Selected Topics Communications and Mobile Computing (Smart Health)

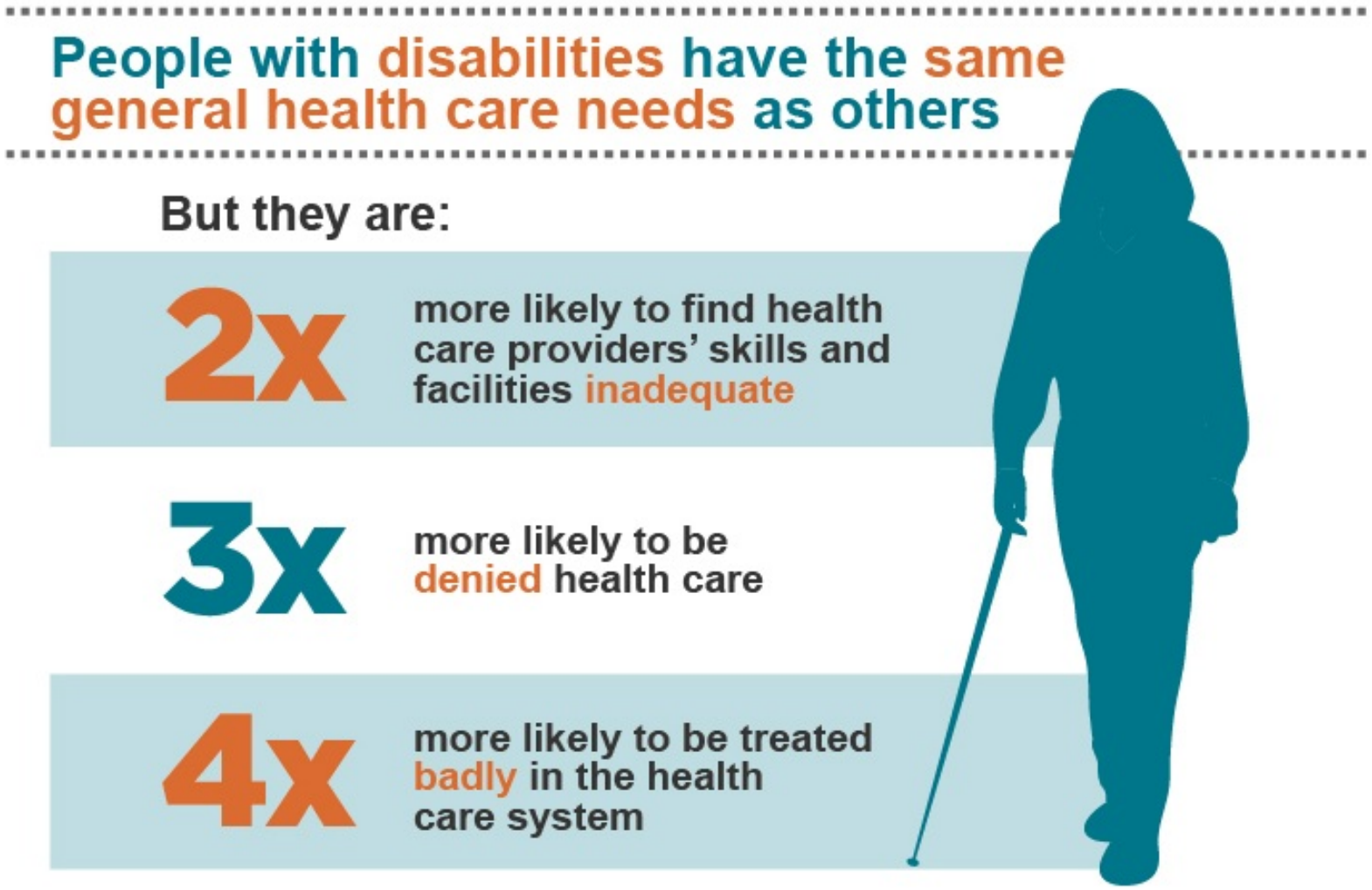
TU Graz

University of Notre Dame

Disabilities

- Around 150 million adults experience **significant** difficulties functioning.
- Disability prevalence is increasing.
- Disproportionately affects vulnerable populations: women, older people, and poor households.

Barriers to Healthcare



Barriers to Healthcare

1/2

of people with disabilities cannot afford health care

They are:

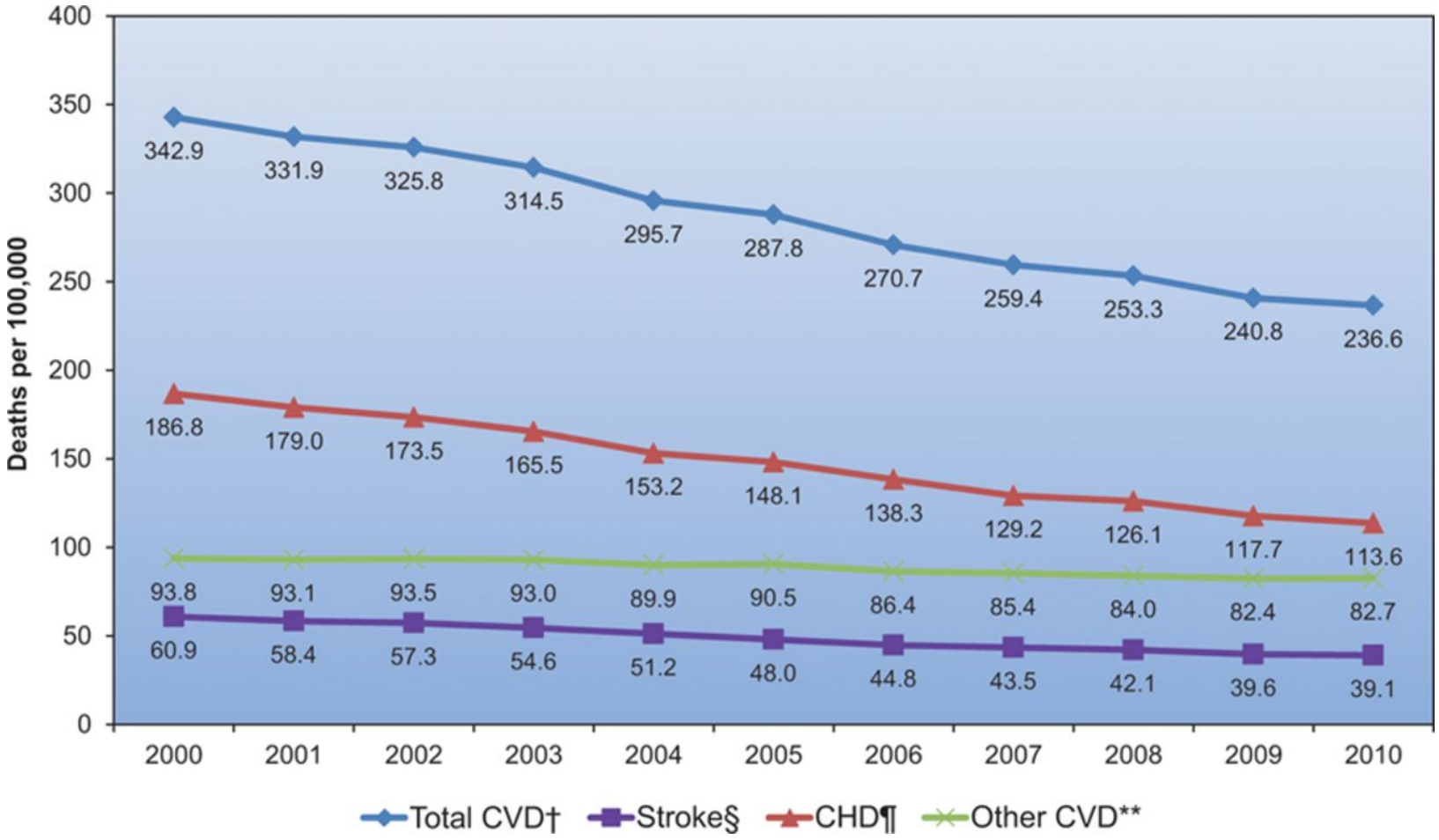
50%

more likely to suffer catastrophic health expenditure

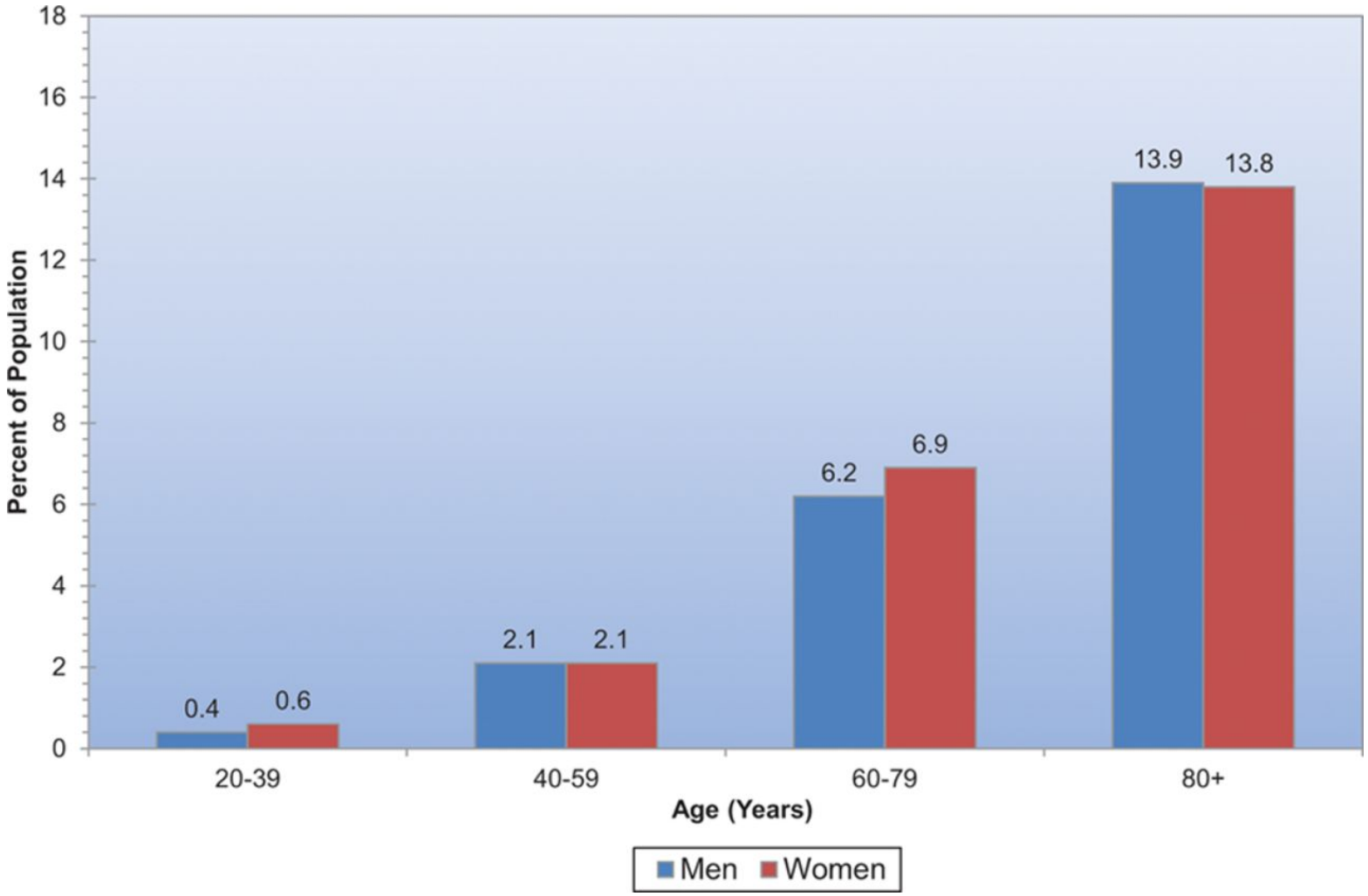
Stroke

- ~795,000 (U.S.) & ~1.1 million (Europe) new or recurrent strokes/year
  - 87% ischemic (arteries to your brain become narrowed or blocked)
  - 10% ICH (intracerebral hemorrhage; bleeding within the brain tissue itself)
  - 3% SAH (subarachnoid hemorrhage; blood vessel just outside the brain ruptures)
- 1 stroke every 40 seconds in US
- 1 death from stroke every 4 minutes in US
- 4^{th} leading cause of death in US
- Decline in stroke mortality

U.S. Age-Standardized Death Rates



Prevalence by Age and Sex



Impact on Brain

	Neurons Lost	Synapses Lost	Accelerated Aging
Per Stroke	1.2 billion	8.3 trillion	36 yrs
Per Minute	1.9 million	14 billion	3.1 wks
Per Hour	120 million	830 billion	3.6 yrs

Risk Factors

1. History of high blood pressure
2. Current smoking
3. Abdominal obesity
4. Diabetes
5. Lack of physical exercise
6. Poor diet (fat, sugar)
7. More than 30 alcoholic drinks a month or binge drinking
8. Ratio of blood fats known as “Apo B/A1”
9. Heart disease
10. Psychosocial stress/depression

Stroke Survivors

- 2/3 of stroke patients survive and require rehabilitation.
- There are over 26 million stroke survivors alive today worldwide. It is estimated that 15-30% of these live with severe disabilities.

Modified Rankin Score

- 0 = No symptoms at all
- 1 = No significant disability despite symptoms: able to carry out all usual duties and activities
- 2 = Slight disability: unable to carry out all previous activities but able to look after own affairs without assistance
- 3 = Moderate disability: requiring some help, but able to walk without assistance
- 4 = Moderately severe disability: unable to walk without assistance and unable to attend to own bodily needs without assistance
- 5 = Severe disability: bedridden, incontinent, and requiring constant nursing care and attention
- 6 = Patient death

Rehabilitation Assessment

- Every stroke patient should be assessed for rehabilitation potential. Stroke rehabilitation should begin as soon as the diagnosis of stroke is established and life threatening problems are under control.

Requirements for Good Rehabilitation Tasks

1. Grounded in data-based assessment to specify the **target activity** to be precisely rehabilitated.
2. Adjustable in terms of **difficulty level** from something that is possible for the user to perform, to a level representing the desired end-goal performance.
3. Capable of **repetitive and hierarchical administration** to the user.
4. Capable of providing the user with **strategic feedback** as to the outcome of performance.
5. **Quantifiable** in order to measure performance and progress.
6. Relevant to real world ecologically **relevant** functional activity.
7. Capable of **motivating** user engagement and interaction with the task.

Traditional Stroke Rehabilitation

- Patients practice motor skills and compensatory strategies for daily living activities
  - Within a clinical setting
- Skills gained in a clinical environment
  - Generalize to the patients' home environments
- Labor intensive
- Limited in intensity and duration of repetition
- Carryover outside of the rehabilitation setting is uncertain

Virtual Reality

Can Virtual Reality Change Your Mind?
Thong Nguyen; TEDx Minneapolis

https://www.youtube.com/watch?v=eFHj8OVC1_s

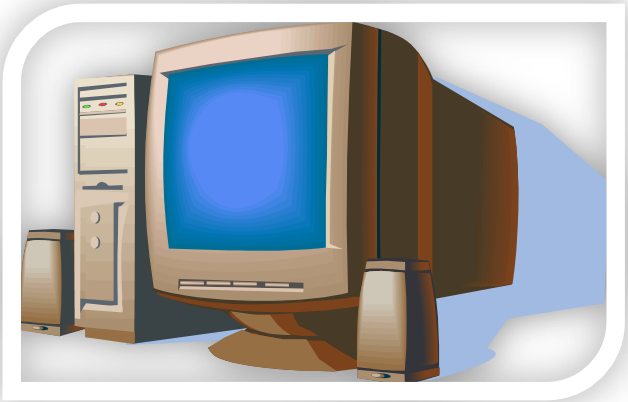
Definition & Types

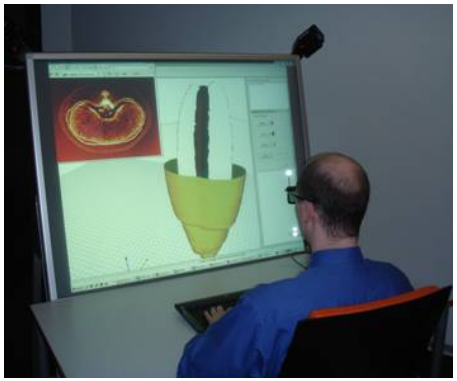
- A computer generated simulation that enables people to interact with visual and sensory three-dimensional objects or environments through the use of computer modeling.

- Desktop VR
  - Used widely, mostly for entertainment
  - Low-cost
- Immersive VR
  - Used in industry mainly
  - Expensive

Desktop VR

- Everyday computers, laptops, phones
- Gaming consoles
- Non-immersive environments
- Common associated inputs:
  - computer mice, keyboards, and game controllers





Immersive VR

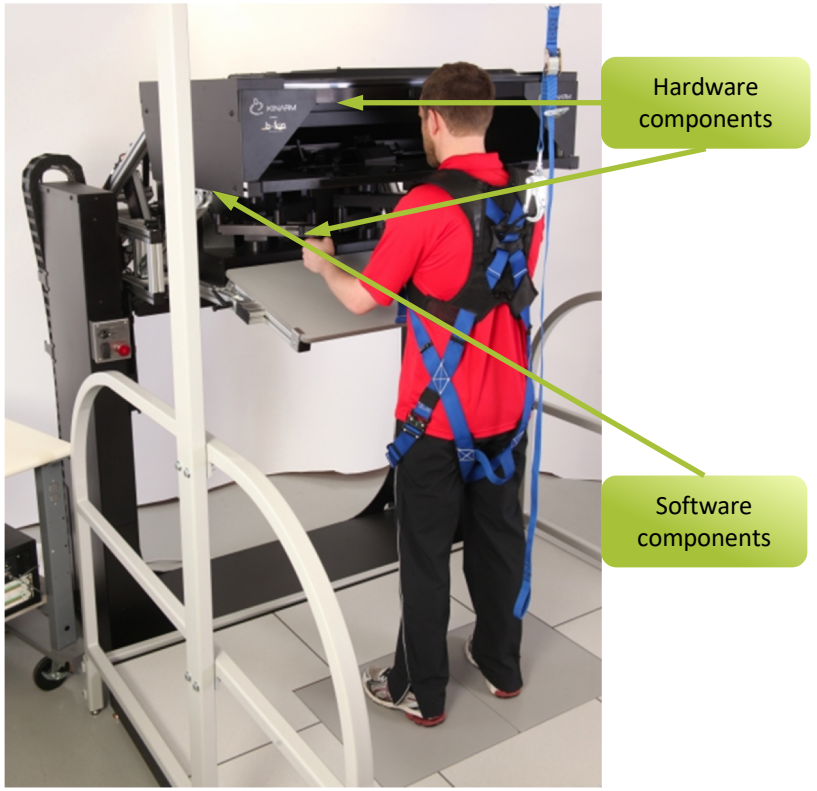
- Presentation of an artificial environment that replaces a user's real-world surroundings
- Complex system of software and hardware
- Realistic Experience
- User immersion in environment
- Easily amount to hundreds of thousands of dollars for professional applications

Virtual Reality

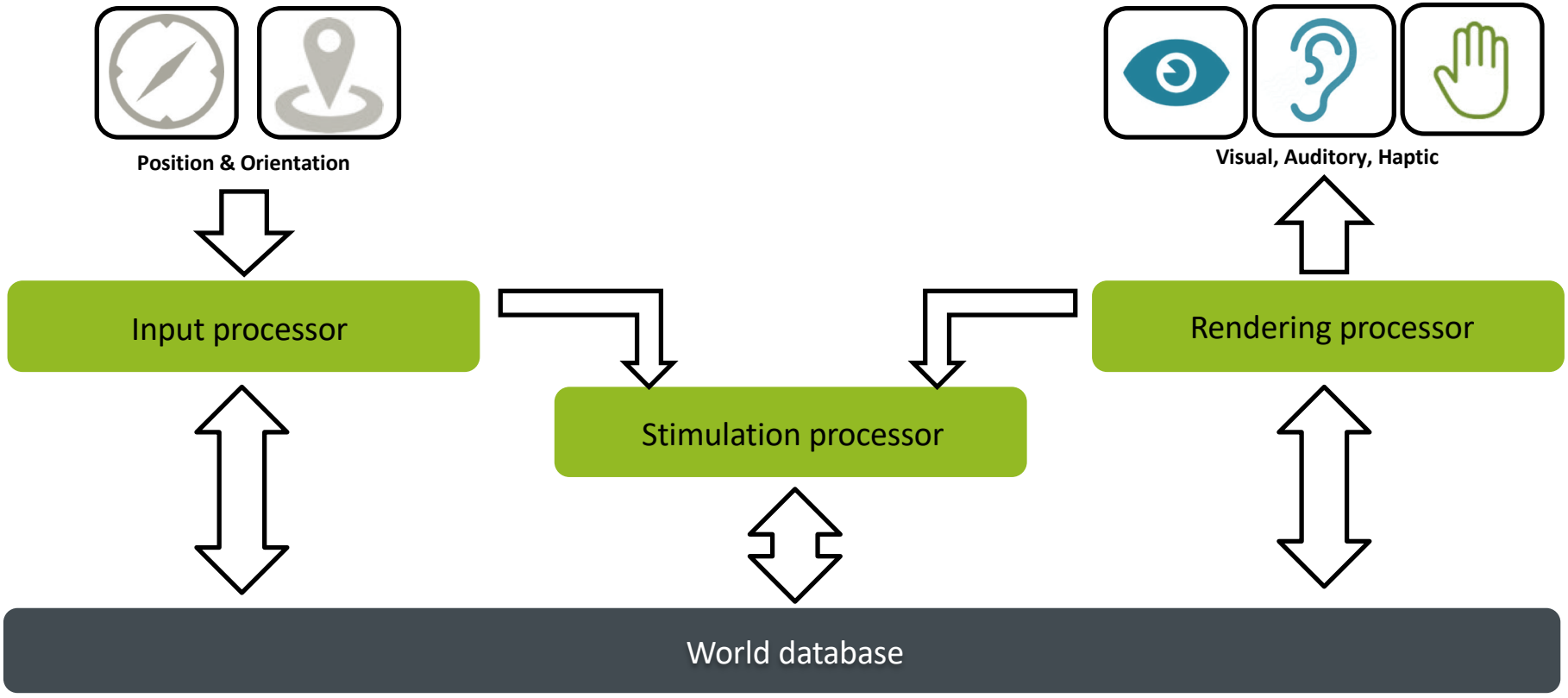
- High interest in technology in 1980s, 1990s (consumer PC era), but technology not advanced sufficiently
- Became (expensive) niche technology (soldier training, pilots, doctors, …)
- Over last decade, knowledge & technology reached point needed for effective VR (CPU, memory, graphics, 3D, materials and screens, software, understanding of brain and senses, …)

VR Example

- HW components
  - Primary user inputs
  - Tracking interface
  - Visual, auditory, haptic interfaces
- SW components
  - Input process
  - Simulation process
  - Rendering process
  - World database

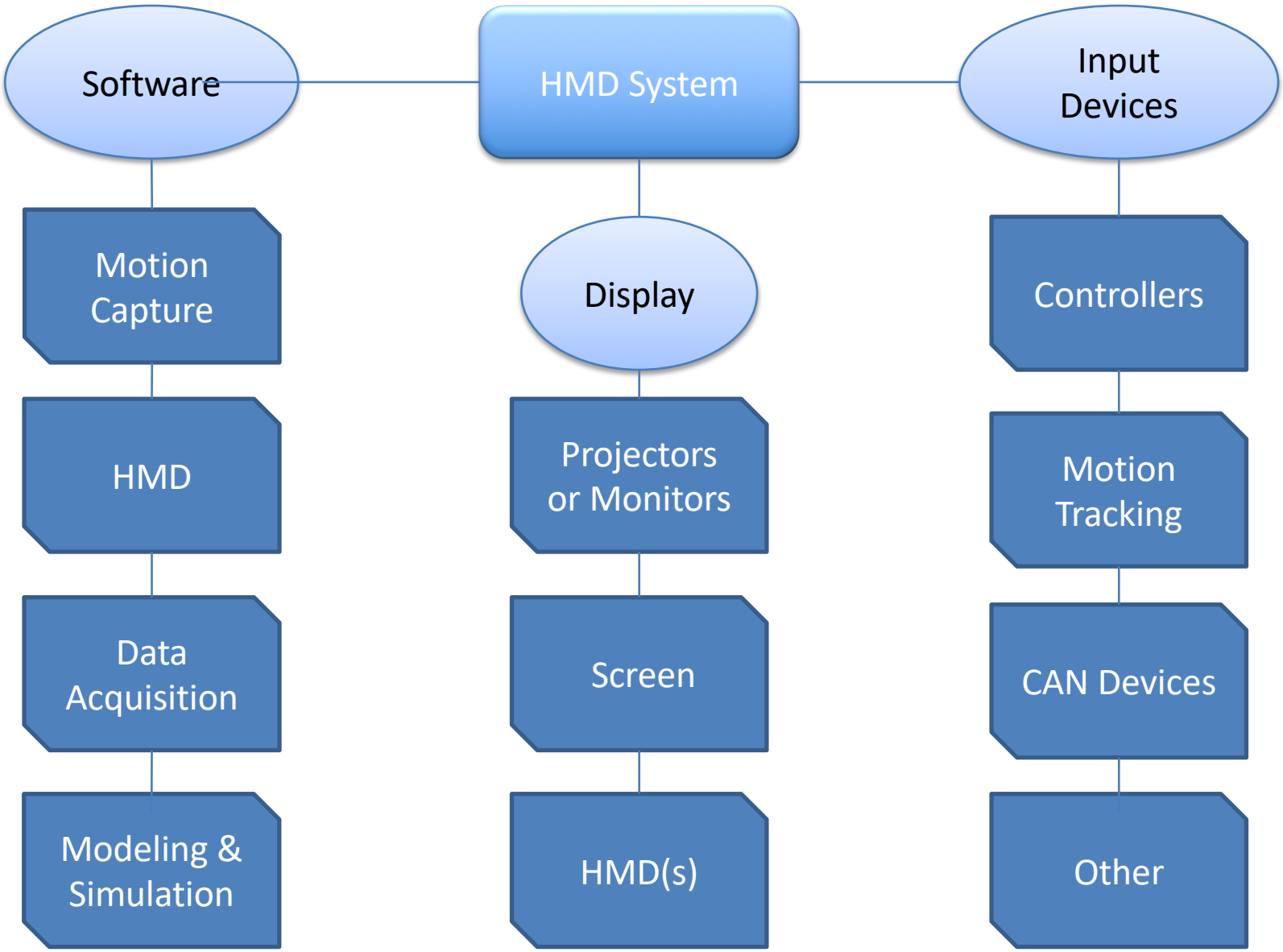


SW Architecture



Virtual Reality: Devices

	Immersive	Non-Immersive		
		Total-body movement		**Non total-body movement**
		Motion capture via camera/video	Motion capture via sensor device	Interaction via keyboard, mouse, joystick
	Rehabilitation specific	Rehabilitation specific Commercially available	Rehabilitation specific Commercially available	Rehabilitation specific Commercially available
	Head mounted display Force feedback gloves	Camera detects users' body movements	Motion sensors detect movement of device (remote control, glove) or user movement on/in device (platform, robot)	Mouse, joystick or keyboard
	Fully immersed; first person view	Mirror-image reflection	Represented as an avatar or user invisible; 1st person or 3rd person view	Represented as an avatar or user invisible; 1st person or 3rd person view


Software
HMD System
Input Devices
Motion Capture
HMD
Data Acquisition
Modeling & Simulation
Display
Projectors or Monitors
Screen
HMD(s)
Controllers
Motion Tracking
CAN Devices
Other

Head-Mounted Device (HMD)

- Takes over your vision; field of view limited
- Displays the virtual environment and objects to the user
- Quality/price range from high-end (PC VR) to low-end (mobile VR)

Example: Oculus Rift

- Created by Palmer Luckey
  - 2012: Kickstarter project ($2.4M)
  - 2014: Bought by Facebook
  - 2016: First release (Rift)
  - 2019: Second release (Rift S)

Samsung Gear VR

Baofeng Mojing III

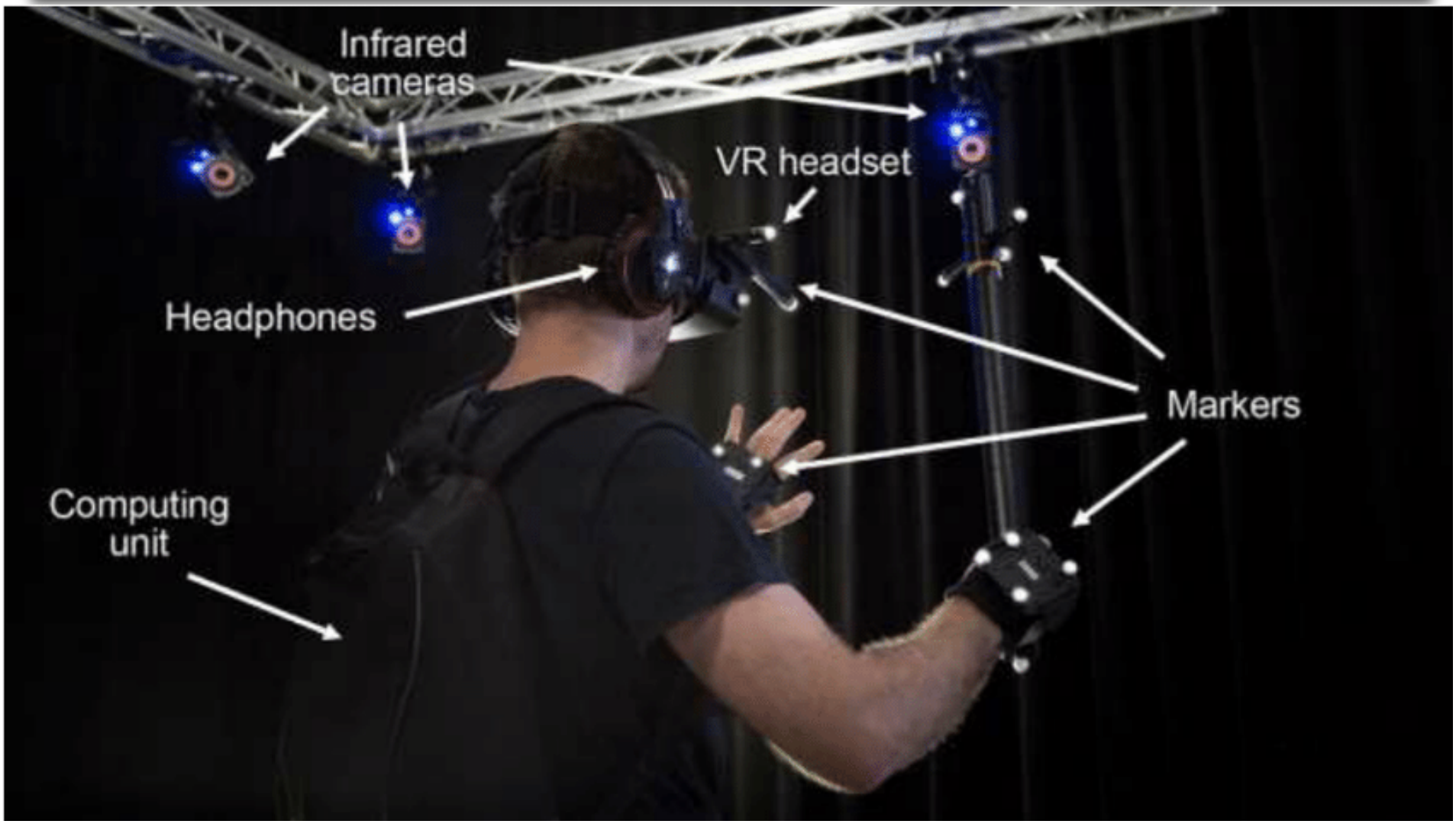
Motion Capture Systems

- Optical
  - Cameras
- Magnetic
  - Sensors
- Electro mechanical
  - Sensor suits

Optical Motion Capture

- Uses cameras to track markers in a tracking volume
- Tracking data is streamed into VR system
- Vicon Bonita

Optical System

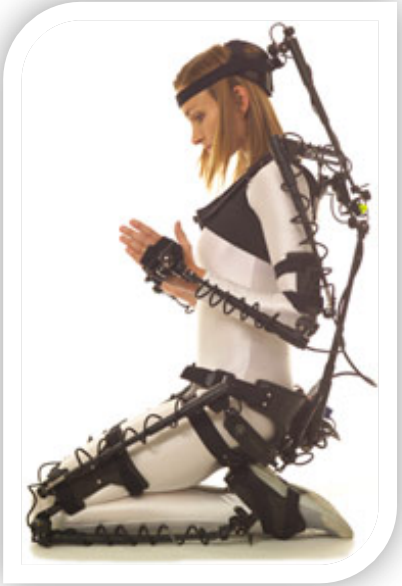


Magnetic Motion Capture

- Uses magnetic sensors to gather data
- Metal can interfere with the sensor readings

Electro-Mechanical Motion Capture

- Uses a suit of sensors to track the wearers motion
- High portability
- Some designs are motion restricting



VR Safety

- Oculus: not safe for children under 13; parents should monitor children
- People (about 1 in 4000) may experience severe dizziness, seizures, or blackouts triggered by light flashes or patterns
- Physical hazards in environment; do not walk or walk carefully
- “Ease into use”; let body adjust to experience
- Take breaks at least every 30 minutes
- Some symptoms (motion sickness) can appear hours after use (careful driving, operating machinery, etc.)
- Oculus: 7 out 14 pages in manual are about safety

Industry Applications

- Manufacturing and Product Development
- Education and Training
- Healthcare Industry
  - Pain
  - Therapy
- Entertainment
  - Gaming
  - Movies

Manufacturing Product Design

- Companies such as John Deere, BMW, and Ford use VR in their product design
- Reduced cost
  - Fewer physical prototypes
  - Faster concept analyzing
  - More evaluations
  - Fewer defects
- Used to check ISO visibility standards

Education and Training

- Simulations for operator training
  - Operator can make mistakes in VR
  - Use real controls
- Helps demonstrate proper methods
  - Assembly technique
  - Repairs
  - Maintenance
- Allows anyone to familiarize themselves with machines in the field

Entertainment

- Movie production
  - Animated films
  - CGI
- Gaming
  - Animations
  - PlayStation Move
  - Xbox Kinect
  - Wii

Healthcare

- Diplopia (Lazy Eye): https://youtu.be/HJ4AtzQaGiw
- SnowWorld: https://www.youtube.com/watch?v=jNlqyyypojg
- Surgical Training: https://www.youtube.com/watch?v=4FG7ML0LrCc

VR in Healthcare

- Recent advancements in VR have led to increasingly cost-effective and innovative VR applications
  - Including more options for use in therapeutic VR
- Emergence of VR systems as part of the resources available within common therapy gyms
  - Therapy-focused virtual reality, directed in and out of the therapy gym
- VR becoming a more accessible and soon to be complementary part of our lives

VR in Healthcare

1. Higher motivation
2. Active participation
3. Supporting motor learning
4. Fun and risk free environment

Assessments with VR

- Simulates real-world complexities
- Continuous analysis
- Deeper insights

w679wf: Session Details

12/7/2016 10:04 AM

Session duration: 0:53:08

Activity Name	Start Time	Activity Duration	Reaches	Coins	Badge	Subtask Completion Time	Peak Hand Speed	Normalized Speed	MAPR	Motor Difficulty	Cognitive Difficulty
OrganizingCloset 1	12/7/2016 10:06:57 AM	0:06:08	32	480		11.0 s	0.65 m/s	0.38	0.52	Hard	Hard
SoupKitchenVolunteering 1	12/7/2016 10:18:09 AM	0:08:43	43	670		22.5 s	0.70 m/s	0.32	0.40	Hard	Hard
OrganizingCloset 2	12/7/2016 10:27:19 AM	0:04:37	32	470		11.8 s	0.63 m/s	0.37	0.51	Hard	Hard
SoupKitchenVolunteering 2	12/7/2016 10:33:23 AM	0:07:21	43	624		17.1 s	0.58 m/s	0.34	0.44	Hard	Hard
GroceryShopping 1	12/7/2016 10:42:08 AM	0:15:13	30	260		6.4 s	0.76 m/s	0.36	0.43	Hard	Hard
Total		0:42:02	180	2504		12.9 s	0.66 m/s	0.36	0.48		

Benefits of VR-Based Rehabilitation

- Getting physical therapy is difficult
  - Too costly
  - Travelling difficulties for stroke patients
  - Not enough providers
- Repetition
  - Greater repetition in a VR activity than a traditional therapy session
- Engagement
  - Games are fun and entertaining
- Meaning
  - Personalized ADL tasks

Activities of Daily Living (ADL)

- “Activities of Daily Living (ADL)” is used in rehabilitation as an umbrella term relating to self care, comprising those activities or tasks that people undertake routinely in their every day life.

- **Basic ADL (BADL):** typically restricted to activities involving functional mobility and personal care.

- **Instrumental ADL (IADL):** instrumental activities of daily living functions are concerned with a person's ability to cope with her/his environment (domestic and community activities).

Activities of Daily Living (ADL): Basic

- Feeding: handling utensils/cups, chewing & swallowing
- Grooming: oral care, washing, shaving
- Dressing: retrieving clothing, dressing/undressing, shoes/socks, prosthesis/orthosis
- Bathing: washing/drying, managing clothes
- Toileting: hygiene

Activities of Daily Living (ADL): Mobility

- Bed mobility
- Wheelchair mobility
- Transfers (from one surface to another)
- Ambulation

Activities of Daily Living (ADL): Communication

- Reading/writing
- Using the telephone and other communication devices
- Using the computer/tablet

Instrumental ADLs

- Home management (cooking, cleaning)
- Community living skills (money management, shopping, public transport)
- Health management (medications, knowing health risks, making appointments)
- Safety management (identifying dangerous situations, calling emergency numbers)

Saebo VR

https://www.youtube.com/watch?v=gUErCHMxMTA&t=67s

Saebo VR

- Virtual activities of daily living (ADL) rehabilitation system.
- Physical and cognitive ADL challenges and games.
- Uses Kinect camera to detect motion and register body positioning.
- Works with SaeboMas and SaeboGlove
- Patients engaged in the Saebo VR therapy demonstrated improvement on Fugl-Meyer measures (stroke-specific, performance-based impairment index)

Saebo VR

ADL Tasks and Games

Shopping

Meal Prep

Pet Care

Gardening

Jintronix

https://jintronix.vids.io/videos/4c9ad9b61016e3c3c4/jintronix-demo-video

Jintronix

- Utilizes Microsoft Kinect camera for continuous ROM (Range of Motion) assessment
- Therapist designed games
- Studies demonstrating:
  - Positive user experience
  - Improvements in post-stroke function
  - Improvements in strength and ROM for other non-stroke patients

Microsoft Kinect

- Microsoft/Xbox Kinect sensor used in Saebo and Jintronix systems.
- In-house applications can also be developed using open-source platforms, such as NeuroVR
- https://www.youtube.com/watch?v=jJglCYFiodI

Cost Comparison

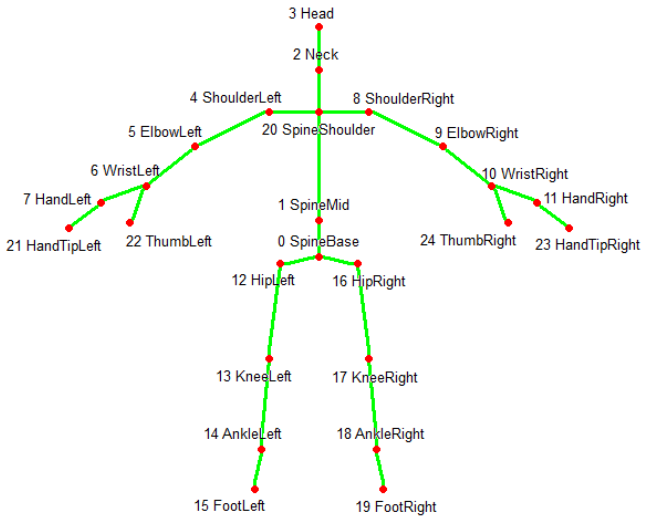
	Saebo VR	Jintronix	Xbox Kinect
Cost	$10,000 startup fee	$425 per month	$369 for system plus cost of additional games
Benefits	- Therapy-focused VR tasks - Highly regarded system for teaching ADLs and incorporating other Saebo products (SaeboMAS)	- Therapist Designed Games - Healthcare providers can monitor progress from a distance. - New games added regularly targeting cognition and physical rehabilitation.	- Inexpensive - Therapy with games can be performed at home - Readily available for purchase
Drawbacks	- Expensive - May not be cost-effective for patient-home use	- Design setup in patient's home may not be feasible	- Games are not intended for therapy environment - No specific assessment tools

Technical Challenges

- Data pre-processing:
  - Limited sensor spatial resolution; movement may be due to jitter and sensor limitations.
    - 30 frames per second; use sliding time window to average snapshots
  - Erroneous snapshots:
    - Within a time window, remove snapshot if the distance of it to the averaged snapshot > $\mu+3\sigma$ (anomaly filtering)
- Contextual filtering:
  - Gesture segmentation: different gestures; want to analyze movements dynamically during each "gesture period"
    - Concatenate continuous snapshots of the same gesture with temporal gaps smaller than a certain threshold

Technical Challenges

- Contextual filtering:
  - Region segmentation: different regions with different difficulties and intensities
    - Use skeleton data and “segment out” based on that

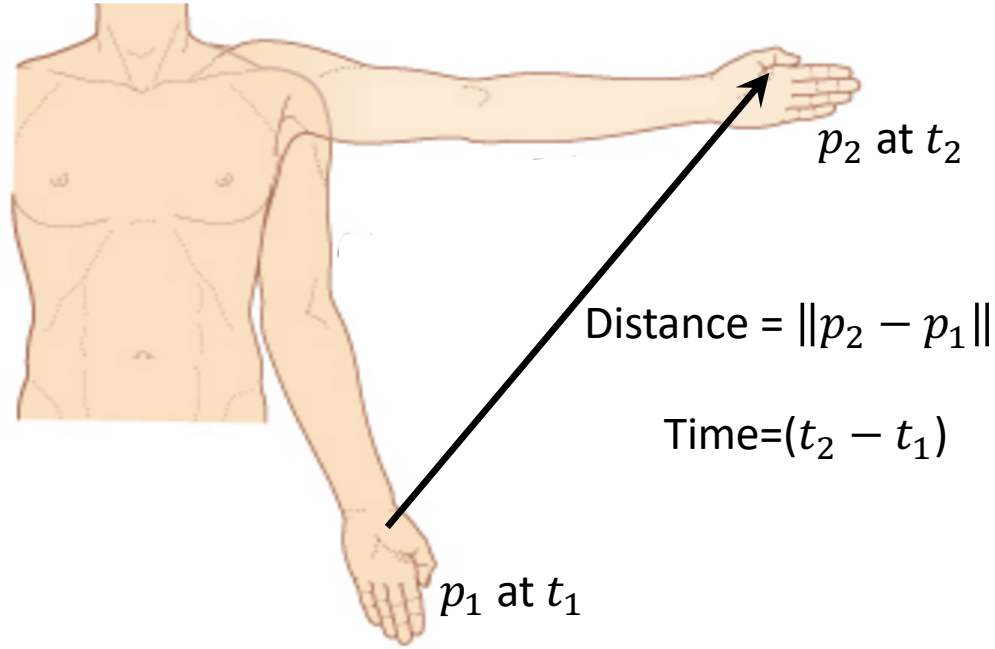


Note: The Kinect treats joints as though you were looking in a mirror. So the "left side" body joints appear on the left in the diagram and the "right side" joints appear on the right.

Rehabilitation Analysis

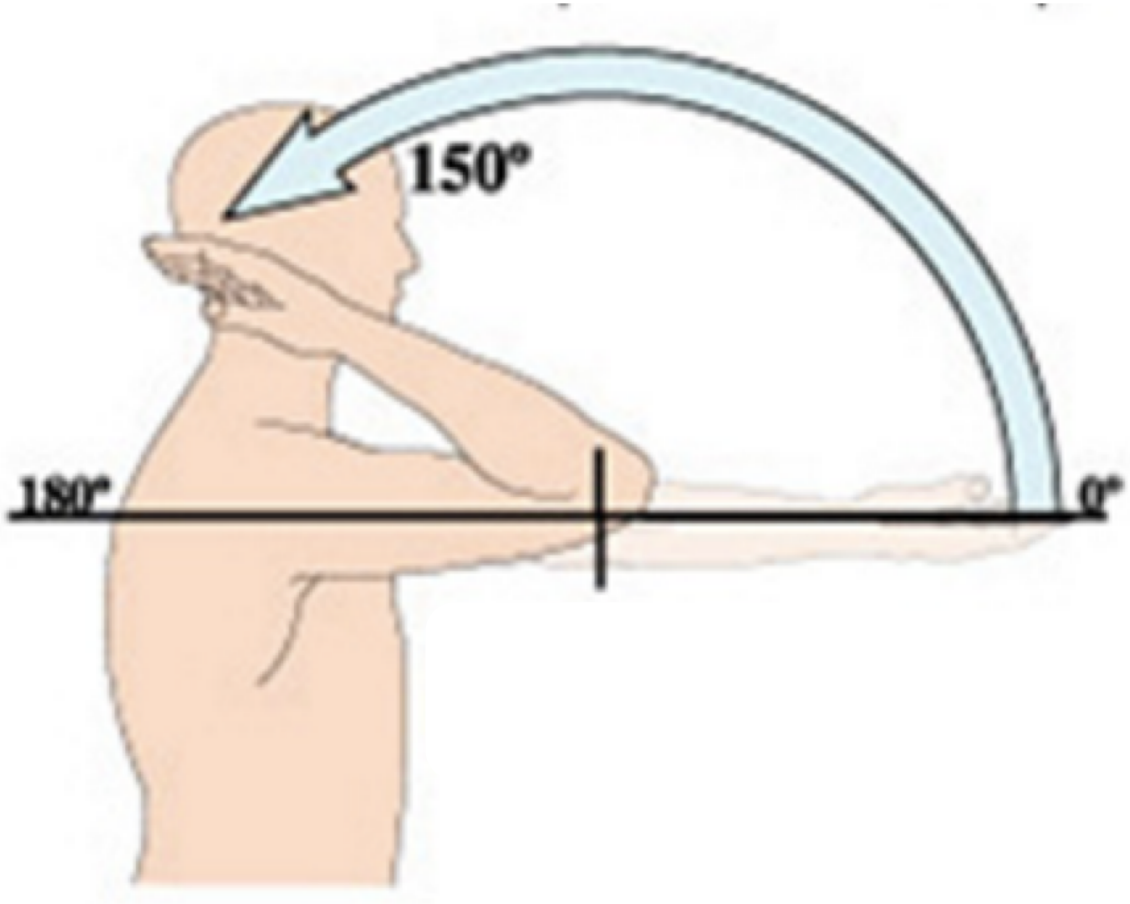
- **Hand speed**: movement speed of hand.

$$v_d = \frac{\sum_{i=2}^{n} \|p_i - p_{i-1}\|}{\sum_{i=2}^{n} (t_i - t_{i-1})}$$



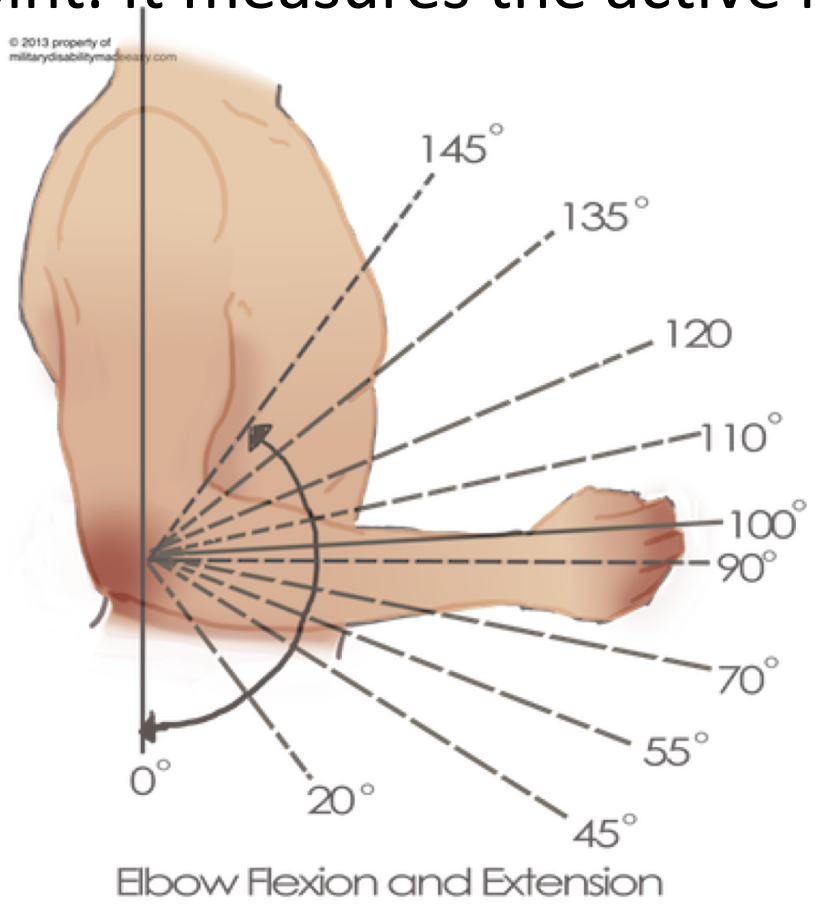
Rehabilitation Analysis

- **Angle speed**: similar to movement speed, but on angle.



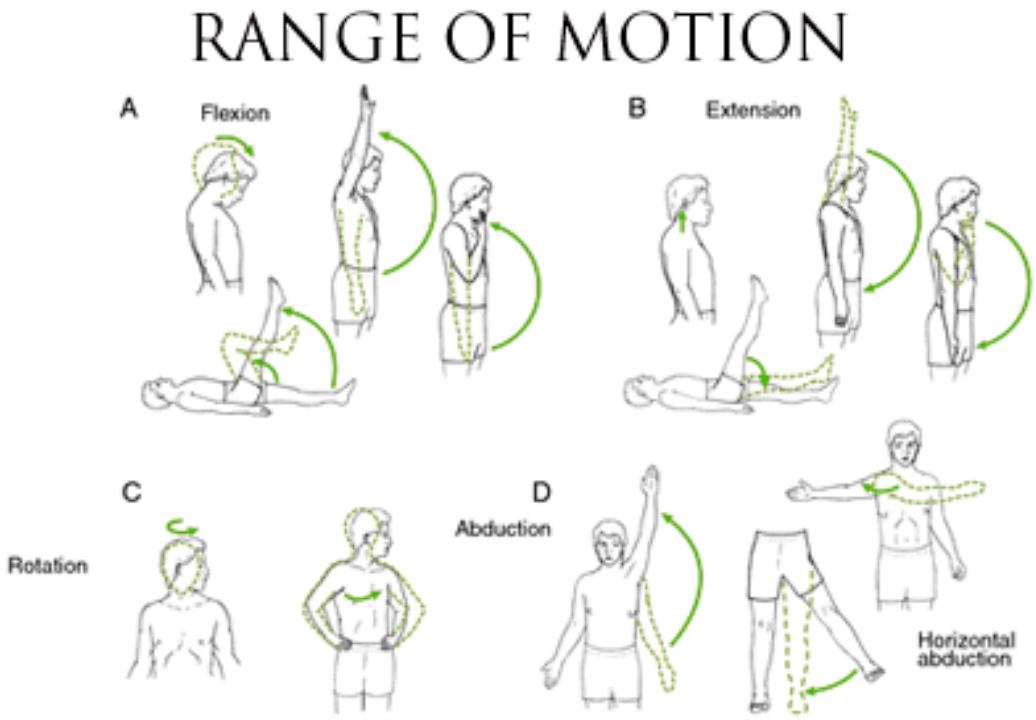
Rehabilitation Analysis

- **<u>Range of Motion</u>**: difference between min and max angles of a body joint. It measures the active range.



Range of Motion

- Full movement potential of a joint.

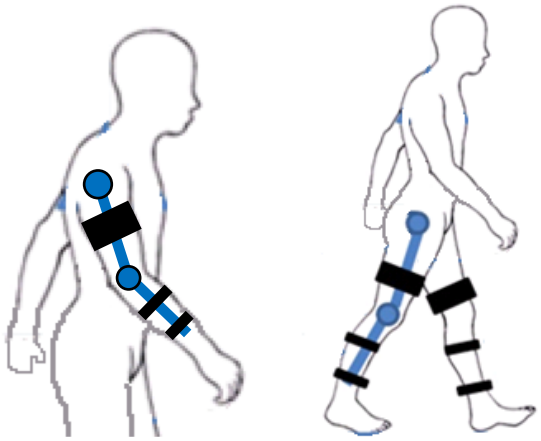


Example

See full video at **https://youtu.be/G5MyBNvNEfg**

Exoskeleton

- Attached to body or body parts
- Joints transmit forces to different robotic segments
- Allows production of physiological movements
- Combination with treadmills, body-weight-support, functional electrical stimulation, virtual reality



Strength enhancement
Haptic functions
Motor rehabilitation

Exosuit Technology

- Wearable robot
- Patients with spinal cord injury, traumatic brain injury, stroke, multiple sclerosis, …
- Replaces reciprocating gait orthosis
- Ambulation helps nearly every aspect of life
- Primarily used indoors, research projects, etc. (e.g., short battery life)

Exosuit

RGO

Exosuit Technology

- Ekso Suit:
  - https://www.youtube.com/watch?v=65LntzuX8f8
- Harvard Lab:
  - https://www.youtube.com/watch?v=YuksGLVhrZY
- Limitations:
  - Heavy, with limited torque and power
  - Cost
  - Discomfort of wearing

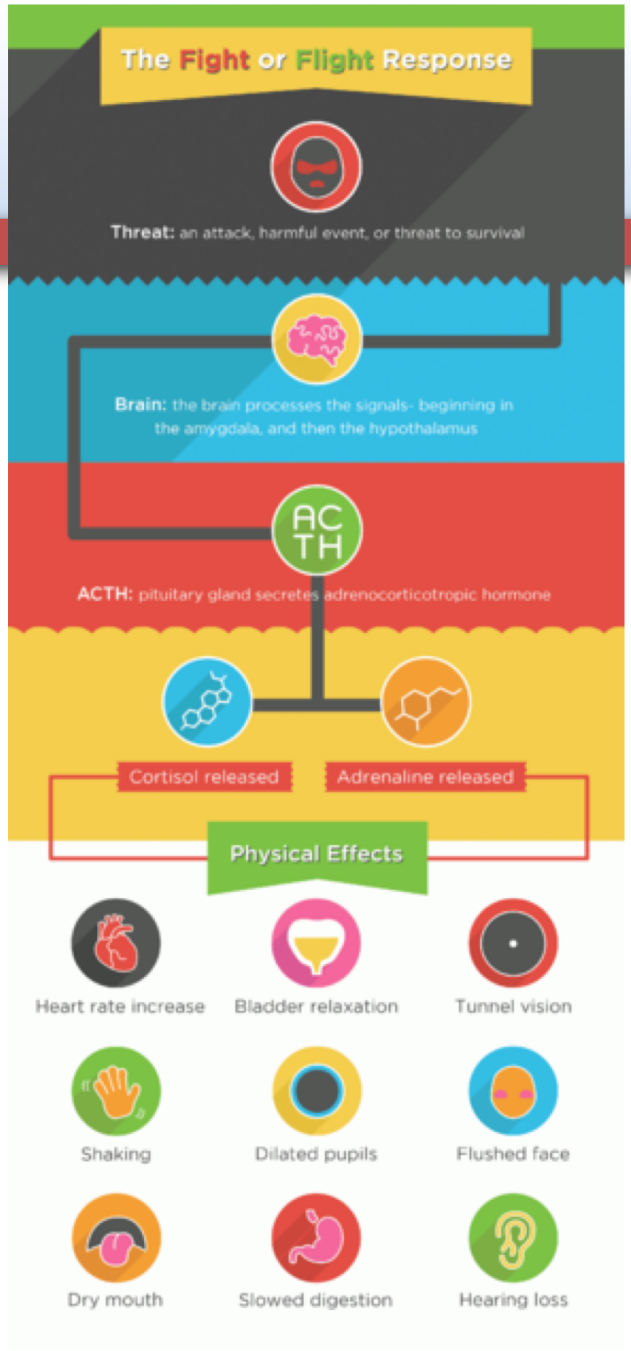
VR for Anxiety Disorders

- Anxiety Disorders (AD) are most common psychiatric disorders (14.6% of general population)
- Consume many healthcare resources (emergency services and other medical services)
- High comorbidity with other psychiatric disorders (affective disorders, substance abuse, personality disorders) as well as physical problems (migraines, muscular tension, irritable bowel syndrome, etc.) and this worsens prognosis
- Affect quality of life (QoL)
- Phobias are most common anxiety disorders

Phobias

- Disproportionate or irrational fear, triggered by the presence or anticipation of a specific object or situation (flying, heights, enclosed spaces, injections, animals, …)
- Exposure to phobic stimulus provokes an immediate anxiety
- Person recognizes that fear is irrational or disproportionate, but usually avoids the situation or faces it with high anticipatory anxiety
- Can interfere with daily routines

Phobias & Panic Attacks



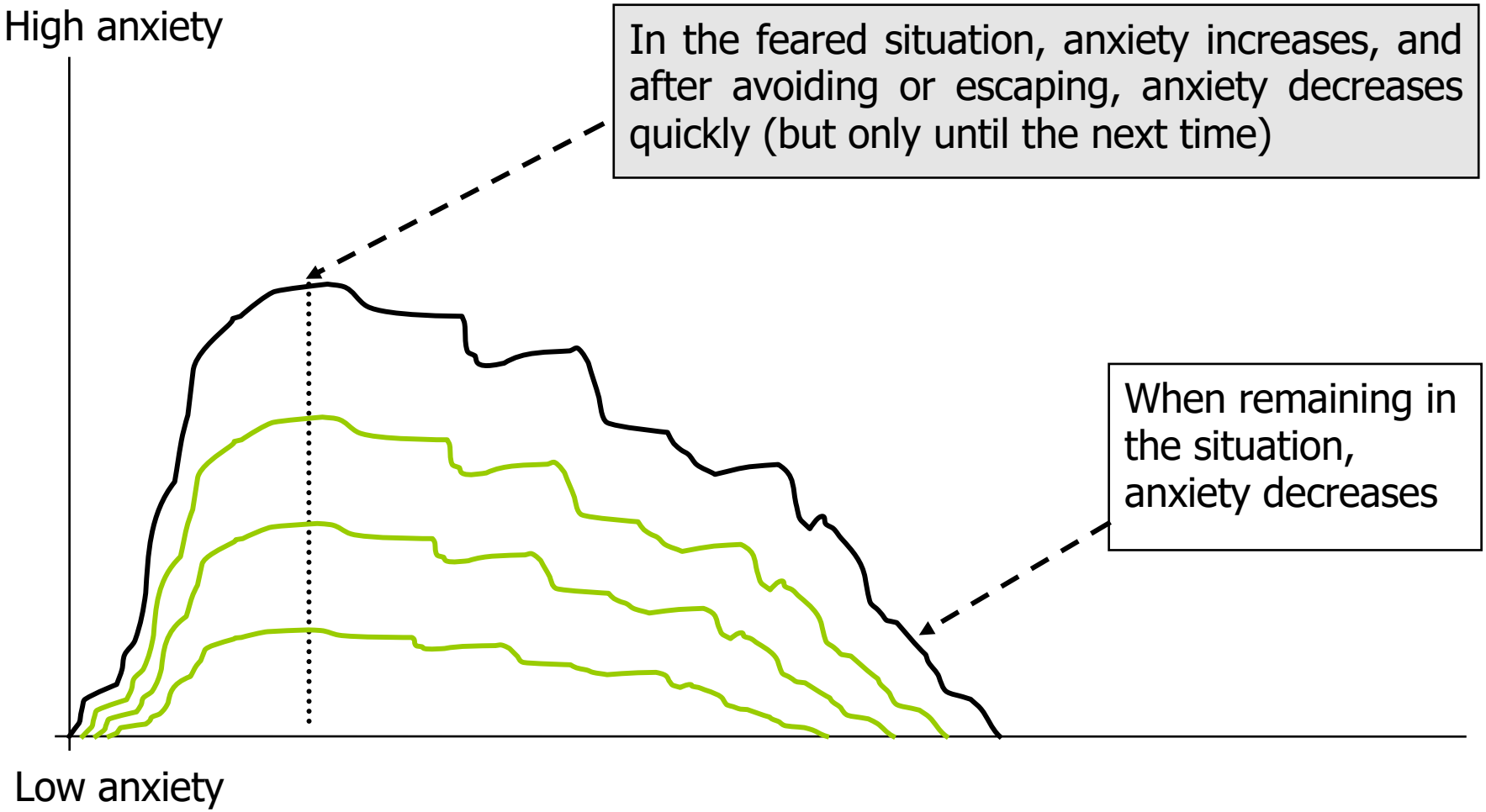
- Stimulus
- Cognitive response
- Somatic response
- Behavior response (fight or flight)

Treatment

- Psychoeducation
  - Anxiety and panic concepts
  - Learn to identify symptoms/thoughts/behavior
- Exposure to symptoms and situations
- Withdraw security and avoidance behaviors
- Cognitive techniques

- One of the most effective techniques to deal with fear is to confront a feared situation repeatedly, gradually, and systematically:
  - By imagination
  - In vivo
  - Using virtual reality

Exposure

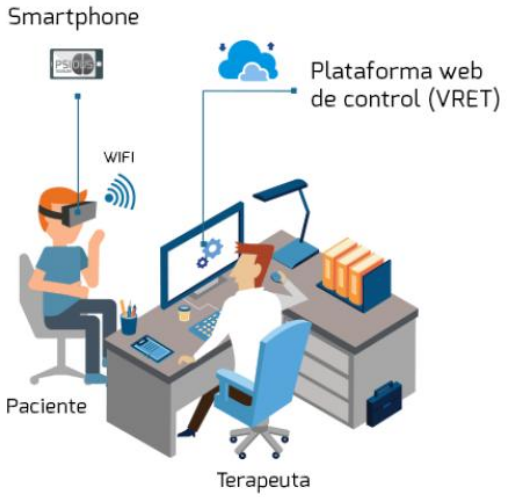

High anxiety
In the feared situation, anxiety increases, and after avoiding or escaping, anxiety decreases quickly (but only until the next time)
When remaining in the situation, anxiety decreases
Low anxiety

VR and Phobias

- Approach:
  - Assessment to plan best therapy
  - Start exposure from lowest degree and gradually increase
  - Assess response (e.g., sweating)
- Advantages:
  - Better immersion degree than imagination
  - Allows multi-sensory stimulation
  - Fewer resources than in vivo exposure (user often prefers VR; about 25% cannot deal with in vivo)
  - Therapist can monitor and control immersion; interact with patient; personalize treatment
  - Secure environment; practice at home; no technical knowledge needed; generate reports automatically; privacy and confidentiality

VR and Phobias

- Problems
  - Dizziness, headaches, disorientation, nausea, accidents
  - No standardized protocols yet
  - Not all medical providers have the resources
  - Lack of proof of effectiveness for some disorders



Examples

Fear of flying

Miedo a Volar

Fear of needles

Miedo a las Agujas

Acrophobia

Acrofobia

Claustrophobia

Claustrofobia

Agoraphobia

Agorafobia

Social phobia

Miedo a hablar en público

Relaxation

Relajación

Fear of driving

Miedo a Conducir

Fear of insects

Miedo a los Insectos

VR and AR

Virtual Reality

Augmented Reality

Example: VR for PTSD

- VR therapy has been reported to reduce PTSD in soldiers returning from Iraq and Afghanistan significantly for 62% of those undergoing treatment
- Studies show positive impacts on survivors and first responders of 9/11 attack

- PTSD: https://www.youtube.com/watch?v=Oe_3uL4JxEc

- Spider World: https://www.youtube.com/watch?v=csD1ue-RuNw