9	0.511
Pain VAS	3.9±2.7	1.1±1.9	<0.001	3.7±2.4	1.7±2.0	0.014
BORG	3.8±2.4	1.1±1.8	<0.001	5.6±2.1	3.2±2.0	0.002

Table 2. Mean ± standard deviation of the physiological variables assessed before the first session of therapy (Pre 1st S), immediately after it (Post 1st S) and before the last session (Pre Last S). The p-values refer to the Wilcoxon test with respect to the Pre 1st S evaluation.

Physiological parameters	VR Group			Control Group		
	Pre 1st S	Post 1st S	Pre Last S	Pre 1st S	Post 1st S	Pre Last S
BP max	110±13	110±9 p=0.908	110±8 p=0.828	106±12	103±14 p=0.108	112±14 p=0.021
BP min	72±8	70±6 p=0.111	71±9 p=0.916	65±6	64±6 p=0.060	67±7 p=0.326
HR	78±10	80±10 p=0.075	75±11 p=0.171	73±12	75±13 p=0.097	76±11 p=0.321
SPO2	97.7±1.4	97.7±1.1 p=0.873	98.4±0.8 p=0.026	97.2±1.1	97.3±1.3 p=0.624	97.6±1.3 p=0.029

4. Discussion

This study aimed to assess the efficacy of integrating virtual reality treatment into a cardiac rehabilitation program, in which patients simulated driving in a different stressful simulated context. Thirty patients received conventional cardiac rehabilitation and the other thirty patients underwent the VR-based treatment combined with conventional therapy. At baseline, the VR group had a slightly lower Borg score for perceived exertion, higher physical health, but also slightly higher blood pressure and heart rate, and reduced mobility in the left elbow.

 doi:10.20944/preprints202506.2518.v1

After rehabilitation, we found that in both groups pain and exertion were reduced, and oxygen saturation increased. For VR group (and not for CG), physical and mental health improved, upper limb mobility improved, and HADS total score was reduced. Conversely, for Control group (and not for VR group) the maximum blood pressure after rehabilitation slightly but significantly increased.

The effects on HADS total score (and to a lesser extent on HADS-anxiety) have already been reported in many previous studies on the use of VR in cardiac rehabilitation [23-26].

However, some other studies reported contrasting results. One study showed a positive effect of VR in cardiac rehabilitation on selective attention, conflict resolution ability, and executive functions, but not on quality of life, depression, anxiety and stress [27]. This latter study included smaller patient groups compared to our study and the previously cited ones, which could have limited the statistical power of the performed analyses. Another study tested exergaming, performed with a commercial videogame console, in cardiac rehabilitation, without finding clinically or statistically significant improvements compared to those obtained with conventional rehabilitation [28]. However, the use of video-game based trainings is very different from the use of virtual reality systems, which are immersive and facilitate the sense of presence and the sense of action in the digital environment [2].

The impact of VR on quality of life is also controversial. We found positive improvements in terms of physical and mental health only in the VR group, and not in the control group. Our findings were in accordance with a previous study reporting the positive effects of a VR-based video game program in ergometry, resistance to fatigue, and health-related quality of life, with excellent adherence and patient-perceived satisfaction in individuals with ischemic heart disease [29]. However, another study reported no statistically significant impact of VR on health-related quality of life in patients undergoing cardiac rehabilitation [30]. At the same time, this study confirmed the positive impact of VR on HADS score.

In our study, also kinematic (ranges of motion) and kinetic (muscle strength) aspects of upper limb were assessed, finding significant positive effects in the group of patients who experienced the VR system, especially at shoulder level. This result is in accordance with the positive effect of VR rehabilitation on upper limb strength already observed in neurological patients [31].

There are two main pitfalls in using VR in rehabilitation: the definition of VR systems, and the poor importance given to content [2]. The former problem is related to the fact that in some studies commercial consoles and computer-based systems were used, but authors referred to them as VR systems, even if they are not immersive [27,32]. The latter problem is that most of the studies discussed the effects of VR regardless of the type of stimuli or games used. In our study, we used a car driving simulator featuring realistic 360° VR videos that depicted real-life city driving. This setup provided a highly controlled and safe environment for practice within the hospital, offering a realistic simulation of an important daily activity patients aim to recover and may sometimes fear resuming. Our application also allowed for progressive increases in task difficulty during rehabilitation by adjusting speed, the number of cars, and street width.

Our study has some limitations that should be taken into account when generalizing its results to the population of cardiac patients needing rehabilitation. First of all, the wide variability in the subjects limited the significance of between-group differences, and statistically significant results were mainly found for within-group analyses. Then, despite enrolling 60 patients, the sample is quite small when that variability is taken into account. Finally, we tested only one driving simulator, and hence, to replicate our results, similar software would be required.

5. Conclusions

Cardiac rehabilitation aims to help individuals recover from heart events or procedures by improving their cardiovascular health and overall well-being. It encompasses a multi-faceted approach including exercise training, lifestyle modification, education, and psychological support for returning to a complete independence and functioning during the activities of daily living. The use of VR in cardiac rehabilitation has shown some positive findings in the scientific literature, but also

 doi:10.20944/preprints202506.2518.v1

some controversial results [5,6,33]. These controversies could be due to the developed tasks. We tested a VR system with a car driving simulator that combined realistic 360° video and computer graphics. This approach led to significant improvements in physical and mental health, psychological well-being, and upper limb ranges of motion, which were not observed in patients undergoing a conventional therapy program. Other parameters, such as oxygen saturation, showed improvements in both groups. In conclusion, VR seems to be a promising technology that could be easily and positively integrated into cardiac rehabilitation, but it is fundamental to take into account the type of digital task proposed to the patients according to a personalization of therapy within the framework of evidence-based rehabilitation. We selected a car driving simulated task because allowed a progressive increment of difficulty, involving a mix of psychological and physiological factors, and a good level of engagement of patients also because driving is a fundamental activity that the subjects would recover for recovery their autonomy.

Author Contributions: Conceptualization, M.I., R.D.G, G.T.; methodology, M.I., C.S., D.D.B.; software and 3d modelling, S.B.; validation, R.D.G.; statistical analysis, M.I.; patients' screening and enrollment, A.P.; assessment of patients, R.C., F.G., C.R., S.C.; treatment administration R.C., F.G., C.R., S.C.; writing—original draft preparation, M.I.; writing—review and editing, R.D.G., C.S., D.D.B., G.T.; supervision, A.P.; project administration, M.I.; funding acquisition, M.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Sapienza University of Rome, grant number RM123188B4C92FF4, grant name: Project HeART.

Institutional Review Board Statement: Local Independent Ethical Committee approved this study (approval code: CE/PROG.795, date of approval 2nd December 2019).

Informed Consent Statement: Signed written informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Anonymous data are available on request to send to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest

References

1. Burdea G, Coiffet P. Virtual reality technology. Presence: Teleoperators Virtual Environ. 2003;12(6):663e664.
2. Tieri, G., Morone, G., Paolucci, S., & Iosa, M. (2018). Virtual reality in cognitive and motor rehabilitation: facts, fiction and fallacies. Expert Review of Medical Devices, 15(2), 107–117. https://doi.org/10.1080/17434440.2018.1425613
3. Fiorenzato, E., Zabberoni, S., de Simone, M. S., Costa, A., Tieri, G., Taglieri, S., Peppe, A., Carlesimo, G. A., Caltagirone, C., Antonini, A., & Cona, G. (2025). Effects of virtual reality cognitive training on executive function and prospective memory in Parkinson's disease and healthy aging. Journal of the Neurologi-cal Sciences, 473. https://doi.org/10.1016/j.jns.2025.123507
4. Reale, G., Fusco, A., Calciano, R., Vallario, N., Vagnarelli, G., Caliandro, P., Castelli, L., Moci, M., Tieri, G., Iasevoli, L., & Padua, L. (2023). The Immediate Effects of Immersive Virtual Reality on Autonomic Nervous System Function in Patients with Disorders of Consciousness after Severe Acquired Brain Injury: A Pilot Study. Journal of Clinical Medicine, 12(24). https://doi.org/10.3390/jcm12247639
5. Micheluzzi, V., Navarese, E. P., Merella, P., Talanas, G., Viola, G., Bandino, S., Idini, C., Burrai, F., & Casu, G. (2024). Clinical application of virtual reality in patients with cardiovascular disease: state of the art. Frontiers in cardiovascular medicine, 11, 1356361. https://doi.org/10.3389/fcvm.2024.1356361
6. Wang, S., Jiang, J., Zhang, C., Lv, M., Xu, H., Meng, H., & Guo, L. (2025). Effect of Virtual Reality-Based Cardiac Rehabilitation on Mental Health and Cardiopulmonary Function of Individuals With Cardiovascular Disease: A Systematic Review and Meta-analysis. Archives of physical medicine and rehabilitation, 106(6), 949–960. https://doi.org/10.1016/j.apmr.2024.11.005
7. Zhang, M., Liu, S., Xiong, X., Liu, M., Wang, Y., Yang, Y., & Xiang, Q. (2024). Effectiveness of virtual reality in cardiac rehabilitation patients for exercise capacity and negative emotions: A systematic review and meta-analysis. Medicine, 103(49), e40812. https://doi.org/10.1097/MD.0000000000040812
8. Alves da Cruz, M., Laurino, M., Christofaro, D., Ghisi, G., & Vanderlei, L. (2024). Long-term effects of virtual reality-based therapy in cardiovascular rehabilitation: A longitudinal study. Physiotherapy theory and practice, 40(4), 727–735. https://doi.org/10.1080/09593985.2022.2160222

9. Micheluzzi, V., Casu, G., Burrai, F., Canu, A., Sircana, A., Merella, P., Laconi, A., Chelo, A., Cozzula, P., Piredda, M., & Vellone, E. (2025). The experience of immersive virtual reality in patients with heart failure during cardiac rehabilitation: a qualitative study. Frontiers in medicine, 12, 1578399. https://doi.org/10.3389/fmed.2025.1578399
10. Iosa, M., Aydin, M., Candelise, C., Coda, N., Morone, G., Antonucci, G., Marinozzi, F., Bini, F., Paolucci, S., & Tieri, G. (2021). The Michelangelo Effect: Art Improves the Performance in a Virtual Reality Task Developed for Upper Limb Neurorehabilitation. Frontiers in psychology, 11, 611956. https://doi.org/10.3389/fpsyg.2020.611956
11. Tieri, G., Iosa, M., Fortini, A., Aghilarre, F., Gentili, F., Rubeca, C., Mastropietro, T., Antonucci, G., & De Giorgi, R. (2024). Efficacy of a Virtual Reality Rehabilitation Protocol Based on Art Therapy in Patients with Stroke: A Single-Blind Randomized Controlled Trial. Brain sciences, 14(9), 863. https://doi.org/10.3390/brainsci14090863
12. Jia, Y. Y., Song, J. P., & Yang, L. (2024). Can virtual reality have effects on cardiac rehabilitation? An overview of systematic reviews. Current problems in cardiology, 49(2), 102231. https://doi.org/10.1016/j.cpcardiol.2023.102231Author 1, A.; Author 2, B. Title of the chapter. In Book Title, 2nd ed.; Editor 1, A., Editor 2, B., Eds.; Publisher: Publisher Location, Country, 2007; Volume 3, pp. 154–196.
13. Gaudet, J., Mekary, S., Bélanger, M., & Johnson, M. (2016). Effects of an aerobic exercise program on driving performance in adults with cardiovascular disease. International journal of rehabilitation research. Internationale Zeitschrift fur Rehabilitationsforschung. Revue internationale de recherches de readaptation, 39(2), 117–122. https://doi.org/10.1097/MRR.0000000000000150
14. Blumenfeld, M. B., Simmich, J., Doig, E. J., Russell, T., & Ross, M. H. (2025). Patient and clinician perspectives of the use of driving simulators for rehabilitation after traumatic brain injury. Neuropsychological rehabilitation, 1–22. Advance online publication. https://doi.org/10.1080/09602011.2025.2503338
15. Okazawa, K., Hamai, S., Fujita, T., Nasu, Y., Kawahara, S., Nakashima, Y., Ishikawa, H., Fujii, H., & Katoh, H. (2025). The Relationship Between Driving Performance and Lower Limb Motor Function After Total Knee Arthroplasty Using a Driving Simulator: A Pilot Study on Elucidating Factors Influencing Accelerator and Brake Operations. Life (Basel, Switzerland), 15(5), 768. https://doi.org/10.3390/life15050768
16. Iani, L., Lauriola, M., & Costantini, M. (2014). A confirmatory bifactor analysis of the Hospital Anxiety and Depression Scale in an Italian community sample. Health and quality of life outcomes, 12, 84. https://doi.org/10.1186/1477-7525-12-84
17. Costantini, M., Musso, M., Viterbori, P., Bonci, F., Del Mastro, L., Garrone, O., Venturini, M., & Morasso, G. (1999). Detecting psychological distress in cancer patients: validity of the Italian version of the Hospital Anxiety and Depression Scale. Supportive care in cancer : official journal of the Multinational Association of Supportive Care in Cancer, 7(3), 121–127. https://doi.org/10.1007/s005200050241
18. Apolone, G., & Mosconi, P. (1998). The Italian SF-36 Health Survey: translation, validation and norming. Journal of clinical epidemiology, 51(11), 1025–1036. https://doi.org/10.1016/s0895-4356(98)00094-8
19. Price, D. D., McGrath, P. A., Rafii, A., & Buckingham, B. (1983). The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. Pain, 17(1), 45–56. https://doi.org/10.1016/0304-3959(83)90126-4
20. Borg G. A. (1982). Psychophysical bases of perceived exertion. Medicine and science in sports and exercise, 14(5), 377–381.
21. Lovett, R.W. The Diagnosis, Prognosis and Early Treatment of Poliomyelitis. J. Am. Med. Assoc. 1922, 78, 1607–1611.
22. Cuthbert, S.C.; Goodheart, G.J. On the Reliability and Validity of Manual Muscle Testing: A Literature Review. Chiropr. Osteopat. 2007, 15, 4.
23. Szczepańska-Gieracha, J., Jóźwik, S., Cieślik, B., Mazurek, J., & Gajda, R. (2021). Immersive Virtual Reality Therapy as a Support for Cardiac Rehabilitation: A Pilot Randomized-Controlled Trial. Cyberpsychology, behavior and social networking, 24(8), 543–549. https://doi.org/10.1089/cyber.2020.0297
24. Jóźwik, S.; Cieślik, B.; Gajda, R.; Szczepańska-Gieracha, J. The Use of Virtual Therapy in Cardiac Rehabilitation of Female Patients with Heart Disease. Medicina 2021, 57, 768. https://doi.org/10.3390/medicina57080768
25. Jóźwik, S.; Cieślik, B.; Gajda, R.; Szczepańska-Gieracha, J. Evaluation of the Impact of Virtual Reality-Enhanced Cardiac Rehabilitation on Depressive and Anxiety Symptoms in Patients with Coronary Artery Disease: A Randomised Controlled Trial. J. Clin. Med. 2021, 10, 2148. https://doi.org/10.3390/jcm10102148
26. Jóźwik, S.; Wrzeciono, A.; Cieślik, B.; Kiper, P.; Szczepańska-Gieracha, J.; Gajda, R. The Use of Virtual Therapy in Cardiac Rehabilitation of Male Patients with Coronary Heart Disease: A Randomized Pilot Study. Healthcare 2022, 10, 745. https://doi.org/10.3390/healthcare10040745
27. Vieira, Á., Melo, C., Machado, J., & Gabriel, J. (2017). Virtual reality exercise on a home-based phase III cardiac rehabilitation program, effect on executive function, quality of life and depression, anxiety and

doi:10.20944/preprints202506.2518.v1

stress: a randomized controlled trial. Disability and Rehabilitation: Assistive Technology, 13(2), 112–123. https://doi.org/10.1080/17483107.2017.1297858
28. Jaarsma, T., Klompstra, L.,Ben Gal T., etal. Effects of exergaming on exercise capacity in patients with heart failure: results of a ninternational multicenter randomized controlled trial. Eur J Heart Fail 2021; 23: 114–24. https://doi.org/10.1002/ejhf.1754
29. García-Bravo, S., Cano-de-la-Cuerda, R., Domínguez-Paniagua, J., Campuzano-Ruiz, R., Barreñada-Copete, E., López-Navas, M. J., Araujo-Narváez, A., García-Bravo, C., Florez-Garcia, M., Botas-Rodríguez, J., & Cuesta-Gómez, A. (2020). Effects of Virtual Reality on Cardiac Rehabilitation Programs for Ischemic Heart Disease: A Randomized Pilot Clinical Trial. International journal of environmental research and public health, 17(22), 8472. https://doi.org/10.3390/ijerph17228472
30. Wang, S., Jiang, J., Zhang, C., Lv, M., Xu, H., Meng, H., & Guo, L. (2025). Effect of Virtual Reality-Based Cardiac Rehabilitation on Mental Health and Cardiopulmonary Function of Individuals With Cardiovascular Disease: A Systematic Review and Meta-analysis. Archives of physical medicine and rehabilitation, 106(6), 949–960. https://doi.org/10.1016/j.apmr.2024.11.005
31. De Giorgi, R., Fortini, A., Aghilarre, F., Gentili, F., Morone, G., Antonucci, G., Vetrano, M., Tieri, G., & Iosa, M. (2023). Virtual Art Therapy: Application of Michelangelo Effect to Neurorehabilitation of Patients with Stroke. Journal of clinical medicine, 12(7), 2590. https://doi.org/10.3390/jcm12072590
32. Vieira, Á., Gabriel, J., Melo, C., & Machado, J. (2017). Kinect system in home-based cardiovascular rehabilitation. Proceedings of the Institution of Mechanical Engineers. Part H, Journal of engineering in medicine, 231(1), 40–47. https://doi.org/10.1177/0954411916679201
33. Chen, Y., Cao, L., Xu, Y., Zhu, M., Guan, B., & Ming, W. K. (2022). Effectiveness of virtual reality in cardiac rehabilitation: A systematic review and meta-analysis of randomized controlled trials. International journal of nursing studies, 133, 104323. https://doi.org/10.1016/j.ijnurstu.2022.104323