1 Rehabilitation Engineering

§1.11 *Virtual Reality in rehabilitation*

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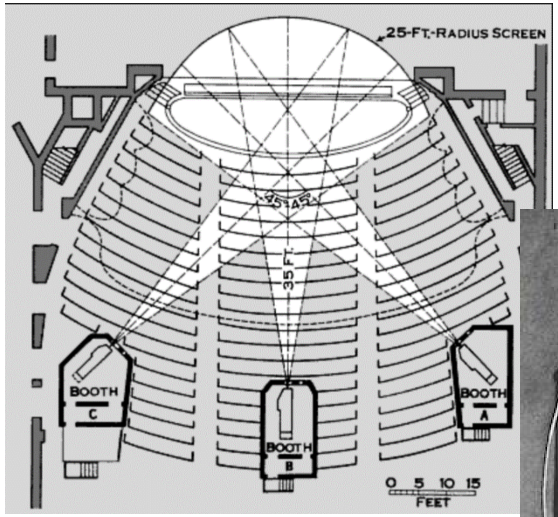
A bit of history



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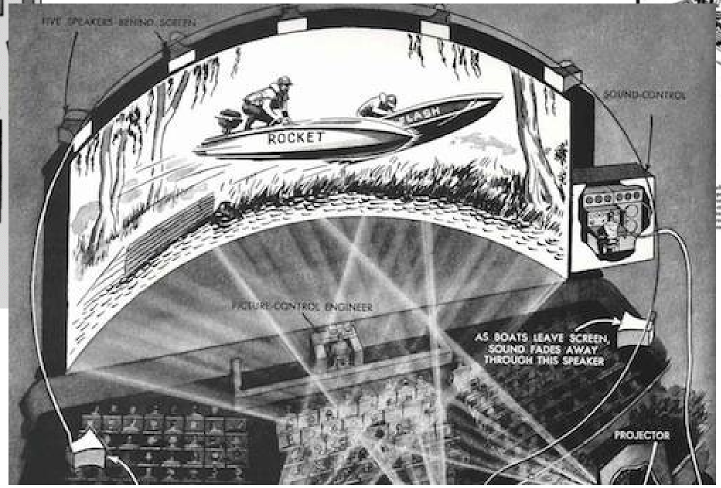
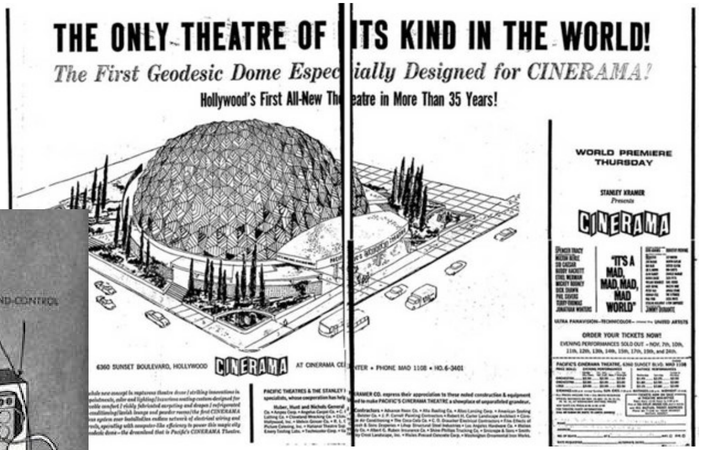




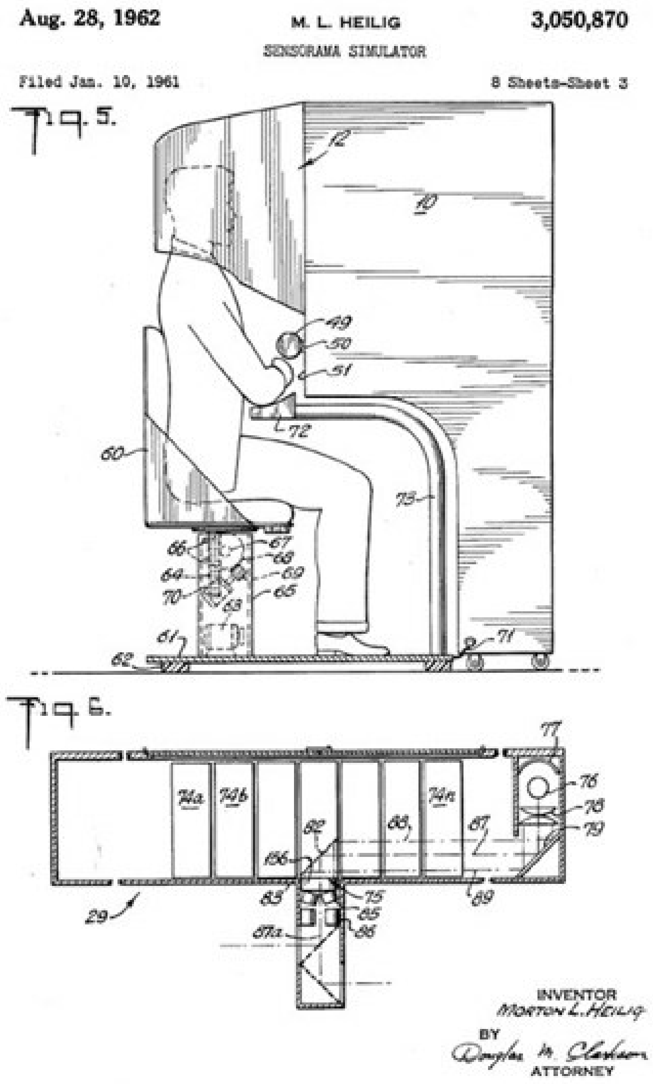
Cinerama, 1946

Napoléon, film by **Abel Gance**, 1927

A bit of history

In 1962, the forerunner of the experience of identification, or the involvement of the entire sensory perception in an entertainment experience, was *Morton Helig*, in fact the true father of the concept of virtual reality, with the construction of a cumbersome mechanical machine called *Sensorama*.

Sensorama, 1962



The appearance is reminiscent of a game room cabinet: the Sensorama user could take a seat in front of a screen capable of showing stereoscopic images, equipped with mechanisms for the diffusion of aromas and odors and stereo speakers, air ducts to simulate the effect of the wind on the face. The user went to sit on a seat equipped with counterweights and levers for the swaying sensations of the body and placed his hands on a handlebar to restore the tactile sensations.

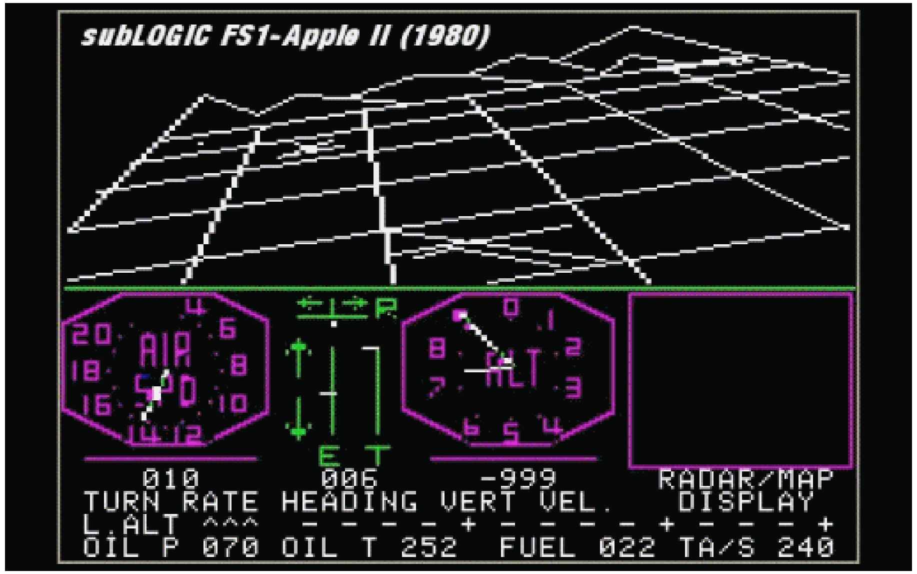
A bit of history

The first head-mounted display (HMD) system was introduced from Ivan Sutherland in 1968.

Since the 1970s, various virtual reality (VR) applications have been developed for different application fields (aviation training, military applications, industrial training for the use of machinery, surgical training).

The application of VR to rehabilitation, is a relatively young, interdisciplinary field where clinical implementation very rapidly follows scientific discovery and technological advancement.

Ivan Sutherland's Sword of Damocles



Bruce Artwick, MS Flight Simulator

Exergaming

Commercial consoles (e.g., Nintento Wii, Playstation EyeToy, Microsoft Kinect, DanceDanceRevolution) offer appealing, motivating, and encouraging exercise concepts both for clinical and healthy populations.

This complementary and alternative training mode might **bridge the gap between playing games and exercising**, commonly termed "*exergaming*." Exergaming uses a computer-generated virtual environment and has been employed to improve general physical fitness and for therapeutic purposes (e.g., cardiac rehabilitation, neuro-rehabilitation). Depending on the type of underlying body movements, the resulting energy expenditure of exergames commonly varies from light to moderate.

In recent years, Exergaming has also been applied to older populations. This approach seems to be a promising means to integratively tackle increasing cognitive and physical dysfunction in seniors. The majority of available exergaming studies in seniors focused on balance and gait training. Stepping as well as static and dynamic balance tasks were playfully arranged within these training concepts. Although the training regimes (type of exercise, duration, repetitions, and sets) vary between studies, most available studies revealed positive effects of exergaming on balance parameters in the elderly.

Exergaming

Implications for Rehabilitation

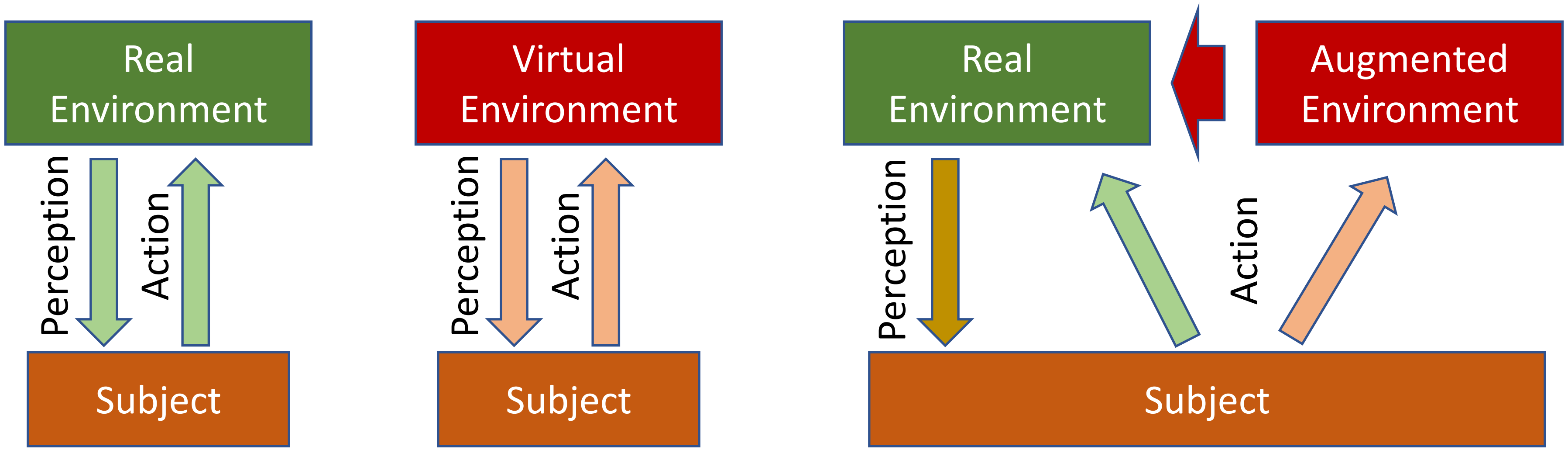
- Exergaming can be deployed as physical activity or exercise using commercially available game consoles for neurologically disabled individuals in the convenience of their home environment and at a relatively inexpensive cost
- Moderate-to-vigorous intensity exercises can be achieved during exergaming in this population of persons with neurological disabilities. Exergaming can also be engaging and enjoyable, yet achieve the recommended physical activity guidelines proposed by ACSM™ or WHO for health and fitness benefits.
- Exergaming as physical activity in this population is feasible for individuals with profound disabilities, since it can be used even in sitting position for wheelchair-dependent users, thus providing variability in terms of exercise options.
- In the context of comprehensive rehabilitation, exergaming should be viewed by the clinician as "at least as good as" (and likely more enjoyable) than traditional arm-exercise modalities, with equivalent aerobic dose-potency as "traditional" exercise in clinic or home environments.

Example: exergaming for MS

https://www.youtube.com/watch?v=REEpVde0qmQ

Exergaming ⟷ **Non-immersive VR**

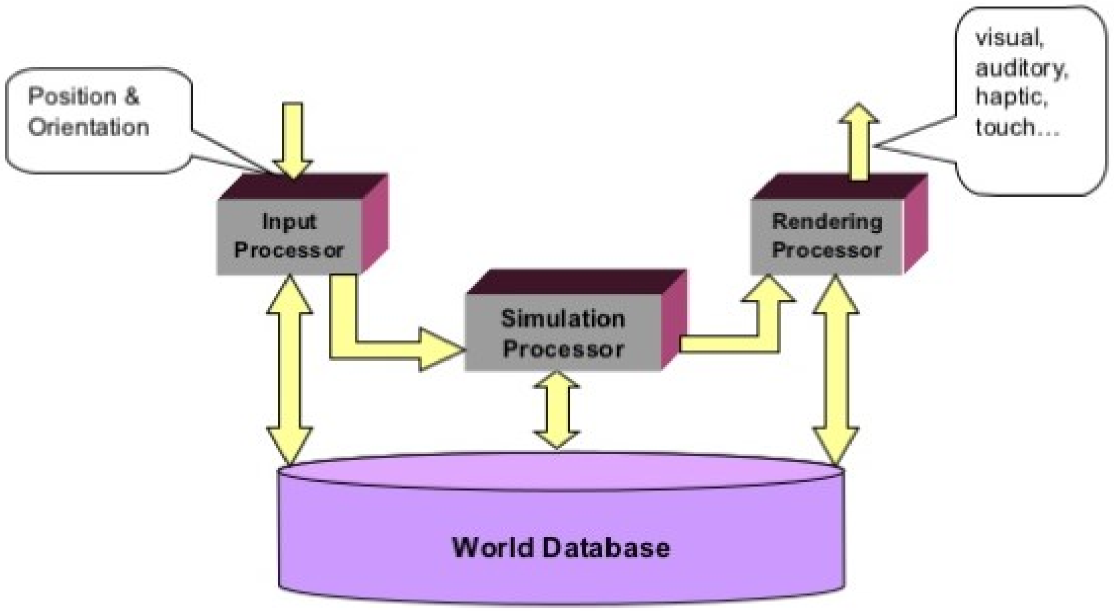
Virtual (VR) vs. Augmented Reality (AR)



- While in the real world we obtain information about the surrounding environment directly from our senses, in VR we use the same senses to obtain information about the virtual environment through the human-machine interface.
- This interface can provide specific information for one or more senses.
- The inputs of the virtual environment can also be combined with those of the surrounding environment and used to generate a set of hybrid inputs for the CNS (in this case it is referred to as augmented reality).

Architecture of a VR system

Virtual reality is a tool composed of interactive computer simulations that perceive the participant's position, his/her actions and replace or increase the responses to one or more of his/her senses, thus leaving him/her the feeling of being mentally *immersed* or *present* in the inside of the virtual world.



Virtual world

Immersivity

Sensory feedback

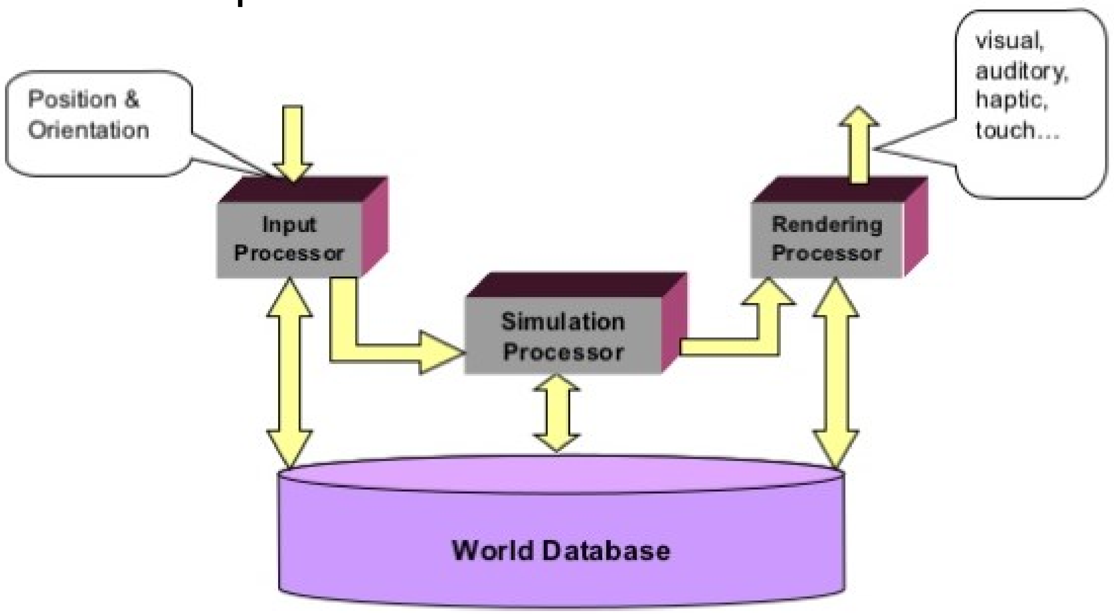
Interactivity

Architecture of a VR systemc

The basic component for a VR system is a **computer** with graphics capabilities such as to allow the processing and real-time representation of 3D environments.
To this are associated:

- hardware for monitoring user movement (*sensors*> *inputs*)
- devices for displaying the environment or for the haptic return of the interaction with the environment for the user (*display*> *rendering*)

All this must obviously be accompanied by software that allows real-time synchronous operation of all devices.



Virtual world

Immersivity

Sensory feedback

Interactivity

Architecture of a VR system

In general, virtual reality programming environments offer the programmer real “PHYSICAL ENGINES”, that is, dedicated software packages capable of performing the simulation in spatial coordinates of the kinematics of the objects present on the scene.

Sometimes these physical engines are integrated into the firmware of the graphics cards (optimized to perform only or almost only this kind of calculation), to speed up the calculation and relieve the central unit's processor(s). Generally, the development environments of virtual reality systems, due to the intrinsic characteristics of the type of application, are based on a type of object-oriented programming.

Main polygon modeling programs:

- Blender, Maya, Modo, 3DStudioMax, Photoshop, etc .;

Audio:

- Logic Pro X, Ableton Live, Steinberg Cubase, Audacity, etc.

The reproduction of a credible and coherent world, in the eyes of the user, is essential to arouse the sense of immersion characteristic of VR software.

VR system components: trackers

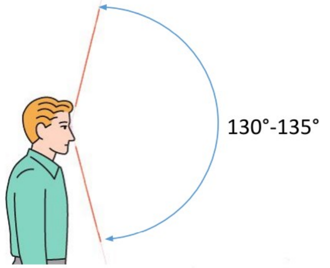
Based on:
-Magnetic Tracking;
-Optical tracking;
-Resistive bend sensing;
-Gyroscopes and accelerometers

CyberGlove

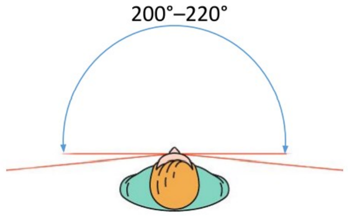
VR system components: visual displays

Technology	Description	Strengths	Weakness
HMDs	Use dual monitors (CRT or LCD) and special optics to present a different image to each eye. The monitors and lenses are mounted in a helmet-type device, usually with a position tracker and ear phones attached.	- Encompassing visual volume - Relative freedom of movement - (CRT-based): Small, high-resolution, high luminance, monochrome displays - (LCD-based): Color displays with low voltages near user's head	- Weight and inertial burden - Single viewer - Bulky optics that introduce distortions - (CRT-based): High voltages near user's head, mechanical or electrical color filtering techniques needed for color, sources of distortion - (LCD-based): Low resolution, slow switching time
Active Glasses	Special glasses with electronic shutters that display images to each eye alternately. Require a special monitor or projection screen that presents left and right eye images as sequential fields.	- Low weight - Multiple viewers possible (static stereo scenes for all but head-tracked user)	- Interocular crosstalk - Not suited for encompassing visual volume - Effectively halves frame rate
Passive Glasses	Special glasses with filters that pass only the image intended for each eye. Require a special monitor or screen in which perspective views for each eye are encoded in form of color or light polarization.	- Low weight - Multiple viewers possible (static stereo scenes for all but head-tracked user) - Inexpensive glasses (though projection display may be expensive)	- Not suited for encompassing visual volume - Poor contrast - Color coding results in eye fatigue
BOOM	Use dual monitors (CRT or LCD) and special optics to present a different image to each eye. The monitors and lenses are mounted in device suspended from a boom in front of the user.	- Weight counter-balanced - Low latency - Ease of switch to keyboard operation	- User movement restricted by mechanical linkages
Autostereoscopic Displays	Common approaches use either lenses positioned behind or before a display screen, or physical barriers in front of the display to cause each eye to see a different image.	- Unencumbering - Multiple viewers possible - Ease of switch to keyboard operation	- Low resolution - Slow switching time - User movement restricted to limited viewing area - Not suited for encompassing visual volume

Headsets: main specifications



- **Resolution:** currently up to 2160x1200 (1080x1200 per eye)

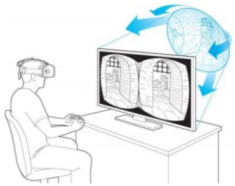


- **Field of View (FOV):** may cover most or all of the user's FOV

- **Degrees of freedom (DOF):** 3 or 6

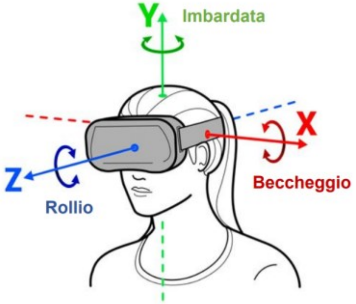
• **3DoF**

L'utente può solo ruotare la testa stando seduto o in piedi sul posto



• **6DoF**

L'utente può muovere la testa e spostarsi all'interno di una area circoscritta



- **Class:** mobile / standalone / high-end

mobile VR

Richiedono l'inserimento di uno smartphone per l'elaborazione e la visualizzazione

standalone VR

Sono dotati internamenti di processore per l'elaborazione e di un display per la visualizzazione

high-end VR

Il PC si occupa dell'elaborazione mentre il visore ha un display per la visualizzazione

VR system components: tactile feedback

Technology	Description	Advantages	Disadvantages
Piezoelectric crystals	Changing electric fields causes expansion and contraction of crystals	- High spatial resolution	- Restricted to resonant frequency
Pneumatic	Takes many forms. As air-jets, provides an array of air nozzles that can be gated to a display pattern. As air-rings (cuffs), like miniature blood pressure cuffs. As bladders (bellows), often the size of a finger pad and held against the finger by a glove or band. As an array of tiny pressurized bladders, many to a single finger pad	- Low mass on hand	- Poor spatial and temporal resolution - Limited bandwidth
Shape Memory Alloy	SMA wires and springs contract when heated and expand again as they cool under stress	- Good power-to-mass ratio	- Low efficiency during contraction - Heat dissipation problems limit relaxation rate of wires
Solenoid	Magnetic coil applies force to ferrous plunger	- High steady-state forces - Better bandwidth than other materials (except for piezoelectric crystals and voice coils)	- Relatively heavy - Nonlinear, can require extra effort to control
Voice coil	Voice coil vibrates to transmit low amplitude, high frequency vibrations to the skin.	- High temporal resolution - Relatively small, does not obstruct normal movement ranges of the fingers	- Poor spatial resolution - Limited scalability
Heat pump	Solid state device that moves thermal energy to heat or cool the skin	- No fluids required	- Poor spatial and temporal resolution - Bulky - Limited bandwidth

VR system components: force feedback

Technology	Description	Advantages	Disadvantages
Electromagnetic Motors	Electromagnetic motors produce torque with two time-varying magnetic fields, caused by two coils or a coil and a magnet	- Easy to control - Clean, quiet - Easy design and installation	- Heavy components - Low power densities at small scales - Heat dissipation problems - Low static force capability
Hydraulics	A hydraulic fluid is pressurized by a power plant, controlled by servo-valves and delivered to rotary or linear actuators through pressurized fluid lines	- Force capability, power output, stiffness, and bandwidth unmatched by other technologies	- High mass - Tendency for fluid leaks - Design difficulty - Expensive
Pneumatics	A gas (normally air) is pressurized by a power plant, controlled by servo-valves, and delivered to rotary or linear actuators through pressurized fluid (air) lines	- Good static force capability - Lighter than hydraulics - Pneumatic power plants and distribution systems easier to manage than hydraulics	- Relatively low bandwidth - Low actuation stiffness - Low power capability
Piezoelectric	Piezoelectric motors translate the vibration of piezoelectric materials to linear or rotary motion using frictional forces to produce usable torques or forces at low speeds, without the need for gear reduction.	- High forces at low speeds in small package	- Requires precision machining - Necessary power gating can cause annoying and potentially hazardous noise, depending on the design
Magnetorestrictive	Magnetorestrictive materials change shape when subjected to magnetic fields. Magnetorestrictive motors also mechanically rectify small oscillatory motions of the driving element(s).	- High forces at low speeds in small package	- Necessary power gating can cause annoying and potentially hazardous noise, depending on the design - Heat dissipation can be a problem - Requires precision machining
Shape Memory Alloy	SMA wires and springs contract when heated and expand again as they cool under stress.	- Good power-to-mass ratio	- Low efficiency during contraction - Heat dissipation problems limit relaxation rate of wires - Limited bandwidth

Rationale of using VR in rehabilitation

One of the most recent fields of application of VR is that of rehabilitation, for which various systems have been developed that have already been applied to patients with different rehabilitation needs.

Key concepts in motor rehabilitation:

- **Repetition**
- **Feedback**
- **Motivation**

Repetition is important for motor learning and for the changes at the cortical level associated with it; the repetition, however, must be associated with the incremental satisfaction of some task or goal, obtained through a trial-error activity, which provides *feedback* on the success of the performance provided by the senses. To repeat the movements numerous times the subjects must be *motivated*.

Rationale of using VR in rehabilitation

VR is a powerful tool to provide the patient with all these elements:

- repeated activities,
- performance feedback,
- motivation.

Particularly in VR, feedback on performance can be increased. Despite the limited number of experimental evidences, repetition in VR seems to be effective in that it makes the task simpler, less dangerous, more adapted, more fun, easier to learn because the main feedback is provided immediately.

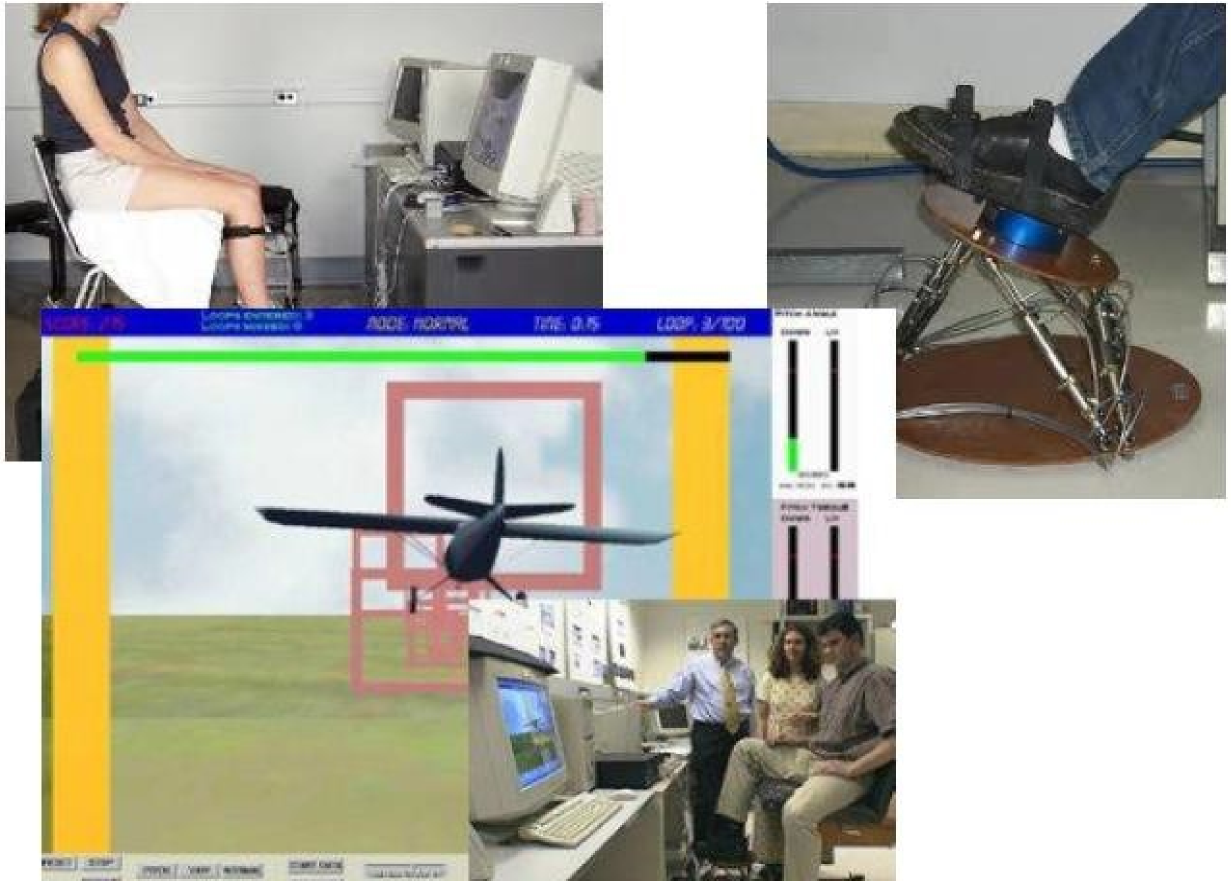
Other VR aspects that can improve learning:

- display of end-point tracking,
- display of numerous repetitions by the instructor (***learning by imitation***).

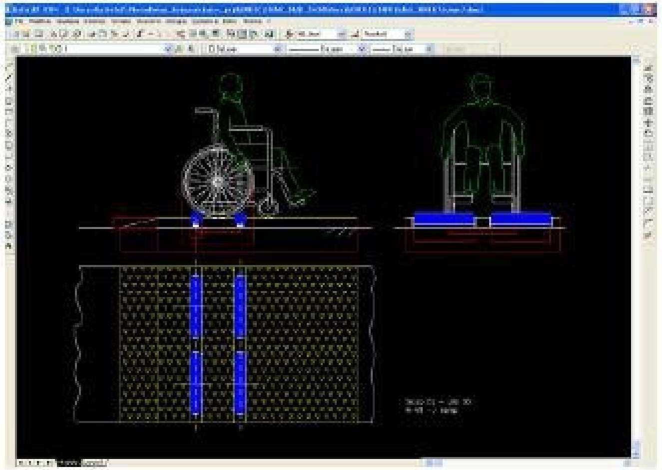
Example: the VRRS System by Khymeia

http://khymeia.com/prodotti/vrrs/

Example: the Rutger Ankle system



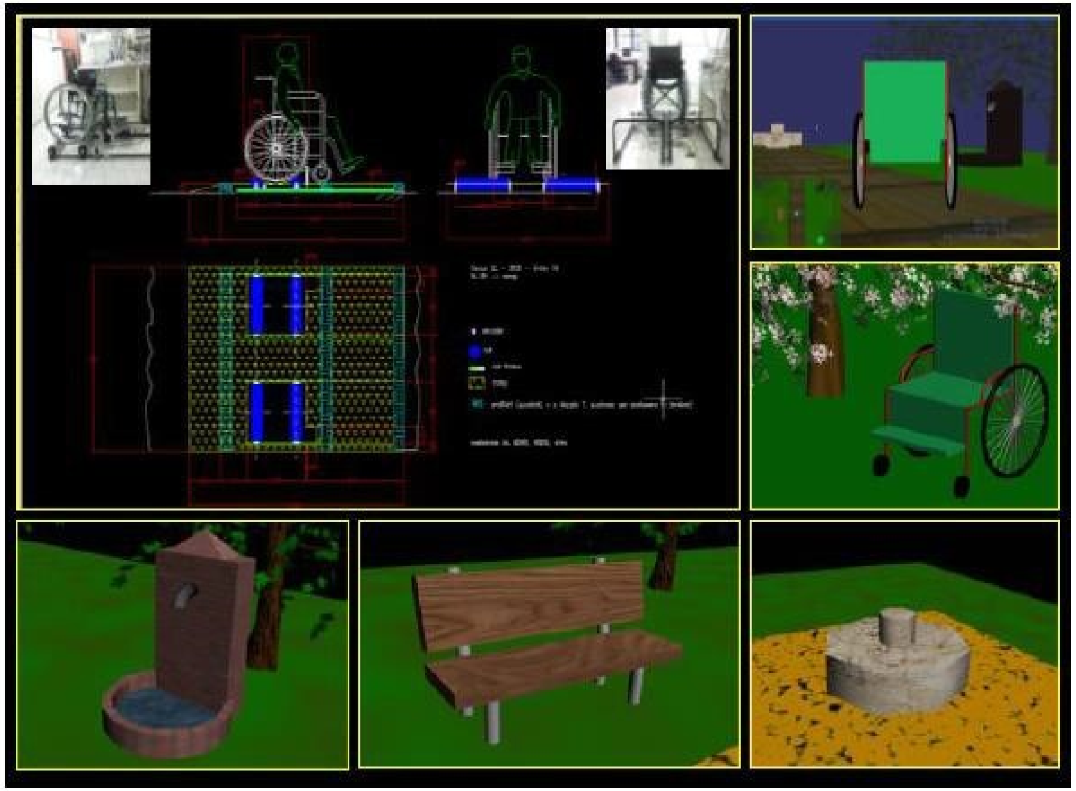
Example: VR Wheel

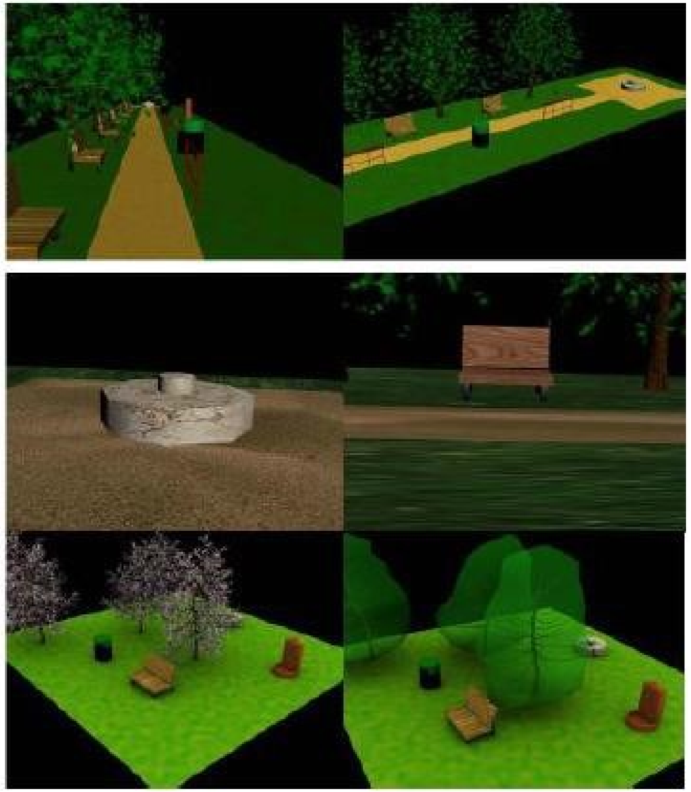


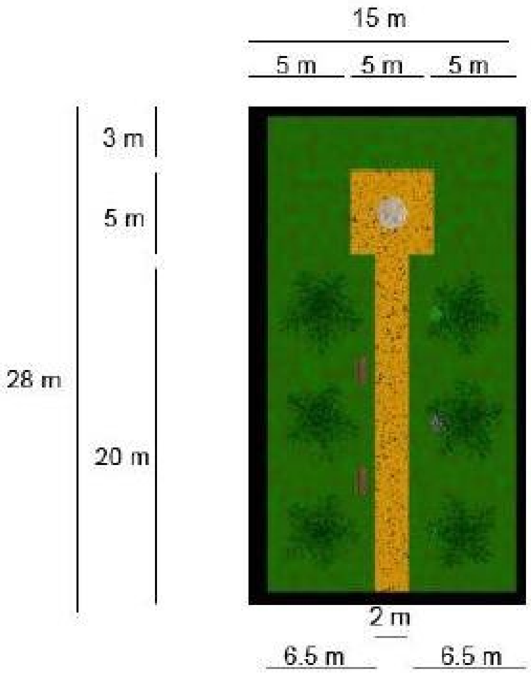
UNIBO in partnership with Montecatone Rehabilitation Institute and INAIL Prosthesis Center

E.L. Secco et al, Virtual Rehabilitation, 2007

Example: VR Wheel







E.L. Secco et al, Virtual Rehabilitation, 2007

Example: Look of Life

Virtual reality technology at home to improve the quality of life of cancer patients

Goal of the project:
The project aims to introduce an innovative technological tool such as the virtual reality viewer, which allows cancer patients assisted by the ANT Foundation to live, at home and independently, an experience that can have positive effects on the state mood and pain.

Evaluate the effects of the VR headset by recording long-term physiological signals.

Fondazione ANT 1978 Onlus **Look of Life 2.0**

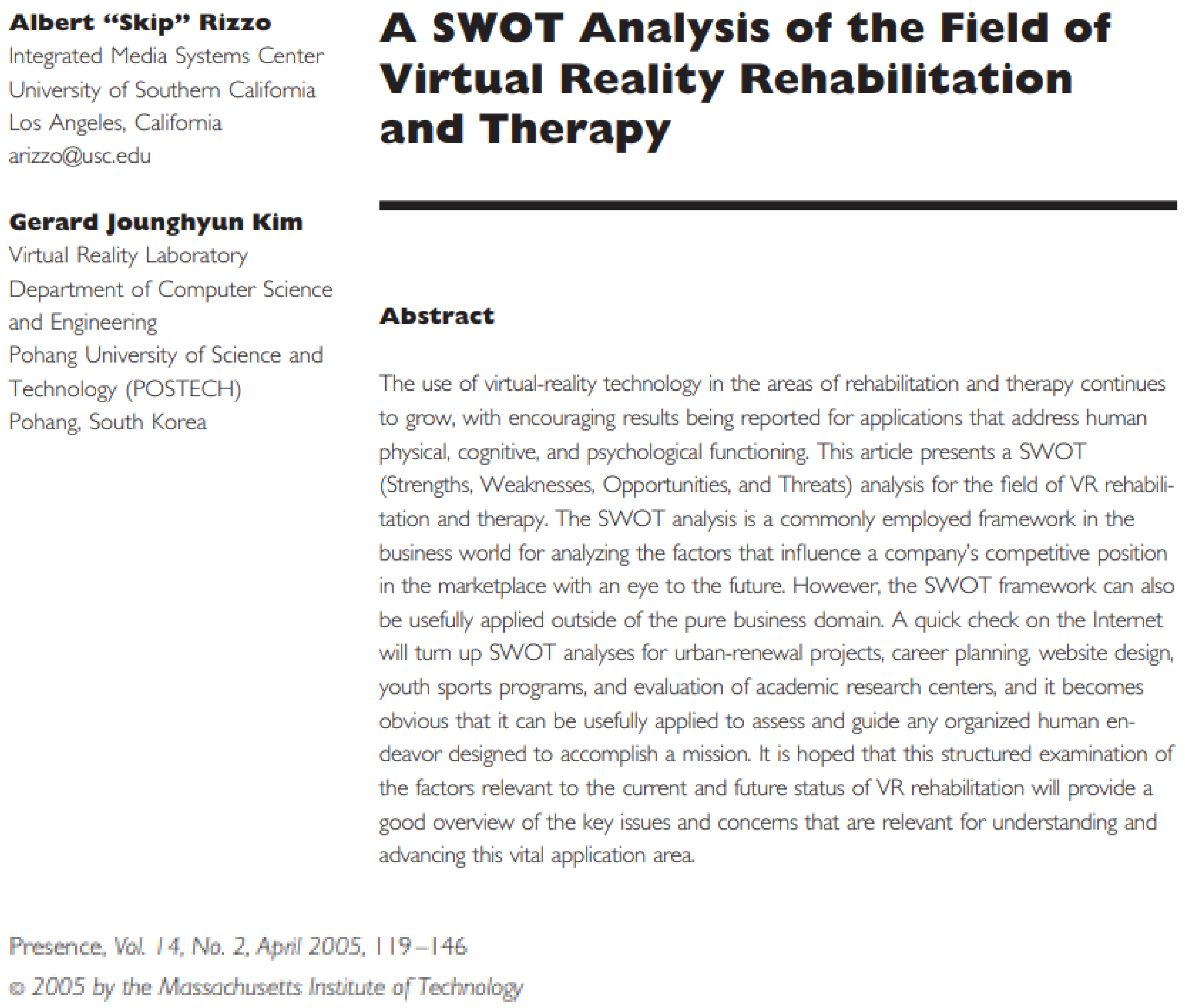
HIT FONDAZIONE CATTOLICA ASSICURAZIONI Fondazione Vodafone Italia SAMSUNG DEYEVR OC! WR DIVE INTO YOUR SOUND IMMERXIVE

Virtual Reality Rehabilitation: Open Issues

Virtual reality is still in its early stages of medical and rehabilitation practices and clinicians still have unresolved questions related to the technology, such as:

- Are there minimal cognitive and perceptual requirements to apply VR for sensorimotor rehabilitation effectively?
- Are semi-immersive systems as effective as immersive environments in promoting motor recovery?

A SWOT Analysis of VR Rehabilitation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A SWOT Analysis of the Field of Virtual Reality Rehabilitation and Therapy

Abstract

The use of virtual-reality technology in the areas of rehabilitation and therapy continues to grow, with encouraging results being reported for applications that address human physical, cognitive, and psychological functioning. This article presents a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis for the field of VR rehabilitation and therapy. The SWOT analysis is a commonly employed framework in the business world for analyzing the factors that influence a company's competitive position in the marketplace with an eye to the future. However, the SWOT framework can also be usefully applied outside of the pure business domain. A quick check on the Internet will turn up SWOT analyses for urban-renewal projects, career planning, website design, youth sports programs, and evaluation of academic research centers, and it becomes obvious that it can be usefully applied to assess and guide any organized human endeavor designed to accomplish a mission. It is hoped that this structured examination of the factors relevant to the current and future status of VR rehabilitation will provide a good overview of the key issues and concerns that are relevant for understanding and advancing this vital application area.

Presence, Vol. 14, No. 2, April 2005, 119–146
© 2005 by the Massachusetts Institute of Technology

A SWOT Analysis of VR Rehabilitation

Strengths	Weaknesses
• Enhanced Ecological Validity • Stimulus Control and Consistency • Real-Time Performance Feedback • Cuing Stimuli to Support "Error-Free Learning" • Self-Guided Exploration and Independent Practice • Interface Modification Contingent on User's Impairments • Complete Naturalistic Performance Record • Safe Testing and Training Environment • Gaming Factors to Enhance Motivation • Low-Cost Environments That Can be Duplicated and Distributed	• The Interface Challenge 1: Interaction Methods • The Interface Challenge 2: Wires and Displays • Immature Engineering Process • Platform Compatibility • Front-End Flexibility • Back-End Data Extraction, Management, Analysis, Visualization • Side Effects
Opportunities	**Threats**
• Emerging Tech 1: Processing Power and Graphics/ Video Integration • Emerging Tech 2: Devices and Wires • Emerging Tech 3: Real-Time Data Analysis and Intelligence • Gaming-Industry Drivers • VR Rehabilitation with Widespread Intuitive Appeal to the Public • Academic and Professional Acceptance • Close-Knit VR Rehabilitation Scientific and Clinical Community • Integration of VR with Physiological Monitoring and Brain Imaging • Telerehabilitation	• Too Few Cost/Benefit Proofs Could Impact VR Rehabilitation Adoption • Aftereffects Lawsuit Potential • Ethical Challenges • The Perception That VR Will Eliminate the Need for the Clinician • Limited Awareness/Unrealistic Expectations

Figure 1. *Summary of a SWOT analysis for VR rehabilitation and therapy.*

Rizzo & Kim, 2005

VR rehabilitation: key points

Initial results from pilot studies are highly encouraging, especially for **post-stroke chronic patients**, and provide insights on the effectiveness of VR-based motor rehabilitation, including:

- It provides a more advanced digital rehabilitation methods as an alternative to traditional therapy, thus maximizing the effect of rehabilitation measures
- Versatility: It allows patients with different neurological disorders to execute actions they are not able to perform in real-life due to their disabilities
- It can provide individualized treatment plans developed on the basis of careful assessment and following case-by-case treatment goals
- It enhances patient’s engagement and motivation with 3D virtual environments and video game-like tasks
- It provides immediate and illustrative feedback
- It improves outcomes through neurophysiological measurements and analysis
- It provides a controlled environment for telerehabilitation

Laver K.E., Lange B., George S., Deutsch J.E., Saposnik G., Crotty M. (2017) Virtual reality for stroke rehabilitation. Cochrane Database of Systematic Reviews. Issue 11

VR rehabilitation: key points

- Virtual reality (VR) might provide unique opportunities to improve understanding of the behavioural and neural underpinnings of gait and balance in people with **Parkinson disease**.
- VR environments can be manipulated in ways that are not possible and/or safe in the real world, with the potential to improve assessment and training of multisensory motor–cognitive integration.
- Non-immersive VR rehabilitation improves gait and balance when compared with no intervention but is not superior to non-VR rehabilitation of similar exercise type and dose.
- Future applications of VR should be tailored to deliver personalized interventions according to each person's profile of deficits and rehabilitation needs.
- Future developments of VR rehabilitation interventions require collaboration between therapists, technology experts and people with Parkinson disease to ensure optimal, engaging exercise that is acceptable for long-term use.
- Therapists should consider the conceptual framework, along with the pros and cons, when selecting VR paradigms to optimize training effects with carry-over into everyday activities.

Canning et al., Nature Reviews Neurology vol. 16, pp. 409–425 (2020)

Evidence

https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD010760.pub2/full#CD010760-sec1-0007

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Virtual reality for rehabilitation in Parkinson's disease

Kim Dockx, Esther MJ Bekkers, Veerle Van den Bergh, Pieter Ginis, Lynn Rochester, Jeffrey M Hausdorff, Anat Mirelman, Alice Nieuwboer   Authors' declarations of interest

Version published: 21 December 2016   Version history

https://doi.org/10.1002/14651858.CD010760.pub2

Collapse all   Expand all

Abstract

Available in English | Español

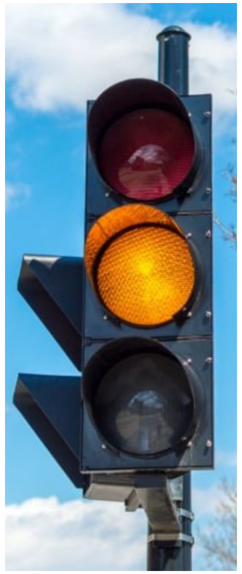
Plain language summary

Available in English | Deutsch | Español | Hrvatski | Polski | Русский

Virtual reality technology as a useful tool for rehabilitation in Parkinson's disease

Review question

The purpose of this review was to determine the effectiveness of virtual reality (VR) exercise interventions for rehabilitation in Parkinson's disease (PD). We aimed to investigate whether VR exercise resulted in greater improvements compared to 1) active control interventions, and 2) passive control interventions, on gait, balance, global motor function, activities of daily living, quality of life, cognition, exercise adherence, and the occurrence of adverse events.



Evidence

https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD010760.pub2/full#CD010760-sec1-0007

Key results

VR interventions may lead to greater improvements in step and stride length compared with physiotherapy interventions. We found limited evidence that improvements in gait, balance, and quality of life were similar to those found in active control interventions. No adverse events were reported. Fewer studies compared VR with passive control interventions, and evidence was insufficient to determine how VR compares with no active intervention. At present, only a few studies have been done, making generalisation of the findings difficult. Further study is needed to confirm and expand the evidence base for VR in PD.

Quality of the evidence

In general, the quality of the evidence was low or very low. This was the result of small sample sizes and a large amount of heterogeneity between trials with regard to study design and outcome measures used.

Authors' conclusions

Implications for practice

Although the results were inconclusive, low-quality evidence indicated that virtual reality (VR)-training was at least as effective as conventional physiotherapy. Whether these improvements were relevant and reached the minimal important difference for gait, balance, and other secondary outcome measures is not clear from this review. Further study is needed before full integration of VR-based exercise into physiotherapy programs for people with Parkinson's disease can be considered.

Implications for research

Additional high-quality studies are needed to provide a deeper insight into the potentially beneficial mechanisms of VR technology and to reveal the differential effects of various VR applications. Future research should standardise the outcome measures and realise adequate follow-up of at least 12 weeks (preferably 12 months) to examine the long-term effects of VR.

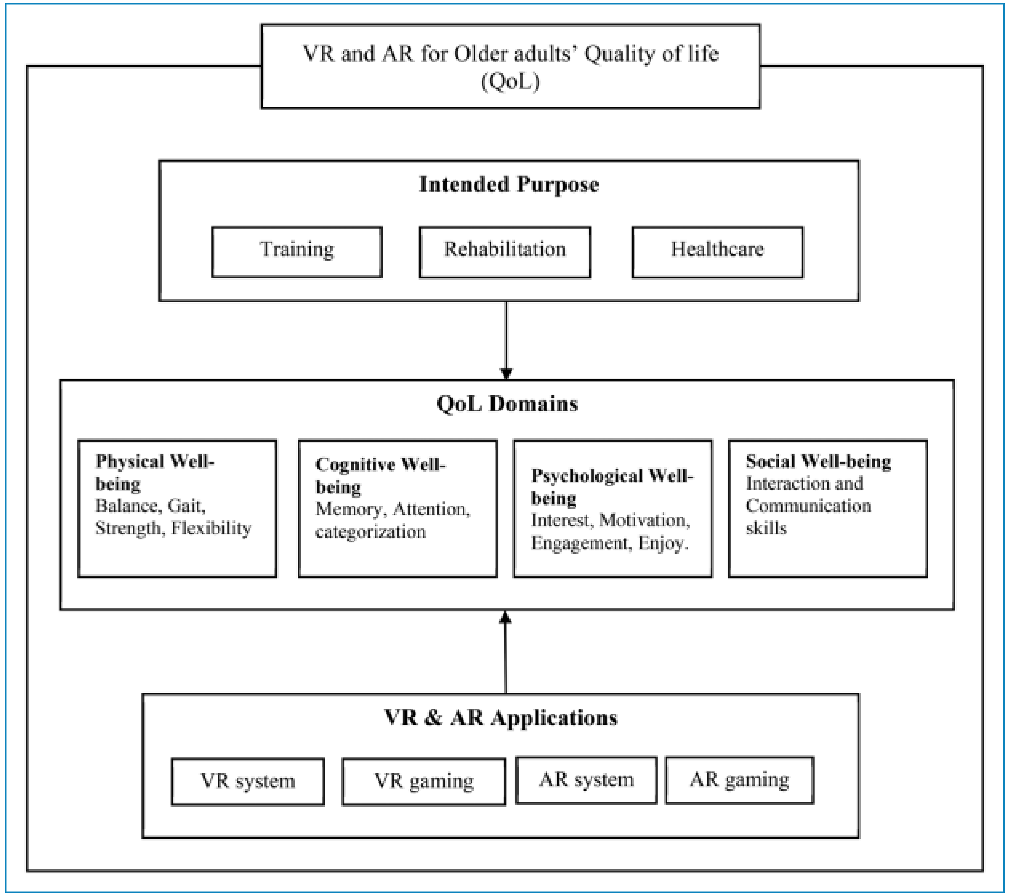
Furthermore, the examination of VR interventions in different disease stages is recommended to ascertain whether there is a role for technology-based exercise in the prevention of physical deterioration in early-stage Parkinson's disease and in the management of disease progression in the moderate to late stages. Finally, empirical evidence is required to provide well-substantiated recommendations regarding frequency, duration, and content of the VR intervention.

VR for older adults

Technologies such as virtual reality (VR) and augmented reality (AR) have the potential to assist older adults in overcoming their challenges and limitations by allowing them to monitor and maintain their health and, ultimately, improve their Quality of Life (QoL).
Recent research of VR and AR applications for older adults has increased significantly, with positive results across multiple QoL domains. These technologies can effectively benefit and assist older adults in improving their QoL domains of daily living (e.g., see Vázquez et al., Efficacy of video game-based interventions for active aging. A systematic literature review and meta-analysis. PLoS One 2018; Silva et al., Virtual reality for older users: A systematic literature review. Int J Virtual Real 2019).
Many studies of older adults have addressed the potential of VR and AR applications to improve their physical and cognitive activities, enhance their social support, engage them in activities, motivate them in training programs, and generally improve their overall QoL.

Baragash RS, Aldowah H, Ghazal S. Virtual and augmented reality applications to improve older adults' quality of life: A systematic mapping review and future directions. Digit Health. 2022

VR for older adults

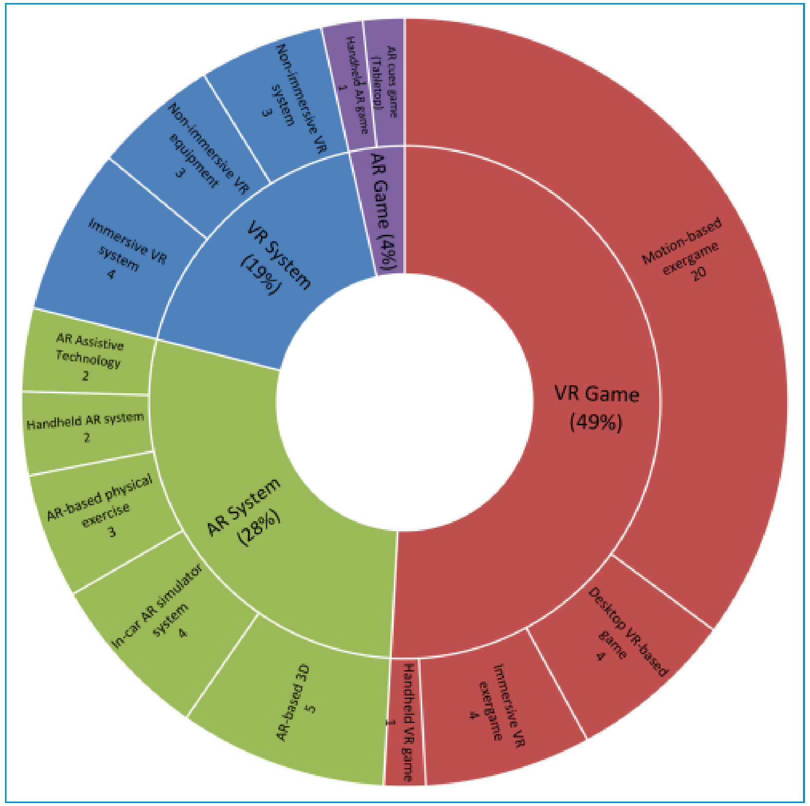


Virtual reality (VR) and augmented reality (AR) applications framework for older adults' quality of life (QoL)

Baragash RS, Aldowah H, Ghazal S. Virtual and augmented reality applications to improve older adults' quality of life: A systematic mapping review and future directions. Digit Health. 2022

VR for older adults

AR and VR types used to support the QoL of older adults



Category	Clarification	Types	Clarification
VR system	The studies using simulation or a non-gaming system that integrates multiple components, including system hardware, support software, virtual world content, and user interface, all of which provide a suitable means for appropriate user interactions.[77–79]	Immersive VR system	High immersive VR HMD or CAVE is used
		Non-immersive VR system	The interaction is by means of a traditional graphic workstation with a monitor display, keyboard, and mouse
		Non-immersive VR-based equipment	VR shown on the computer screen is a component added to equipment, such as treadmill or bicycle
VR game	The studies applying games where the user navigates a virtual world through an avatar controlled by a mouse and a keyboard and/ or a joystick in a 3D artificial environment and exploit the 3D stereoscopic display using HMD or wearable sensors.[79]	Immersive VR exergame	Games are played using high immersive VR HMD
		Motion-based exergame	Exercise through playing video game using consoles, such as Xbox, PlayStation, and Nintendo Wii, or with devices such as motion detection sensors or sensitive tools
		Desktop VR-based game (non-immersive)	Games are played using monitor display, keyboard, and mouse
		Handheld VR game	VR games are played using mobile or tablet
AR system	The studies using an interactive non-gaming system that combines real and virtual worlds with 3D virtual and real objects.[79,80]	AR-based 3D system	AR platform combined with a tangible manual controller to allow users to rotate a virtual 3D model
		In-car AR simulator system	Create an outdoor driving simulator that allows a real-world view
		AR assistive technology	AR in the support living system, such as a robotic platform
		AR-based physical exercise	Integrates AR with a physical training system, such as Otago physical exercise
		Handheld AR system	VR mobile or tablet system is used
AR game	The studies employing real-time integration of visual and audio content from games with the user's environment.[54]	Tabletop-based AR game	Integrates AR element to tabletop touchscreen board games
		Handheld AR game	Playing AR games using mobile or tablet

AR: augmented reality; CAVE: cave automatic virtual environment; HMD: head-mounted display; QoL: quality of life; VR: virtual reality.

Baragash RS, Aldowah H, Ghazal S. Virtual and augmented reality applications to improve older adults' quality of life: A systematic mapping review and future directions. Digit Health. 2022

Readings

- **Understanding Virtual Reality: Interface, Application, and Design** (The Morgan Kaufmann Series in Computer Graphics) 2nd Edition by William R. Sherman (Author), Alan B. Craig (Author) Series: The Morgan Kaufmann Series in Computer Graphics Hardcover: 938 pages Publisher: Morgan Kaufmann; 2 edition (December 17, 2018) ISBN-10: 0128009659 ISBN-13: 978-0128009659