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LMMFE Laboratorij za multimedijo

VIRTUAL TECHNOLOGIES @WESTERN BALKAN UNIVERSITIES

User eXperience in VR

Evaluation of Ux in VR and VR sickness

Asst. Prof. Dr. Jože Guna , Assoc. Prof. Dr. Matevž Pogačnik

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Contents

XR landscape

Technology basics
- AR/VR/MR
- Interactions
- Content

User eXperience
- Basics
- VR UX
- Evaluating the UX
- VR sickness

Study examples

Trends & Challenges

Discussion

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Agenda

DAY 1: Evaluation of Ux in VR and VR sickness		
Moderator: Jože Guna		
Time	**Activity**	**Presenter**
09:00 – 09:30	Registration of participants & remote Coffee	
09:30 – 9:45	Opening speech by the representatives	Assoc. Prof. Dr. Matevž Pogačnik
SESSION I: XR landscape & technology		
9:45 – 11.00	Technology basics and terminology in XR Interactions & Content	Asst. Prof. Dr. Jože Guna Assoc. Prof. Dr. Matevž Pogačnik Klemen Pečnik
11:00 – 11.15	Coffee break	Asst. Prof. Dr. Jože Guna
11:15 – 12:00	User eXperience in VR	Asst. Prof. Dr. Jože Guna
12:00 – 13:00	Lunch break	
SESSION II: User eXperience evaluation and VR sickness		
13:00 – 14:45	User eXperience evaluation in VR VR sickness VR sickness evaluation	Asst. Prof. Dr. Jože Guna Assoc. Prof. Dr. Matevž Pogačnik Klemen Pečnik
14:45 – 15:00	Coffee break	
15:00 – 15:30	VR sickness use case studies	Asst. Prof. Dr. Jože Guna
15:30 – 15:45	Conclusions, Trends&Challenges	Asst. Prof. Dr. Jože Guna
15:45 - 16:00	Discussion and coffee	PhD. Albana Halili
16:00	Closing of the meeting	all

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Univerza v Ljubljani, Fakulteta za elektrotehniko
Žiga Ambrožič
Street View – jul. 2014
LTM@UNI-LJ, FE
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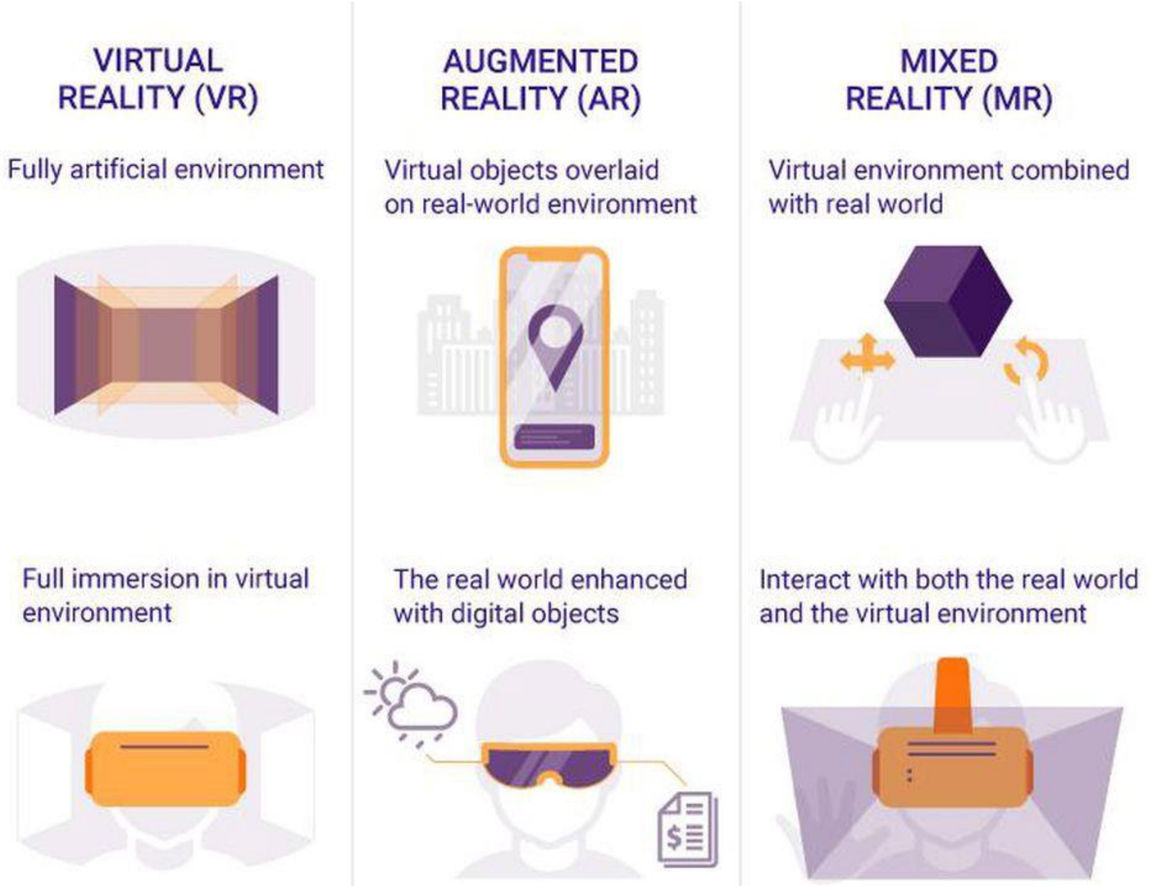
Comedy
Entertainment
Incredible Turkey in 4K (Ultra HD) Around the World Travel
CORAL REEF AQUARIUM COLLECTION • 12 HOURS •
PATAGONIA 8K
Back to top
https://www.google.si/maps/@46.0446156,14.4891489,3a,75y,338.54h,97.13t/data=!3m6!1e1!3m4!1sAF1QipNB1LfLpZpujutkz9rHj2xxEqZvv5OAUfb8GSOV!2e10!7i12000!8i6000
Google

Forms of Reality- VR/AR/MR...RR?



https://uxplanet.org/designing-user-experience-for-virtual-reality-vr-applications-fc8e4faadd96

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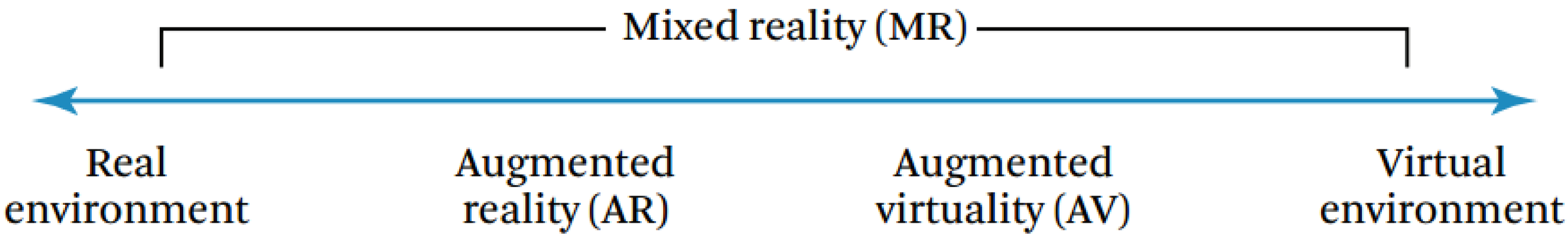
Extended Reality (XR) Landscape



Milgram and Kishino, 1994

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XR solutions taxonomy

- High performance VR tethered systems
  - E.g. Oculus Rift, HTC Vive/pro, MS Windows Mixed Reality HMD
- Mobile VR untethered systems
  - E.g. OculusGO/Quest, HTC Vive Focus
- Mobile phone based VR untethered systems
  - E.g. Samsung GearVR/Google Daydream
- Video console based VR systems
  - e.g. Sony PSVR za PS4
- Untethered AR/MR systems
  - E.g. MS Hololens, MagicLeap
  - E.g. Epson Moverio
- Mobile phone based AR/MR untethered systems
  - E.g. ArCore, Arkit, Vuforia, …
    (Android, iOS)
- Web XR solutions

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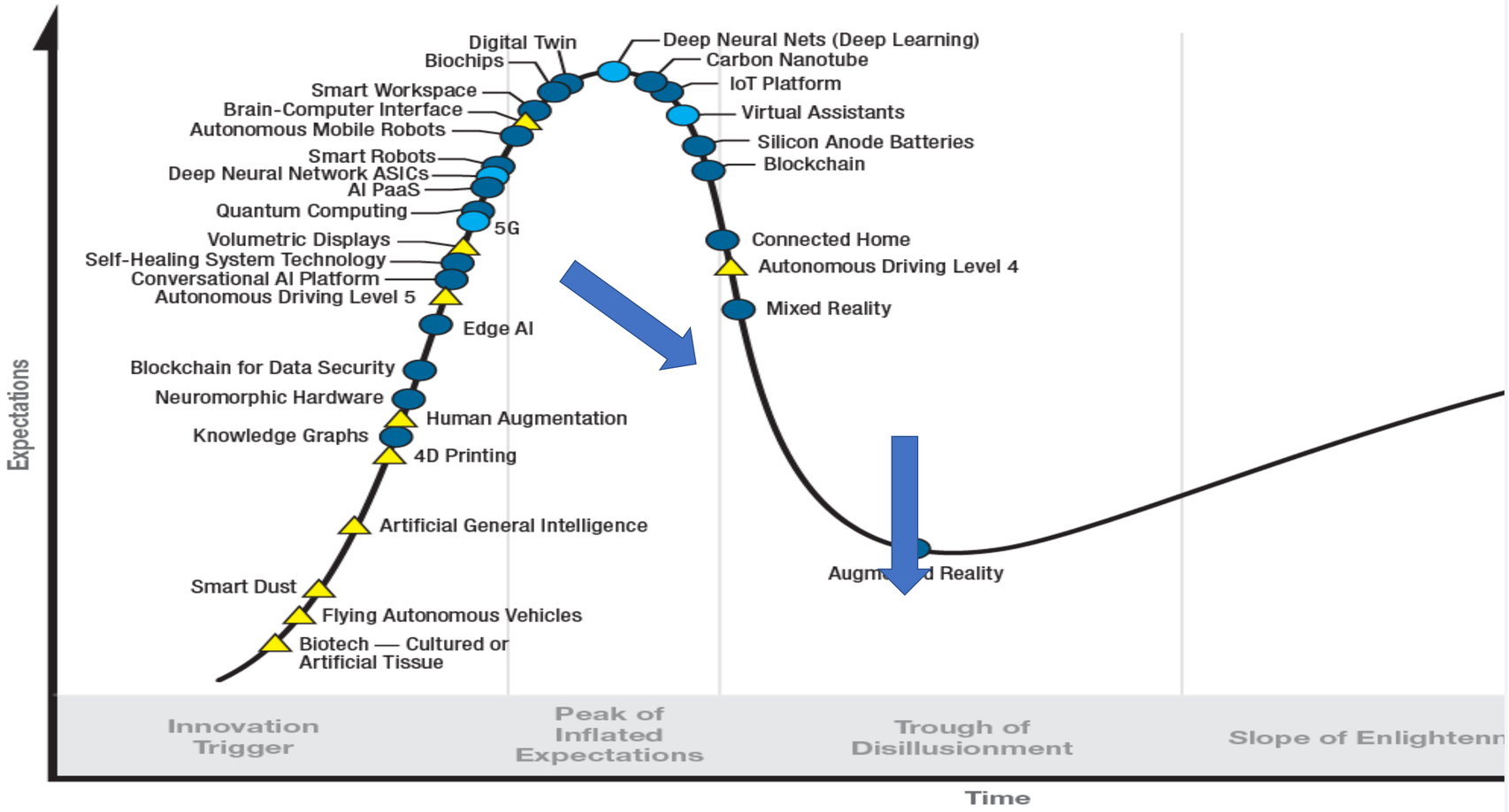
Hype Cycle for Emerging Technologies, 2018



gartner.com/SmarterWithGartner

Source: Gartner (August 2018)

https://www.gartner.com/smarterwithgartner/5-trends-emerge-in-gartner-hype-cycle-for-emerging-technologies-2018/

Top 10 Strategic Technology Trends for 2019

gartner.com/SmarterWithGartner

Source: Gartner

Gartner

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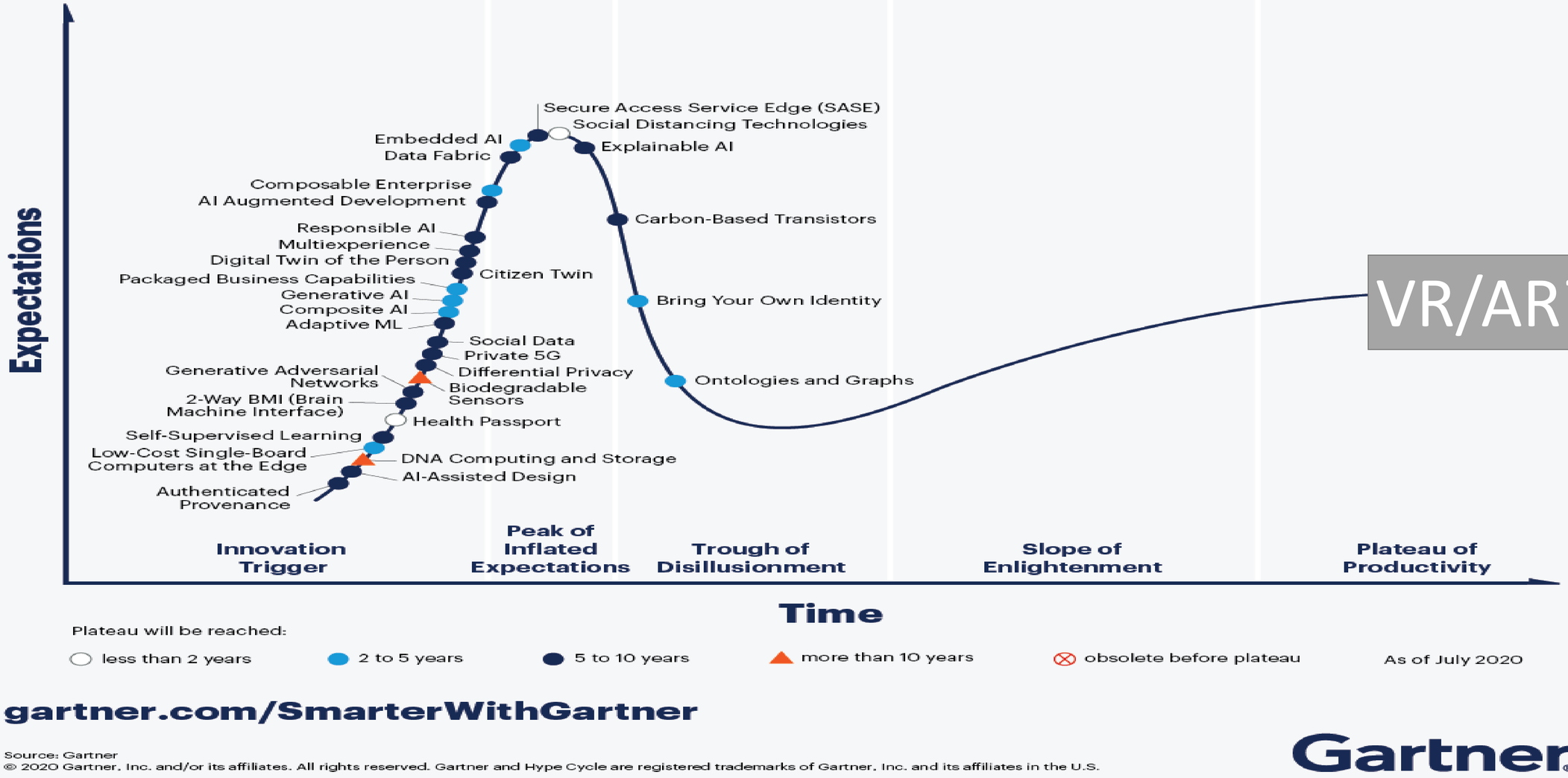
Hype Cycle for Emerging Technologies, 2020



gartner.com/SmarterWithGartner

Gartner

https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020/

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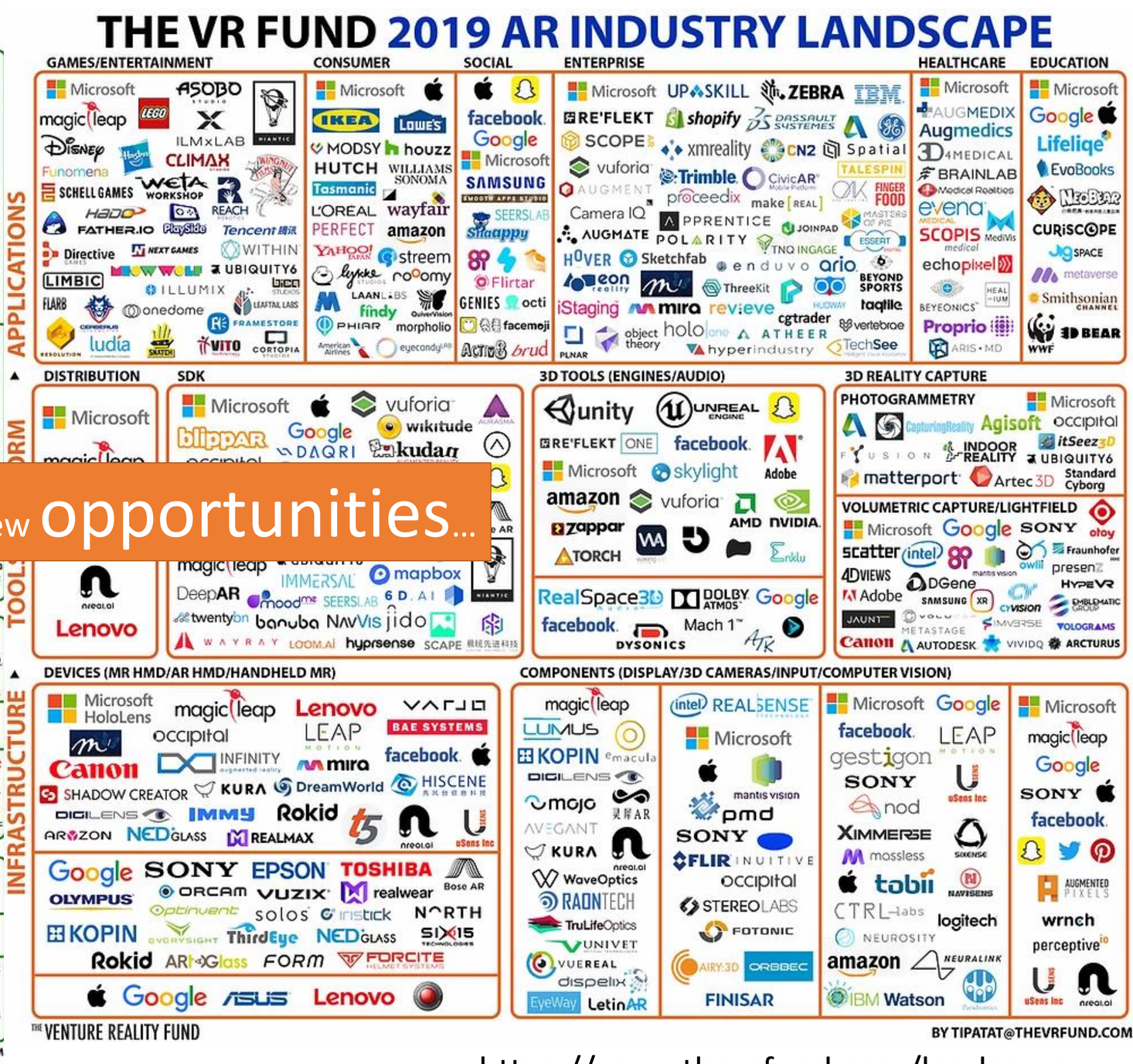

Lots of new opportunities...

https://www.thevrfund.com/landscapes

Recent XR history lessons…

- Augmented Reality
  - Google Glass

- Virtual Reality
  - Oculus Rift DK1

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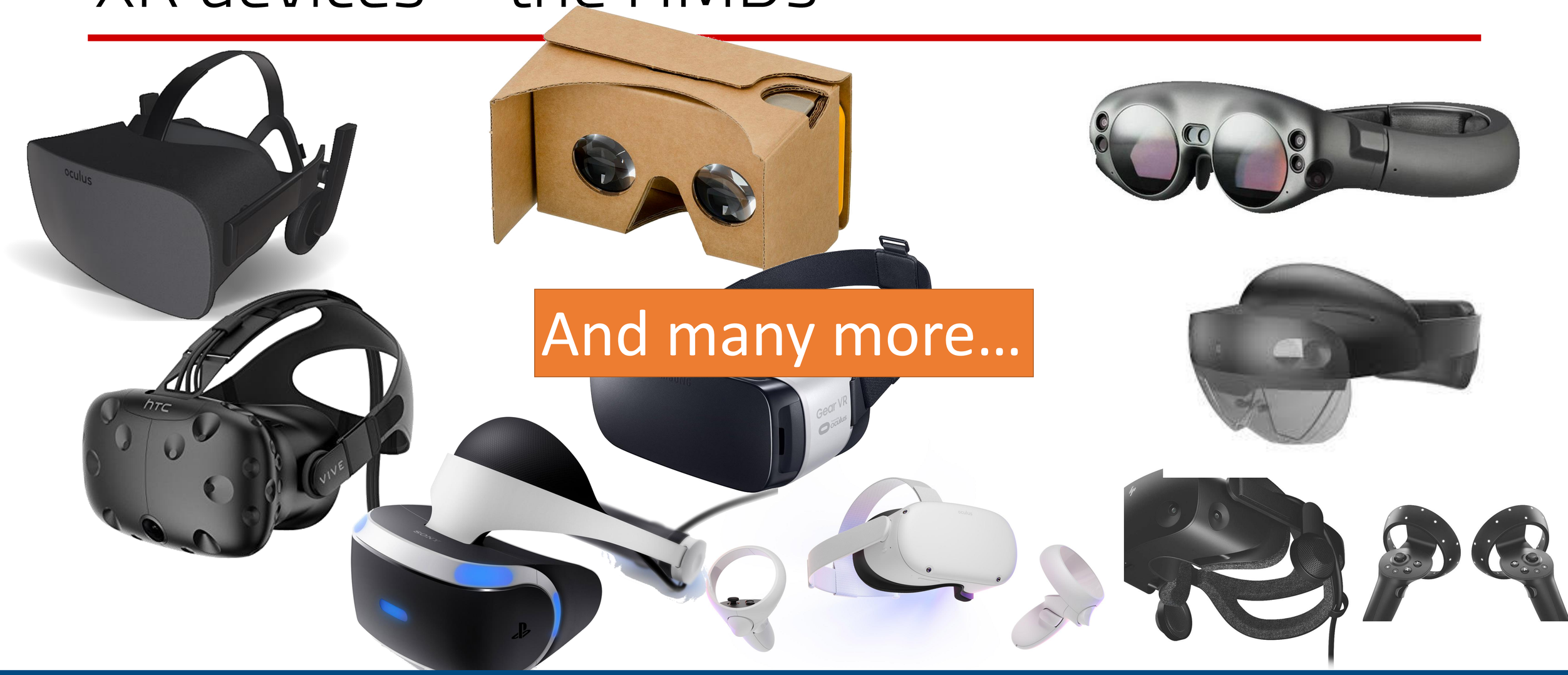
XR devices – the HMDs



And many more…

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VR

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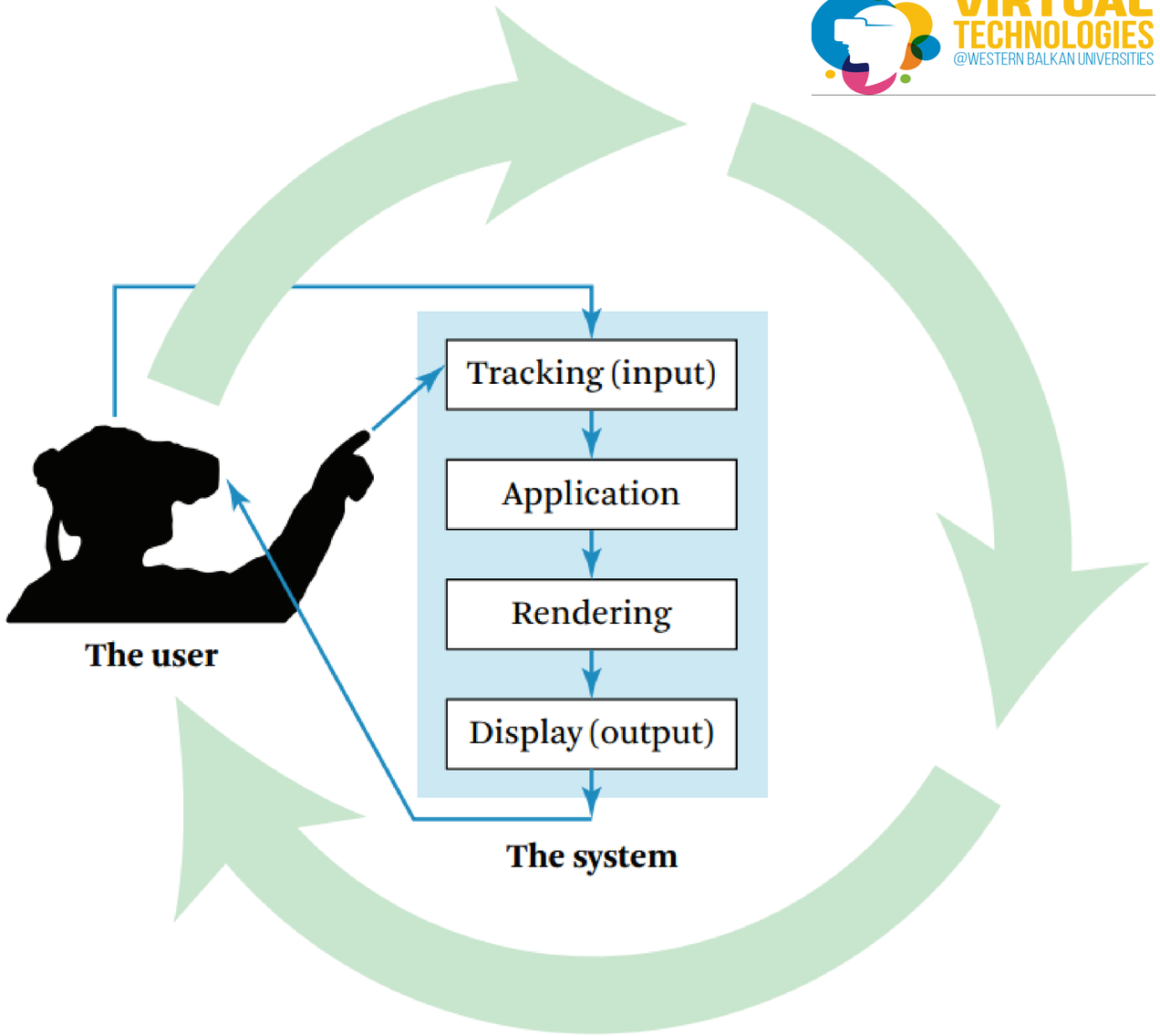
The VR system

- Head Mounted Display

- Audio/video quality
- Interactions
- Location tracking
- Latency

- UX?



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VR HMD system components

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Location tracking

- Laser
- IR camera
- RGB camera

- 3DoF, 6DoF

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Inside-out tracking

- Integrated within the HMD
- HTC/Valve (e.g. Vive Cosmos, Focus)
- FB/Oculus (e.g. Oculus S/Quest 1/2)
- Windows VR systems

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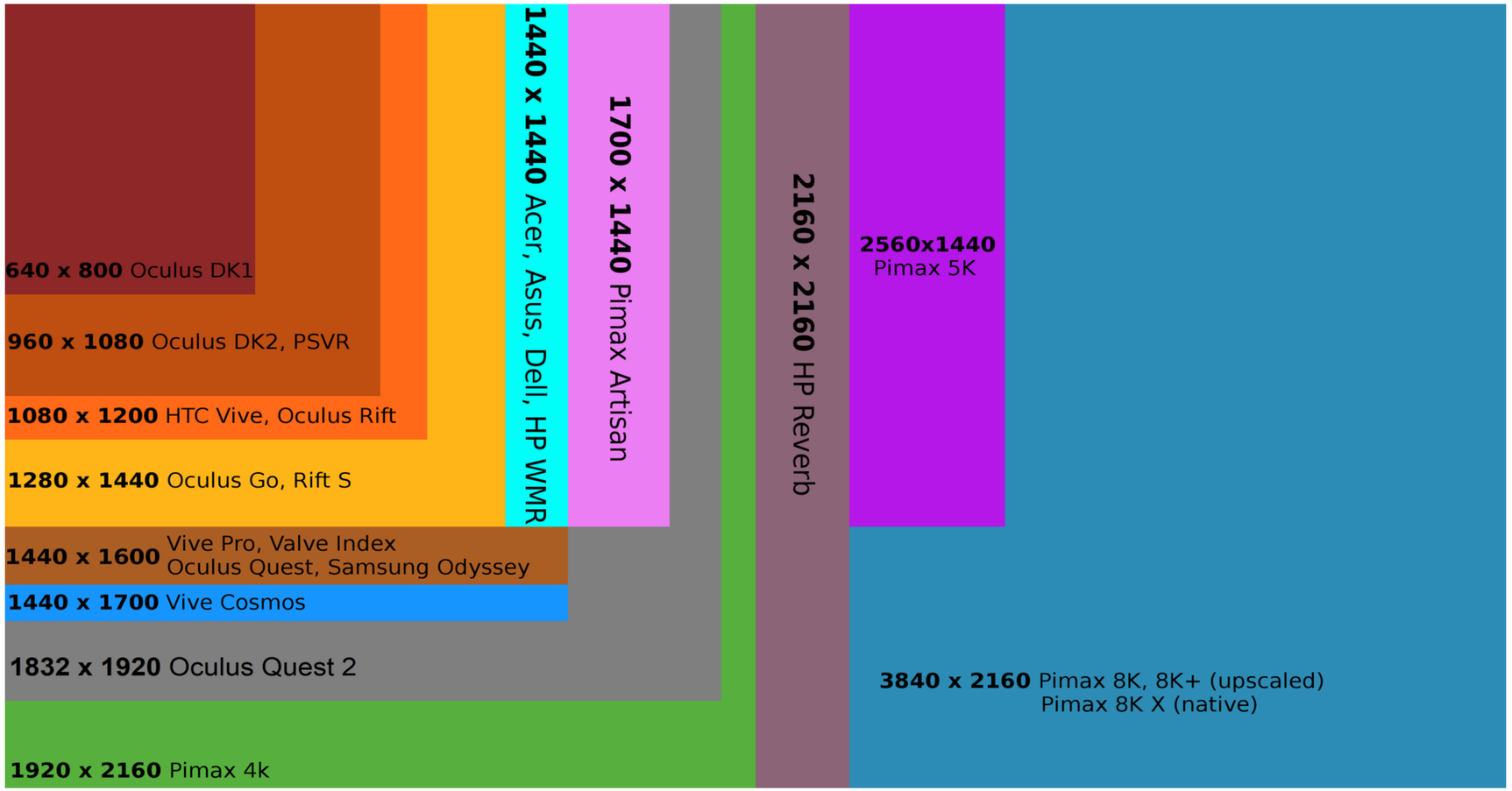
Screen resolution comparison



https://en.wikipedia.org/wiki/Comparison_of_virtual_reality_headsets

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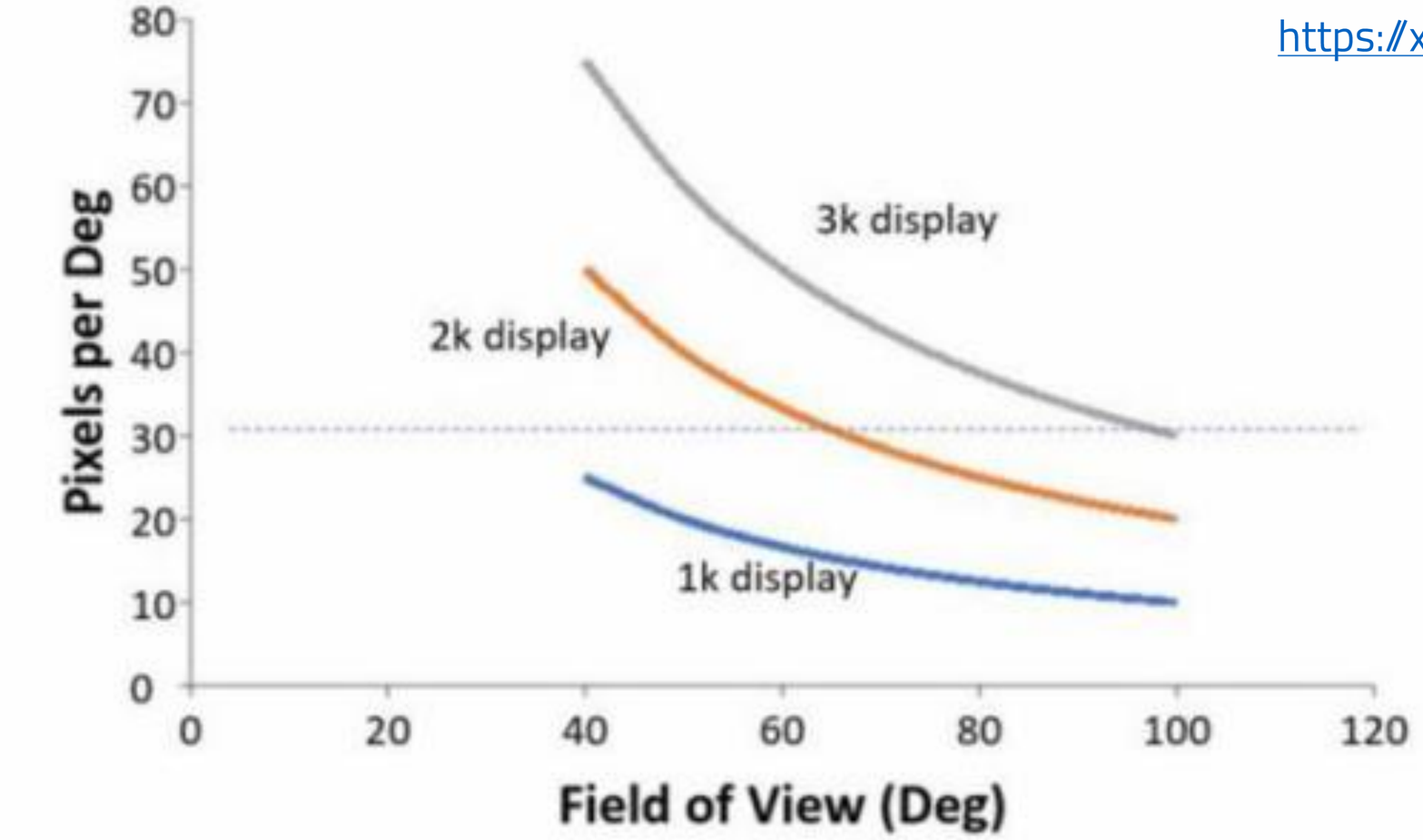
Pixel density and FOV

https://xinreality.com/wiki/Pixel_density



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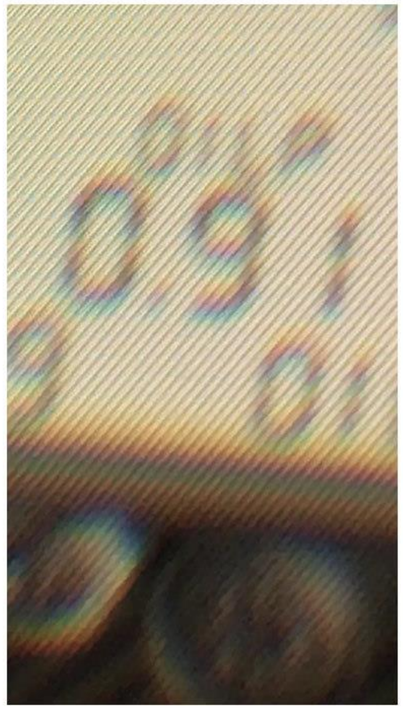
Not enough pixels?!

- PiMax/StarVR 4k/8k VR HMD

HTC VIVE



Oculus CV1

Pimax 4K

Pimax 8K

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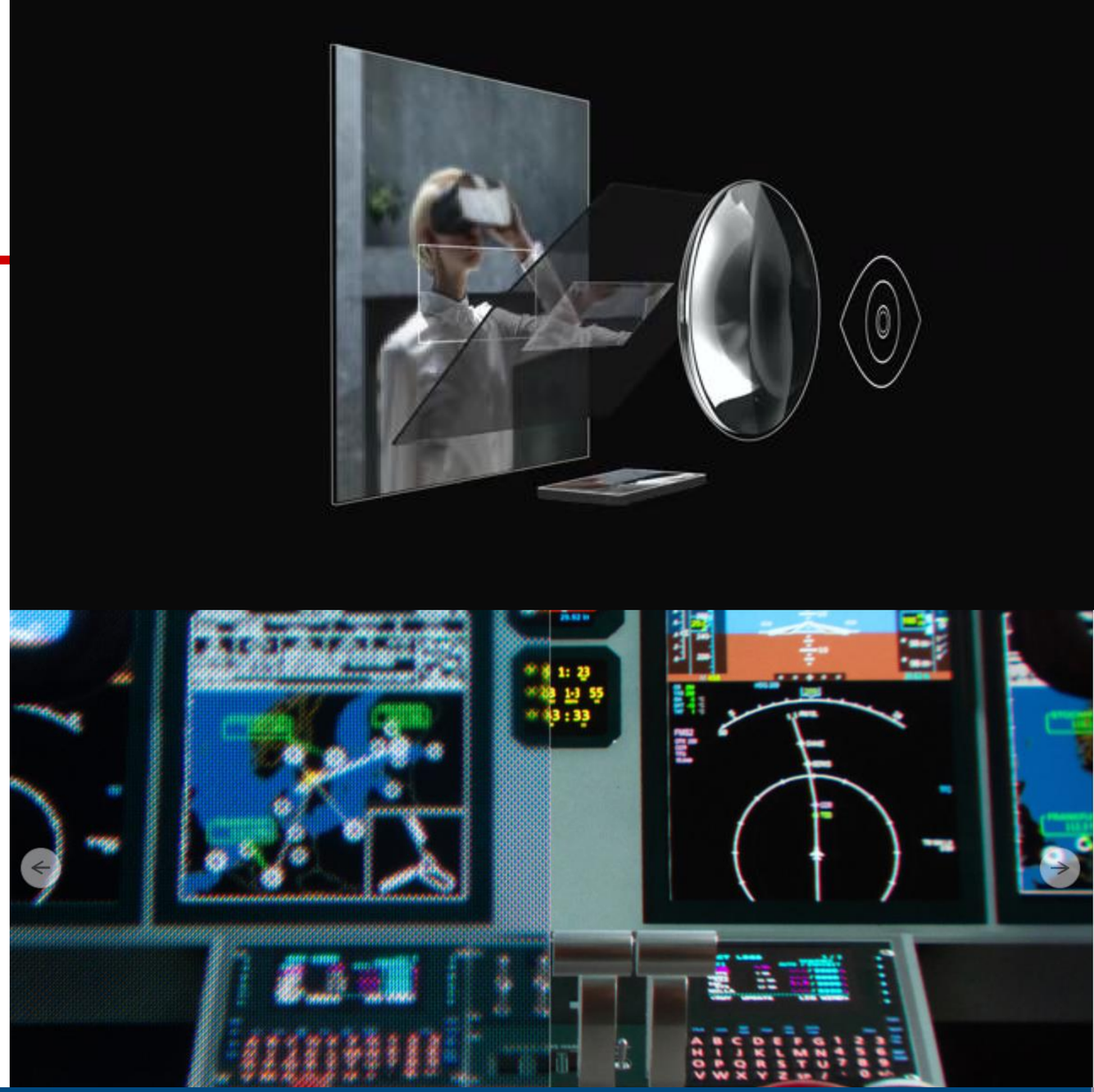
Varjo VR-1/2/3

- Display combination
  - 1920x1080 oled (3000 ppi) central display
  - 1440x1600 amoled peripheral display
- Eye-tracking and image superposition
- FOV~87°

https://varjo.com/products/vr-1/



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picture	manufacturer - model	resolution	refresh rate	view width
	ASUS Windows Mixed Reality	1440 × 1440	90	95
	ANTVR	1080 × 1200	90	110
	ASUS Windows Mixed Reality	1440 × 1440	70	100
	Dell Visor	1440 × 1440	90	110
	FOVE	1280 × 1440	70	100
	GALAX VISION	960 × 1080	60	100
	GameFace	1280 × 1440	90	120

https://benchmarks.ul.com/compare/best-vr-headsets

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picture	manufacturer - model	resolution	refresh rate	view width
	HP Reverb – Pro Edition	2160 × 2160	90	114
	HP Windows Mixed Reality	1440 × 1440	90	95
	HTC VIVE	1080 × 1200	90	110
	HTC VIVE Focus	1440 × 1600	75	110
	HTC VIVE Pro	1440 × 1600	90	110
	ImmersiON-VRelia PRO-DG1	1080 × 1920	60	123
	Lenovo Explorer Windows Mixed Reality	1440 × 1440	90	110

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picture	manufacturer - model	resolution	refresh rate	view width
	Oculus Go	1280 × 1440	60	101
	Oculus Quest	1440 × 1600	72	90
	Oculus Rift	1080 × 1200	90	110
	Oculus Rift S	1280 × 1440	80	110
	OSVR	1080 × 1200	90	110
	PIMAX 4K	1920 × 2160	60	110
	PIMAX 8K	3840 × 2160	120	200

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picture	manufacturer - model	resolution	refresh rate	view width
	Samsung Gear VR	1280 × 1440	60	101
	Samsung HDM Odyssey Windows Mixed Reality	1440 × 1600	90	110
	Sony PlayStation VR	960 × 1080	120	100
	StarVR	2560 × 1440	90	210
	Sulon Q	1280 × 1440	90	110
	Valve Index	1440 × 1600	144	130
	Varjo VR-3	2880 × 2720	90	115
	Vrvana Totem	1280 × 1440	75	120

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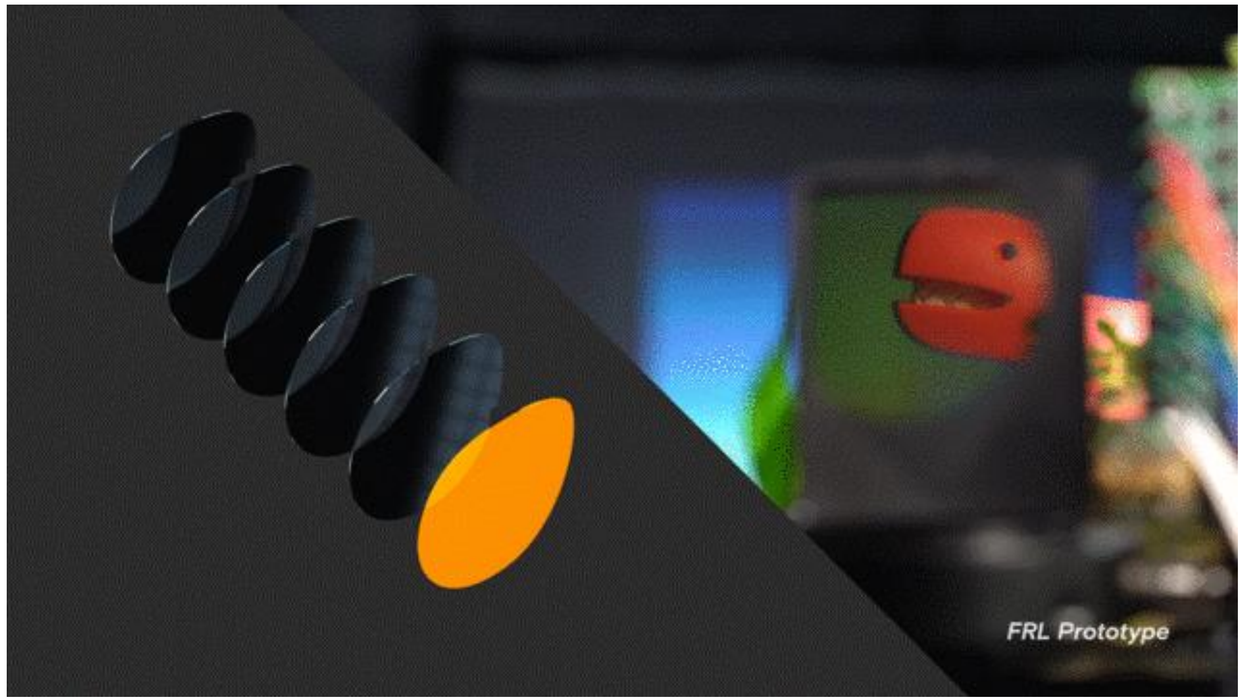
Varifocal display (Oculus)



https://www.oculus.com/blog/half-dome-updates-frl-explores-more-comfortable-compact-vr-prototypes-for-work/

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Interactions

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Interaction modalities

- Traditional (mouse+keyboard)
- Touch&Gestures
- Full body gestures
- Voice
- Eye-tracking
- Tangible interfaces
- Brain Computer Interfaces (e.g. Neuralink)
- …?

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VR/AR/MR

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Touch? - Haptic interfaces

https://haptx.com

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Content

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Content & applications

- Virtual Reality
  - Computer generated (3D)
  - Real content (picture/video)
    - Panoramic video (360 video)
    - Panoramic 3D video (stereoscopy)
    - Volumetric video (6DoF)
  - And combinations
- Augmented/mixed reality
  - Digital holograms set into a real environment
- Interactivity!

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Panoramic 360° video transmission

- Only a small part of the video is really shown at any given time (FOV)
- Video resolution vs perceived resolution

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360° video QoS requirements

VR resolution		Equivalent TV res.	Bandwidth	Latency
Early stage VR (current)	1K*1K@visual field 2D_30fps_8bit_4K	240P	25 Mbps	40 ms
Entry level VR	2K*2K@visual field 2D_30fps_8bit_8K	SD	100 Mbps	30 ms
Advanced VR	4K*4K@visual field 2D_60fps_10bit_12K	HD	400 Mbps	20 ms
Extreme VR	8K*8K@visual field 3D_120fps_12bit_24K	4K	1 Gbps (smooth play) 2.35 Gbps (interactive)	10 ms

Mangiante, Simone, et al. "Vr is on the edge: How to deliver 360 videos in mobile networks." *Proceedings of the Workshop on Virtual Reality and Augmented Reality Network*. 2017.

Huawei. 2016. Whitepaper on the VR-Oriented Bearer Network Requirement. (2016).

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360° video QoS requirements

Requirement		Pre-VR	Entry-Level VR	Advanced VR	Human Perception	Ultimate VR
Experience Duration		less than 20 minutes	less than 20 minutes	less than an hour	/	more than an hour
Video Resolution		3840×1920 (Full-view 4K Video)	7680×3840 (Full-view 8K Video)	11520×5760 (Full-view 12K Video)	21600×10800 (Full-view Video)	23040×11520 (Full view 24K Video)
Single-eye Resolution		1080×1080	1920×1920	3840×3840	9000×8100	9600×9600
Field-of-View (Single-eye)		100×100	110×110	120×120	150×135	150×150
Bit per Color (RGB)		8	8	10	/	12
Refresh Rate		60	90	120	120	200
Pixel per Degree		10	17	32	60	64
Service Require-ment	Uncompressed Bit Rate (Progressive 1:1)*	10.62 Gbps	63.70 Gbps	238.89 Gbps	1007.77 Gbps	1911.03 Gbps
	Transmitting Bit Rate (Low-latency Compression 20:1)	530 Mbps	3.18 Gbps (Full-view) 796 Mbps (FoV)	11.94 Gbps (Full-view) 5.31 Gbps (FoV)	50.39 Gbps (Full-view) 31.49 Gbps (FoV)	95.55 Gbps (Full-view) 66.36 Gbps (FoV)
	Transmitting Bit Rate (Lossy Compression 300:1)	35 Mbps	210 Mbps (Full-view) 53 Mbps (FoV)	796 Mbps (Full-view) 354 Mbps (FoV)	3.36 Gbps (Full-View) 2.10 Gbps	6.37 Gbps (Full-view) 4.42 Gbps (FoV)
	Typical Round Trip Time (RTT)	10 ms	10 ms	5 ms	10 ms	5 ms
	Typical Packet Loss	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}

* Progressive Data rate = (3×Bit per Color) × (Pixel per Degree×Field-of-view (Full-view or Single-eye)) × Refresh Rate / Compression ratio

Cellular-Connected Wireless Virtual Reality: Requirements, Challenges, and Solutions, https://arxiv.org/pdf/2001.06287.pdf

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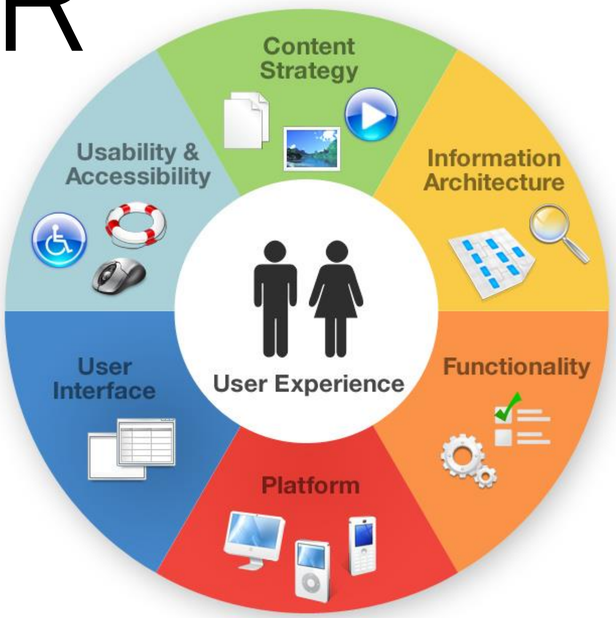
User eXperience in VR



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What is User eXperience?

- “Ux signifies the totality of the effect or effects felt (experienced) internally by a user as a result of interaction with, and the usage context of, a system, device, or product”.
- As such it encompasses the aspects of the effects experienced due to (1) usability, (2) usefulness and (3) emotional impact factors.

Hartson, Rex, and Pardha S. Pyla. The UX Book: Process and guidelines for ensuring a quality user experience. Elsevier, 2012.

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The VR medium

- defined as a technology that induces targeted behavior in an organism by using artificial sensory stimulation, while the organism has little or no awareness of the interference. VR technology stimulates multiple senses and, assisted by multimodal interactions, creates the illusion of presence in virtual environments. As such it enables a first person immersive experience.
- 1st person experience
- Natural interaction

LaValle, Steven. "Virtual reality." (2016).

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Immersion

- Immersion is user's engagement with a VR (virtual reality) system that results with being in a flow state. Immersion to VR systems mainly depends on sensory immersion, which is defined as "the degree which the range of sensory channel is engaged by the virtual simulation"
- In short, a *property of technology*, to what extent, exactly how and which senses it stimulates
- The more senses are stimulated, the stronger the feeling of immersion
- Technology driven

Kim, G., Biocca, F.: Immersion in virtual reality can increase exercise motivation and physical performance. In: International Conference on Virtual, Augmented and Mixed Reality, pp. 94–102. Springer, Cham (2018)

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Presence

- Presence within the context of virtual reality is defined as one's sense of being in the virtual world.
- In short, *a feeling of being there*
- Strong immersion -> usually strong presence in VR/VE
- Story driven

Slater, M.: Immersion and the illusion of presence in virtual reality. Br. J. Psychol. **109**(3), 431 (2018)

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VR UX guidelines – a heuristic refresh

- Give the user control of their movements
- Limit elements that may cause sickness
- Help users feel “safe”
- Create immersive experiences
- Build for different types of users with different mental models
- Place UI where it is easy to work with and read
- Create comfortable & sustainable interactions
- Use cues and prompts to help users get started
- Make controls easy to learn and remember
- Develop natural interactions for the hands

https://medium.com/@oneStaci/https-medium-com-ux-vr-18-guidelines-51ef667c2c49

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Evaluating the UX

In VR

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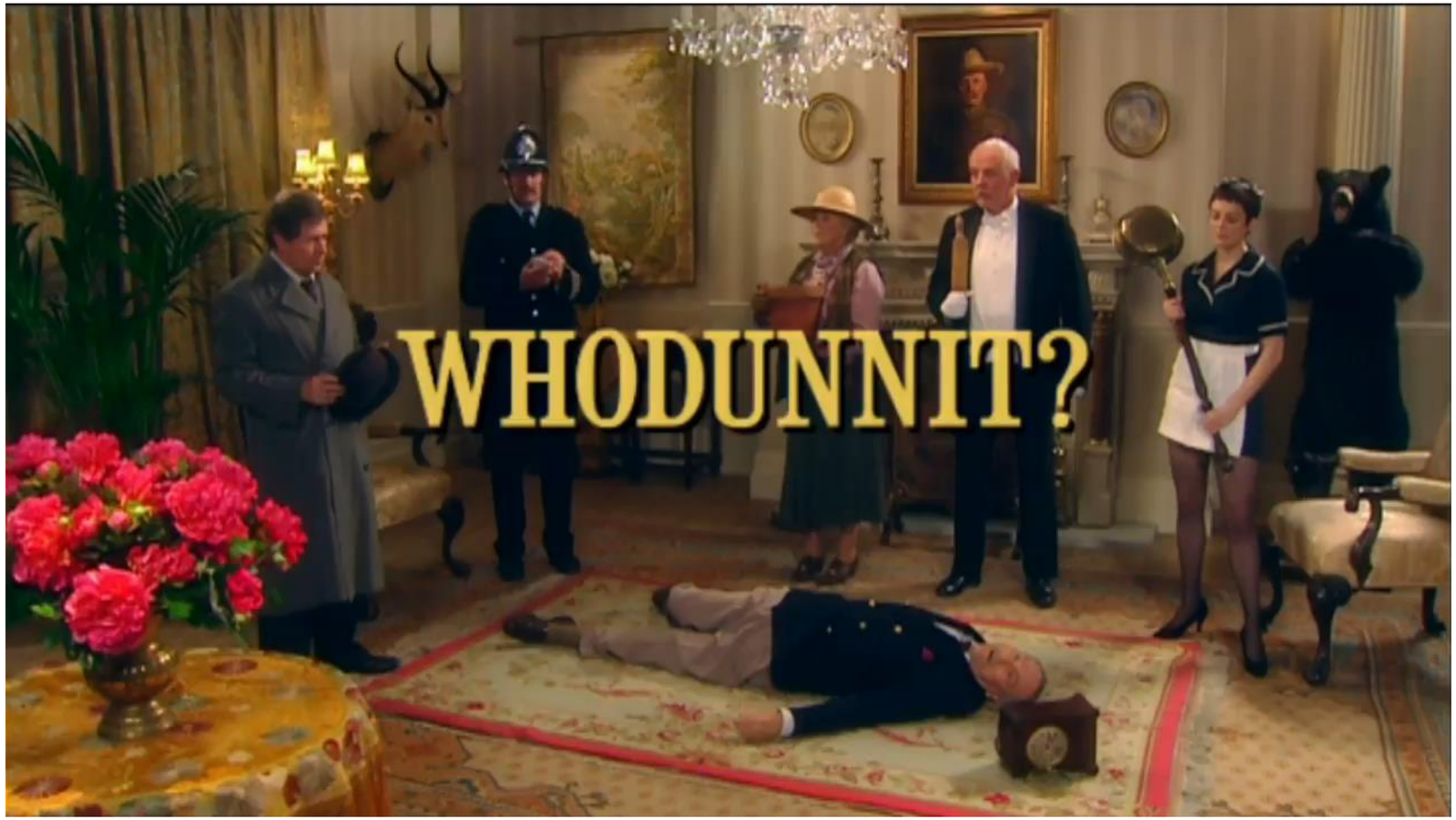
The importance of observation…



https://www.youtube.com/watch?v=ubNF9QNEQLA

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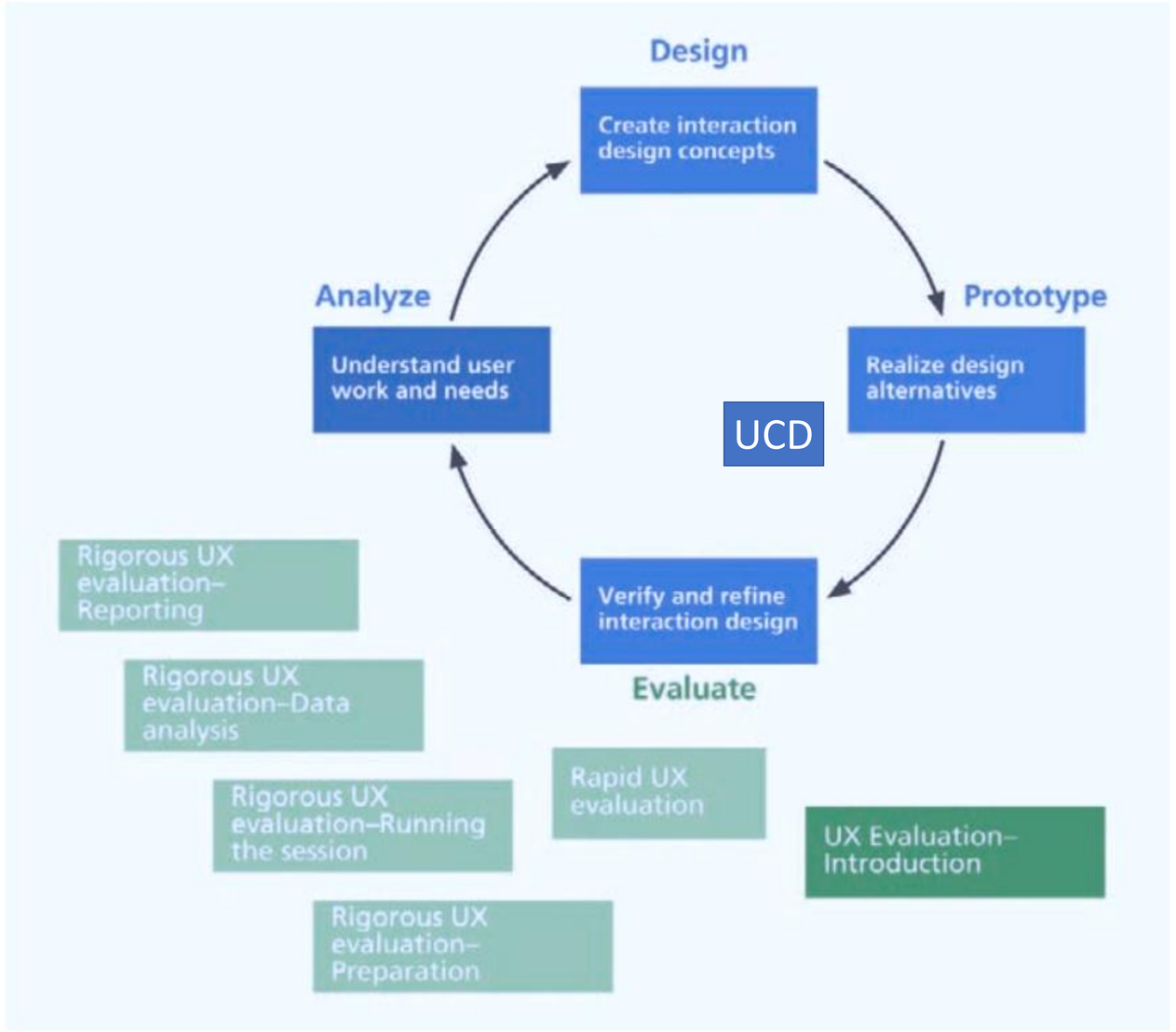

Users

The UX Book- Process and Guidelines for Ensuring a Quality User Experience, Rex Hartson

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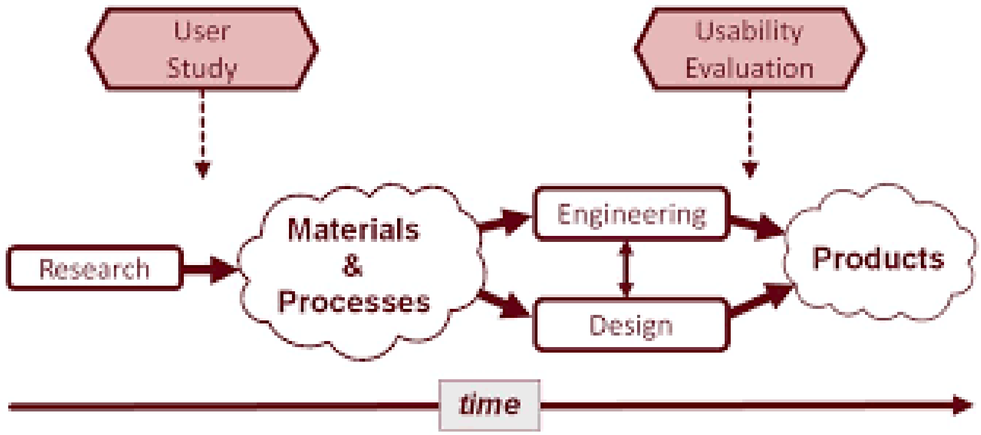
Why?

- **UX-U=X**
- Understanding and solving real issues/needs
- User co-creation, iterative design
- Appropriate evaluation method selection
- GOAL: usability & satisfaction



MacKenzie, I. S. (2015). User studies and usability evaluations: From research to products. Proceedings of Graphics Interface 2015 - GI 2015, pp. 1-8. Toronto: Canadian Information Processing Society

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User study?

- User study? Yes, getting feedback from the users
- User test? No, but
- The study of the target system, solution, application
- „garbage in, garbage out“ principle

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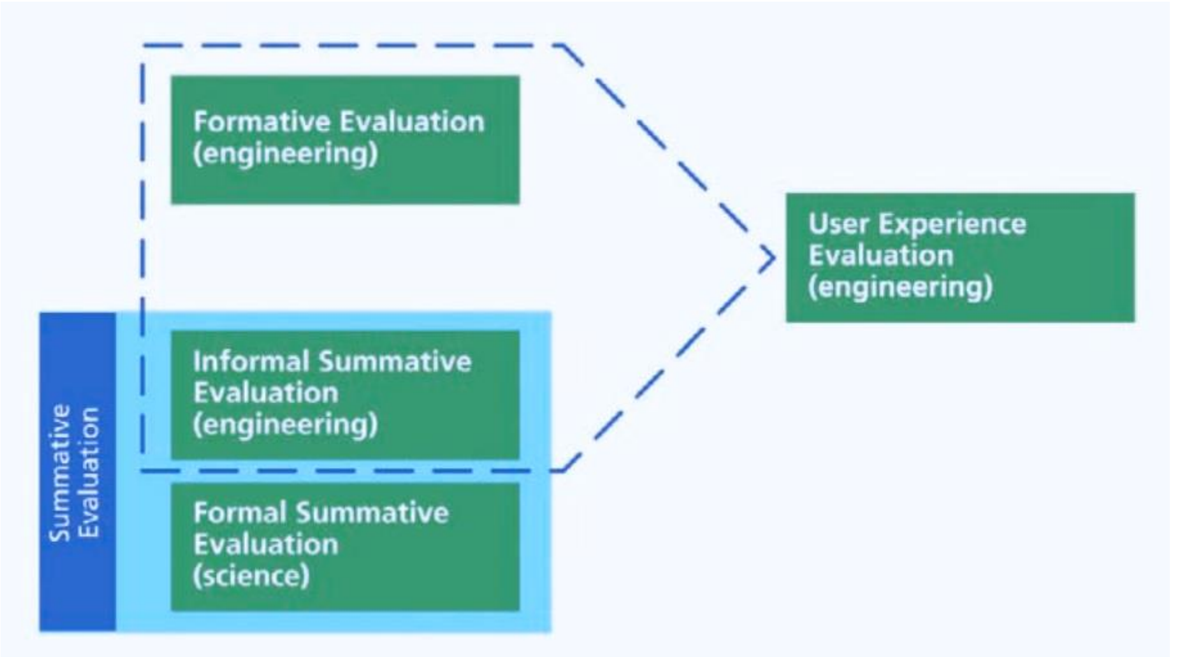
UX evaluation classification

- formative vs. summative
- formal (rigorous, lab) vs. informal (fast)
- empirical vs. analytic
- qualitative vs. quantitative
- objective vs. subjective
- „*life is one big,*
  long formative evaluation.“



The UX Book- Process and Guidelines for Ensuring a Quality User Experience, Rex Hartson

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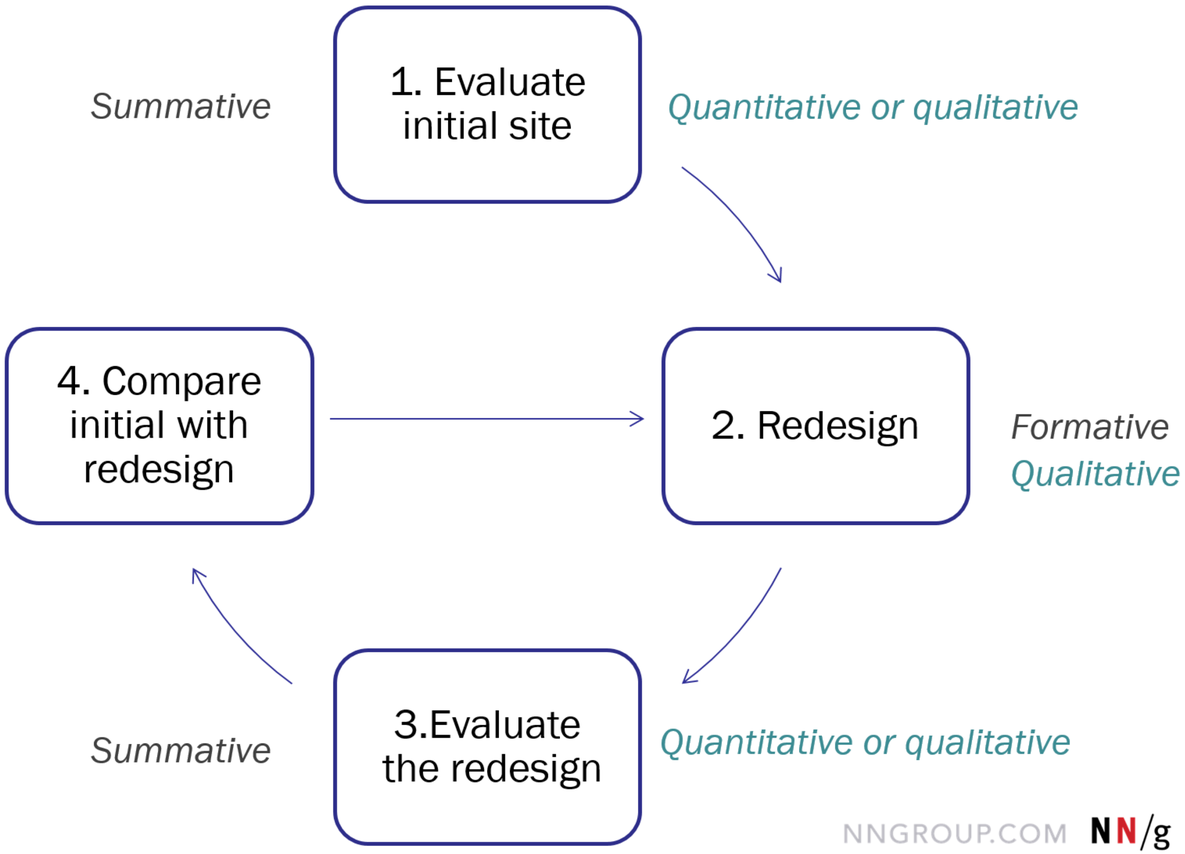
Evaluation lifecycle



NNGROUP.COM NN/g

https://www.nngroup.com/articles/quant-vs-qual/

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Qualitative vs. quantitative evaluation

- Qualitative evaluation – Why?
  - Descriptive feedback, experience
  - observation
- Quantitative evaluation – How much?
  - Numerical feedback, analytics, performance
  - metrics
- Combinations

UxPin: The Guide to Usability Testing, https://www.uxpin.com/studio/ebooks/guide-to-usability-testing/
The UX Book- Process and Guidelines for Ensuring a Quality User Experience, Rex Hartson

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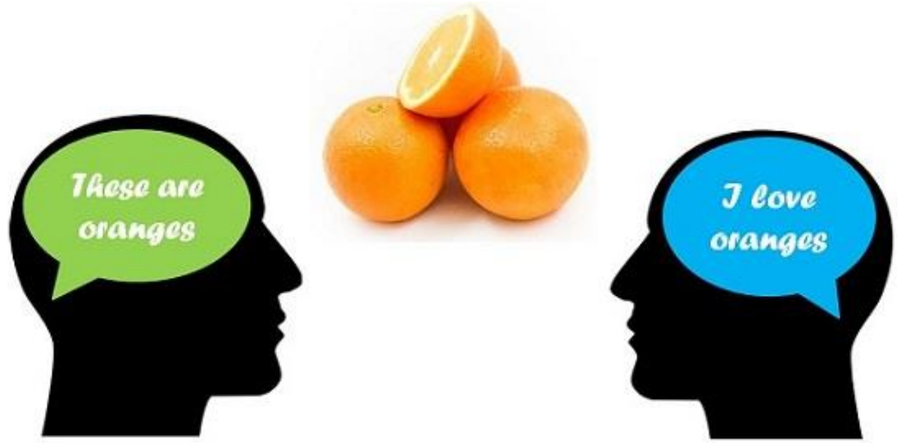
Objective vs. subjective evaluation

- Objective evaluation
  - Measureable, repeatable
  - Measured by the UX expert & tools
  - examples: eye-tracking, psychophysical feedback
- Subjective evaluation
  - Subjective feedback, comments, marks
  - Given by the user directly
  - Examples: semi-structured interviews, questionnaires



The UX Book- Process and Guidelines for Ensuring a Quality User Experience, Rex Hartson

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Which users?

- representative - those who are actually target users
- user modelling
  - User groups
  - Personas
- different user groups (children, elderly,...) & needs
- consideration of special needs (accessibility), context of use
- scientific honesty - the developer is a poor test user
- target user! = necessarily subscriber, payer

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How many users?

- Depends, but more than 0!
  - Small scale iterative evaluations – about 5-10
  - Large scale final evaluations - 30+
  - Depends on application domain
    - Non-critical entertainment
    - Critical domains
- depending on the complexity of the product - probability of occurrence and frequency of UX / usability errors
- *„In our experience, five participants per significantly different class of user is usually enough to uncover the most important usability issues.“*

Albert, William, and Thomas Tullis. Measuring the user experience: collecting, analyzing, and presenting usability metrics.
https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

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Only 5 users?

https://www.nngroup.com/videos/usability-testing-w-5-users-design-process/

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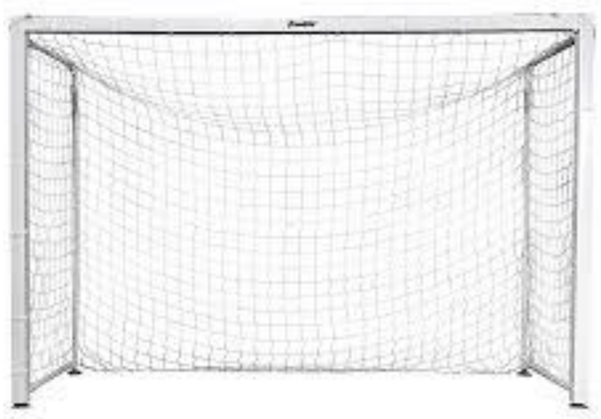
UX goals

- High-level objectives
- user experience goals - How will users perceive our product?
  - ease of use
  - error management and prevention
  - easy learning
  - satisfaction with use



- related to user scenarios and properties of target users (domain knowledge, context, frequency of use)

The UX Book- Process and Guidelines for Ensuring a Quality User Experience, Rex Hartson

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What is being measured?

- performance
  - is the system functional? (usability aspects)
  - rational aspect, quantitative evaluation
  - " *Performance is all about what the user actually does in interacting with the product* ."
- satisfaction
  - is the system easy, pleasant to use? (aspects of satisfaction)
  - emotional aspect, qualitative evaluation
  - " *Satisfaction is all about what the user says or thinks about his interaction with the product* ."

Albert, William, and Thomas Tullis. Measuring the user experience: collecting, analyzing, and presenting usability metrics.

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UX metrics and measures

- UX measure – what is being measured/evaluated?
  - Objective measures
  - Subjective measures
  - Usability, satisfaction
- UX metrics - describes the kind of value to be obtained for a UX measure
  - Time to complete a task
  - Number of errors
  - …

The UX Book- Process and Guidelines for Ensuring a Quality User Experience, Rex Hartson

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Usability

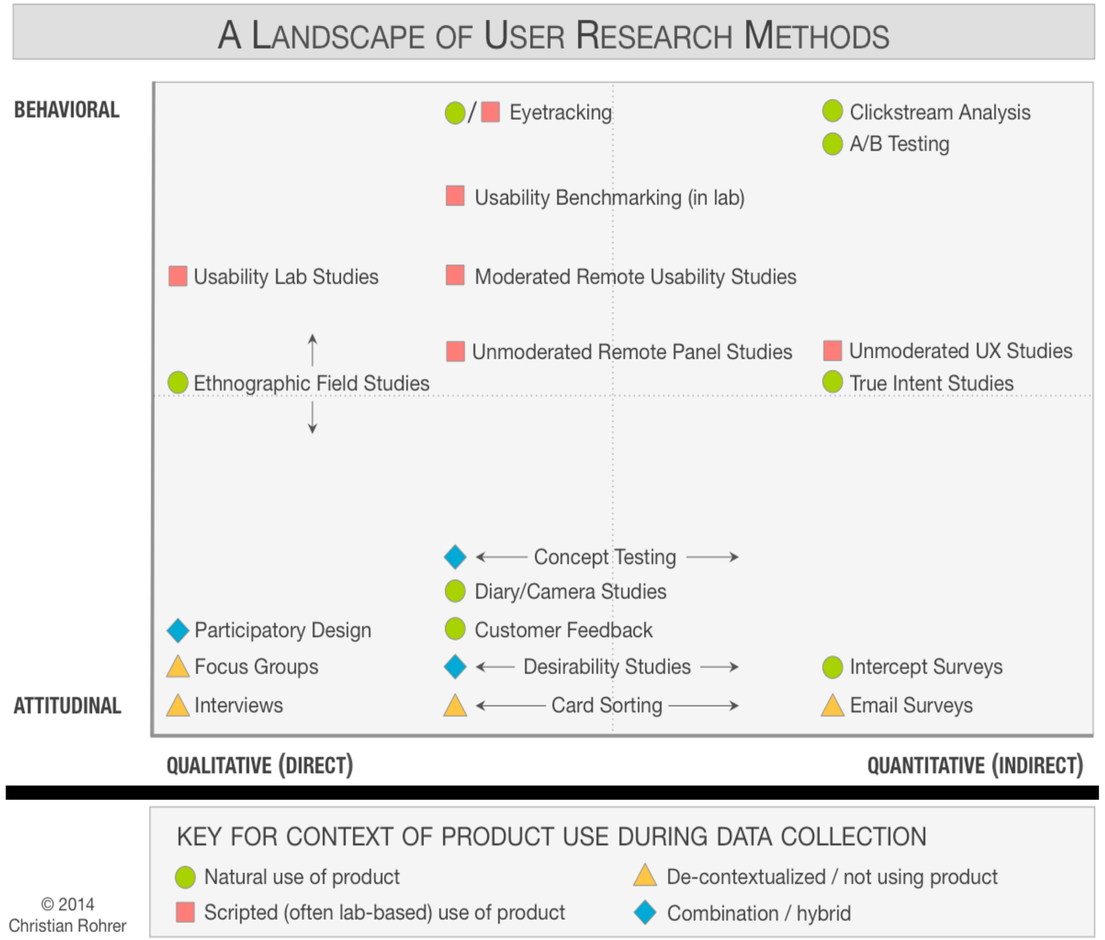
- Effectiveness
  - **how successful?** - successful achievement of objectives with high accuracy
- Efficiency
  - **how fast** - speed of achieving goals
- engagement / satisfaction
  - **how intuitive?** - the pleasantness of using the system and achieving the objectives
- fault tolerance
  - **what kind of error management?** - severity, frequency and ways of resolving errors (e.g. undo, smart error messages)
- learnability
  - **how easy is it to use?** - learning curve, initial required knowledge

The Basics of User Experience Design BY INTERACTION DESIGN FOUNDATION
https://www.interaction-design.org/ebook

Co-funded by the Erasmus+ Programme of the European Union

Method

- a systematic and repeatable approach to problem solving
- classification
  - attitude vs. behaviour - what users say or. how they behave
  - qualitative vs quantitative
  - context of use
- the right choice of method for the right problem / development phase of UX



https://www.nngroup.com/articles/which-ux-research-methods/
https://www.allaboutux.org/all-methods
http://www.designkit.org/methods

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UX metod classification

	Product Development Phase		
	Strategize	**Execute**	**Assess**
Goal:	Inspire, explore and choose new directions and opportunities	Inform and optimize designs in order to reduce risk and improve usability	Measure product performance against itself or its competition
Approach:	Qualitative and Quantitative	Mainly Qualitative (formative)	Mainly Quantitative (summative)
Typical methods:	Field studies, diary studies, surveys, data mining, or analytics	Card sorting, field studies, participatory design, paper prototype, and usability studies, desirability studies, customer emails	Usability benchmarking, online assessments, surveys, A/B testing

https://www.nngroup.com/articles/which-ux-research-methods/

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Which method to use?

https://www.nngroup.com/videos/when-use-which-ux-research-method/

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VR specifics

- Suitability of existing UX methods for UX, usability, sickness
- Presence & Immersion experience distractions during the evaluation
- Health & safety effects
  - Eye strain, photosensitivity
  - Fall injury
  - Hygiene
- Ergonomy
- Asocial behaviour
- **VR sickness aspects**

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VR sickness

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VR sickness terminology

- Different terminology
  - Cybersickness
  - VR Sickness (VRS)
  - Visually-Induced Motion Sickness (VIMS)
  - Virtual Reality-Induced Sympotms and Effects (VRISE)
  - Simulator Sickness (SS)
- Very common, approx. 50% - 80% of users report some VR sickness effects

S. Bruck and P. A. Watters, “Estimating Cybersickness of Simulated Motion Using the Simulator Sickness Questionnaire (SSQ): A Controlled Study,” in *2009 Sixth International Conference on Computer Graphics, Imaging and Visualization*, Tianjin, China, Aug. 2009, pp. 486–488.

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VR sickness effects

- Similar to travel/motion sickness, but caused only by a visual representation of movement
- VR Sickness symptoms are stronger and more pronounced; occur within a shorter time of exposure to stimuli
- Common symptoms: disorientation, dizziness, paleness, sweating, increased salivation, fatigue, apathy, headache, stomach awareness, postural response (loss of balance), nausea, eye discomfort, difficulty concentrating…
- Symptoms may persist for several hours or even days after the experience
- Polysymptomatic (has several different symptoms) and polygenic (expressed symptoms vary by each individual)

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Different origin theories

- Poison Theory
- Postural Instability Theory
- Eye Movement Theory
- Scene Instability
- Sensory Conflict Theory - a user's perception of self-motion is based on incongruent sensory inputs from the visual system, vestibular system, and non-vestibular proprioceptors
- Rest Frame Theory – rest frame as a reference for spatial judgement

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Key factors

- Factors influencing VR Weakness (over 40 factors already detected)
  - The illusion of movement caused by visual stimuli (Vection);
  - Vergence-Accommodation conflict
- 1. Individual factors
    - Age and gender
    - Illness, stress, insomnia, fatigue
    - Susceptibility to travel sickness
- 2. Technology factors
  - Motion-to-photons Latency
  - Tracking errors, poor calibration
  - Optical distortion, blurred image
  - Realism of visual depiction of the image
  - Field-of-View (FOV)
  - Flicker
  - Ergonomics
- 3. Task performance / content
  - Activity / passivity during the virtual experience;
  - Duration of virtual experience;
  - The position of the user during the virtual experience (sitting / standing)
  - Interaction and locomotion methods

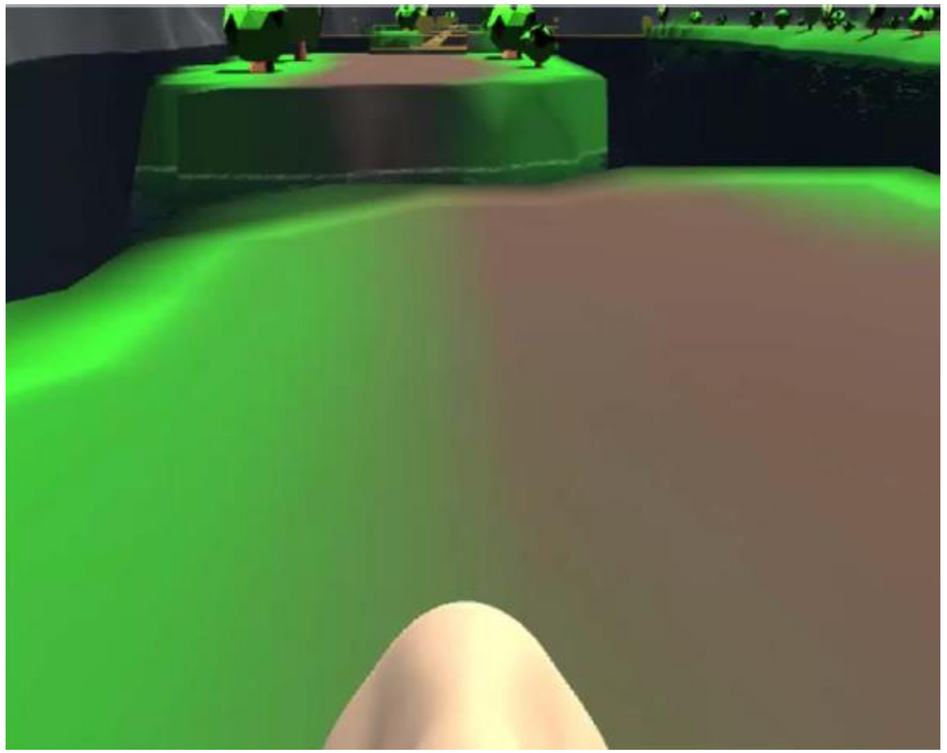
L. R. Rebenitsch, “Cybersickness prioritization and modeling,” Ph.D. Thesis, Michigan State University, East Lansing, MI, USA, 2015

Reference and Rest frames

- **REFERENCE FRAME -** A coordinate system with respect to which positions, orientations and motions can be judged
- **REST FRAME -** The particular reference frame which a given observer takes to be stationary
  - Egocentric RF (Player-fixed Rest Frame) – centered on the user
  - Alocentric RF – centered at an external point in the environment
- Independent Visual Background (IVB)
  - Alternative static rest frame – at a distance and independent of user

Nguyen-Vo, Thinh, Bernhard E. Riecke, and Wolfgang Stuerzlinger. "Simulated reference frame: A cost-effective solution to improve spatial orientation in vr." *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 2018.

Nose – egocentric RF



Wienrich, C.; Weidner, C.K.; Schatto, C.; Obremski, D.; Israel, J.H. ***A Virtual Nose as a Rest-Frame—The Impact on Simulator Sickness and Game Experience***. In Proceedings of the 2018 10th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games), Würzburg, Germany, 5–7 September 2018; IEEE: Wurzburg, Germany, 2018; pp. 1–8.

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Armour– alocentric RF

Z. Cao, J. Jerald, and R. Kopper, "***Visually-Induced Motion Sickness Reduction via Static and Dynamic Rest Frames***," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, Reutlingen, Germany, Mar. 2018, pp. 105–112.

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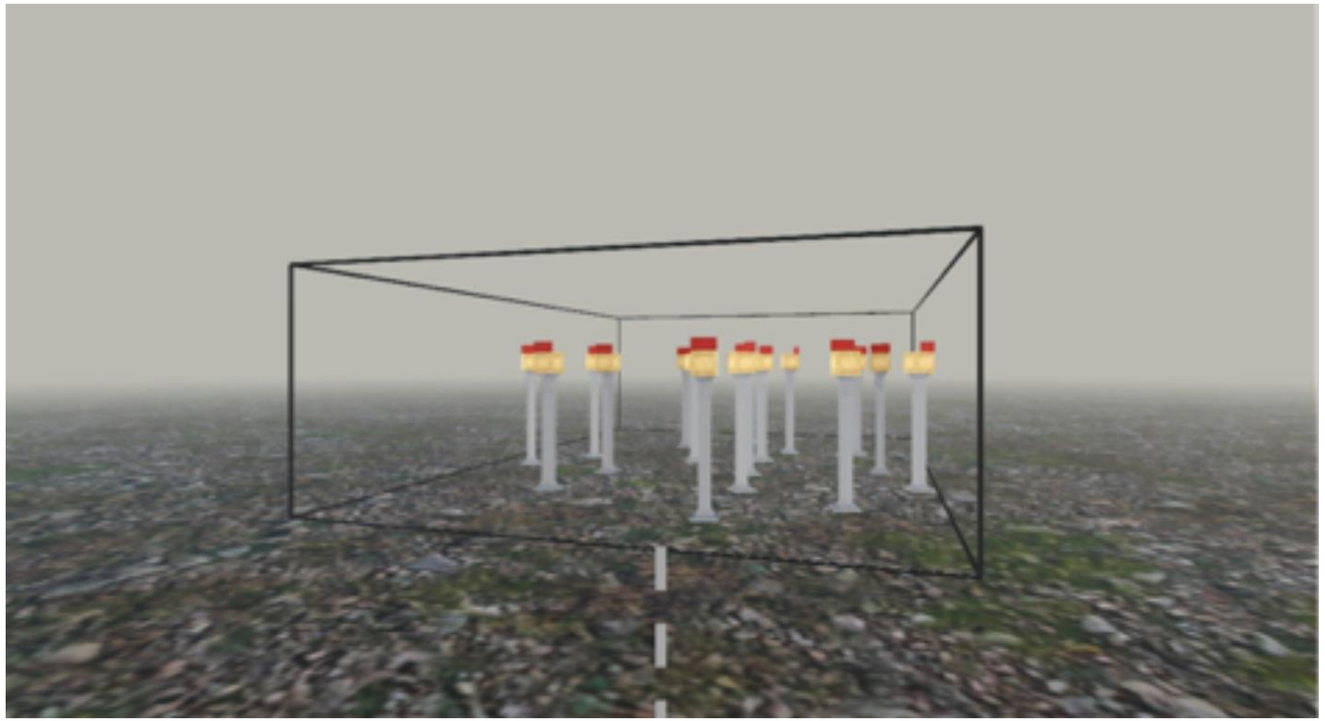
Room boundary – alocentric RF



Nguyen-Vo, T.; Riecke, B.E.; Stuerzlinger, W. ***Simulated Reference Frame: A Cost-Effective Solution to Improve Spatial Orientation in VR***. In Proceedings of the 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Reutlingen, Germany, 18–22 March 2018; IEEE: New York, NY, USA, 2018; pp. 415–422

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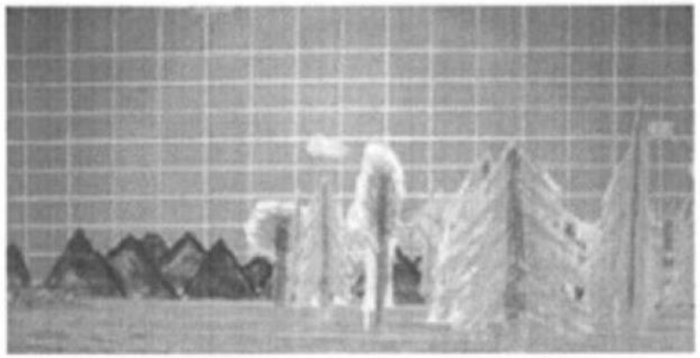
Grid/clouds - Independent Visual Background



GRID IVB

CLOUD IVB

J. J.-W. Lin, H. Abi-Rached, D.-H. Kim, D. E. Parker, and T. A. Furness, "***A 'Natural' Independent Visual Background Reduced Simulator Sickness***," in *Human Factors and Ergonomics Society Annual Meeting*, Baltimore, MD, USA, Sep. 2002, vol. 46, pp. 2124–2128.

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EXAMPLE - spectacles

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EXAMPLE – transparent spectacles

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EXAMPLE - shades

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EXAMPLE - sword

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EXAMPLE – baseball hat

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EXAMPLE - nose

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Rest frame theory

- VR sickness does not arise directly from the mismatch between visual, vestibular, and proprioceptive sensory perceptions, but from opposing RFs indicated by these perceptions
- The way these signs are interpreted - influence the sense of what is and what is not stationary
- VR sickness - linked to the internal mental model of what should be stable
- RF allows for the existence of a mismatch between the senses without causing VR Weakness if these conflicting perceptions are not essential to the stability of the RF

J. D. Prothero and D. E. Parker, “A Unified Approach to Presence and Motion Sickness,” in *Virtual and adaptive environments: Applications, implications, and human performance issues*, Boca Raton, FL, USA: CRC Press, 2003, pp. 47–66.

Alleviating the VR sickness effects

- Habituation (Adaptation) to VR experience
- Proper design of user interface and interactions
- Locomotion that avoids the sensation of movement that does not match the movement of the user (movement in space, multi-directional treadmill, redirected walking)
- Rapid acceleration and braking or the use of teleports for movement in virtual space should be avoided
- Stimulation of the senses (haptic, tactile, smell, hearing - moving sound source, wind, etc.)
- Stimulation of the vestibular system (GVS - Galvanic Vestibular Stimulation, GCS - Galvanic Cutaneous Stimulation, BCV - Bone Conducted Vibration)
- FOV reduction (FOVR) or motion blur (Peripheral Blurring - PB, Rotation Blurring - RB)
- Selective rendering of the image quality (Foveated rendering) in the part detected by the yellow spot
- Adaptive displays, which allow you to increase the resolution and refresh time in selected parts of the VR image
- Use of low persistence screens that do not cause blurred images when moving
- Fast screen refresh time (90 Hz and more) and low delay time (Photons-to-Motions Latency)
- Use of stationary reference frames

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VR sickness evaluation

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UX evaluation in VR

- Objective
  - Psychophysical measurements: skin conductivity, skin temperature, heart rate, respiration rate
  - Postural stability
  - Eye-tracking
- Subjective
  - Questionnaire based methods: UEQ, VRNQ, SPES, SUDS, SSQ, FMS, VAS, …
  - Observation
  - Semi-structured interview

SSQ – Simulator Sickness Questionnaire
SUDS – Subjective Units of Distress Scale
VAS – Visual Analogue Scale
VRSQ – Virtual Reality Symptom Questionnaire
FMS – Fast Motion Sickness score
VRNQ – Virtual Reality Neuroscience Questionnaire

UX evaluation methods

	User Experience Questionnaire (UEQ)	User Experience Questionnaire short (UEQ-S)	Spatial Presence Experience Questionnaire (SPES)	Virtual Reality Neuroscience Questionnaire (VRNQ)
Type	Subjective Questionnaire	Subjective Questionnaire	Subjective Questionnaire	Subjective Questionnaire
Purpose	UX	UX	Presence	Assessing VRISE, user experience, game mechanics and in-game assistance
Number of Questions	26	8	8 (4+4)	20 (5x4)
Scoring	7-point Likert scale (scored from -3 to 3)	7-point Likert scale (scored from -3 to 3)	5-point Likert scale (scored from 1 to 5)	7-point Likert scale (scored from 1 to 7)
Sub-scales	Yes: usability aspects (efficiency, perspicuity, dependability) and user experience aspects (attractiveness, stimulation, novelty)	Yes: pragmatic, hedonic, overall	Yes: user self-location, possible actions	Yes: User Experience, Game mechanics, In-game assistance, VRISE
Execution	After scenario	After scenario	After scenario	After scenario
Administration time	Slow (e.g. 10 min)	Fast (e.g. 1 min)	Medium (e.g., 2–5 min)	Medium (e.g., 2–5 min)
Complexity	High	Medium	Medium	Low
Calculation needed	Yes	Yes	Yes	Yes
Suitable for quick assessment	No	No	No	No

VR sickness evaluation methods

	Simulator Sickness Questionnaire (SSQ)	Subjective Units of Distress Scale (SUDS)	Fast Motion Sickness Score (FMS)	Virtual Reality Neuroscience Questionnaire (VRNQ)
Type	Subjective Questionnaire	A single-item	A single-item (verbal rating scale)	Subjective Questionnaire
Purpose	Assessing VRISE	Assessing physical discomfort related VRISE symptoms	Assessing nausea related VRISE symptoms	Assessing VRISE, user experience, game mechanics and in-game assistance
Number of Questions	16	1	1	20 (5x4)
Scoring	0 (none), 1 (slight), 2 (moderate), 3 (severe)	from 0 to 100(10)	from 0 to 20	7-point Likert scale (scored from 1 to 7)
Sub-scales	Yes: Disorientation (SSQ-D), Nausea (SSQ-N), Oculomotor (SSQ-O)	No	No	Yes: User Experience, Game mechanics, In-game assistance, VRISE
Execution	Before and after scenario	Before and after scenario	Before, during, and after scenario	After scenario
Administration time	Medium (e.g., 5 min)	Very fast (e.g., 15 s)	Very fast (e.g., 15 s)	Medium (e.g., 2–5 min)
Complexity	Medium	Very low	Very low	Low
Calculation needed	Yes	No	No	Yes
Suitable for quick assessment	No	Yes	Yes	No

UEQ - User Experience Questionnaire

- Validated UX questionnaire
- Full (26 questions) and short (8 questions) form

https://www.ueq-online.org

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UEQ - example

English version

Short

obstructive	o o o o o o o	supportive
complicated	o o o o o o o	easy
inefficient	o o o o o o o	efficient
confusing	o o o o o o o	clear
boring	o o o o o o o	exciting
not interesting	o o o o o o o	interesting
conventional	o o o o o o o	inventive
usual	o o o o o o o	leading edge

Full (part of questionnaire)

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13

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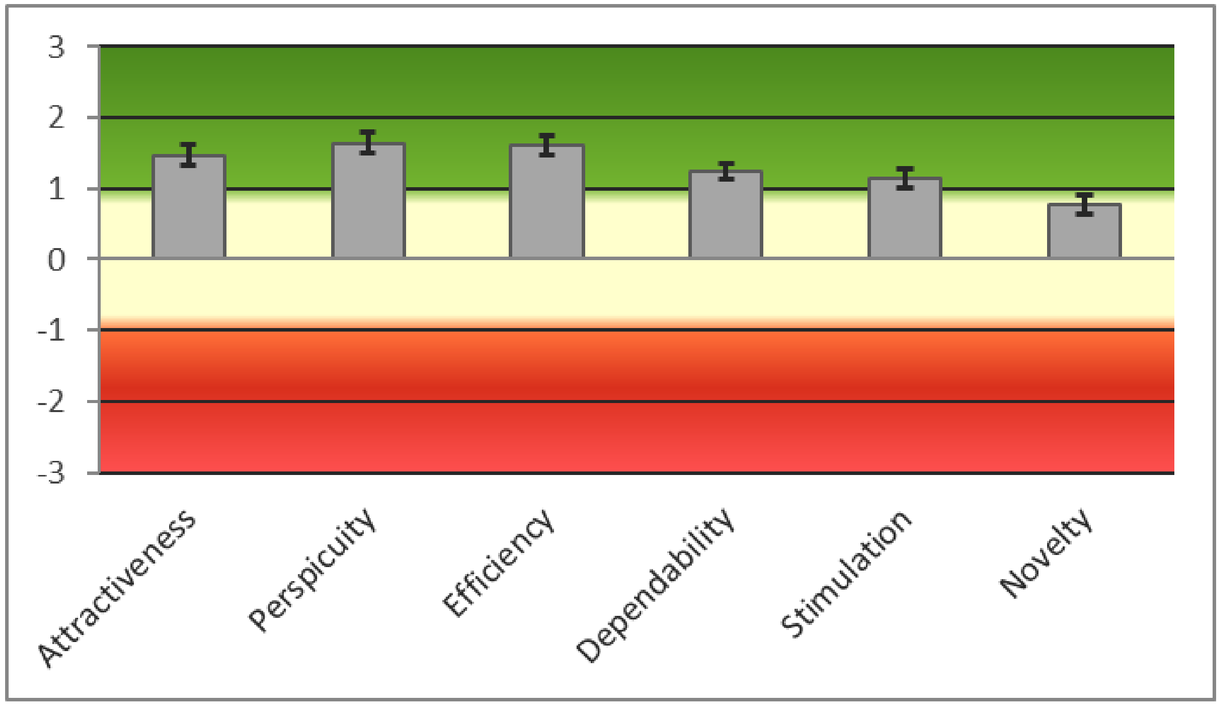
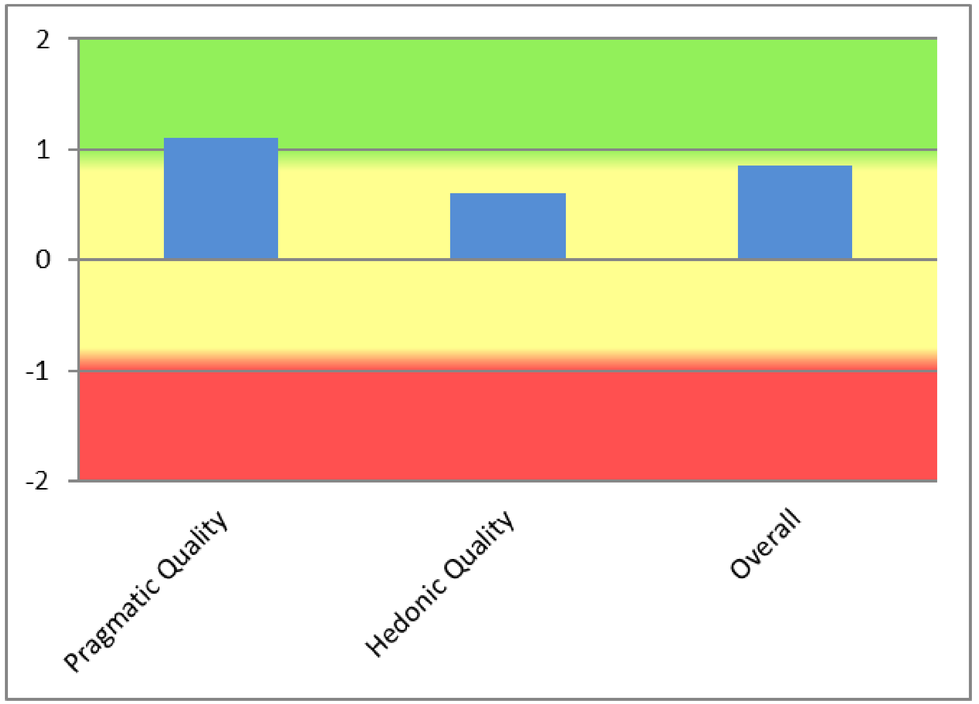
Data analysis (handbook&excel tool)

- Pragmatic & hedonic aspects



Full form



Short form

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SSQ - Simulator Sickness Questionnaire

- VRISE validated questionnaire for VR sickness
- 16 questions, 4-point Likert scale
- Measures 4 sub-scales
  - Nausea (N)
  - Oculomotor (O)
  - Disorientation (D)
  - Total score (TS)

General discomfort	None	Slight	Moderate	Severe

Kennedy, Robert S., et al. "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness." The international journal of aviation psychology 3.3 (1993): 203-220.

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SSQ - example

None = 0
Slight = 1
Moderate = 2
Severe = 3

Score
Nausea = [1] × 9.54
Oculomotor = [2] × 7.58
Disorientation = [3] × 13.92
Total Score = ([1] + [2] + [3]) *3.74

Symptoms	Weights for Symptoms Nausea	Oculomotor	Disorientation
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eye strain		1	
Difficulty focusing		1	1
Increased salivation	1		
Sweating	1		
Nausea	1		1
Difficulty concentrating	1	1	
Fullness of head			1
Blurred vision		1	1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo			1
Stomach awareness	1		
Burping	1		
Total*	[1]	[2]	[3]

Kennedy, Robert S., et al. "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness." The international journal of aviation psychology 3.3 (1993): 203-220.

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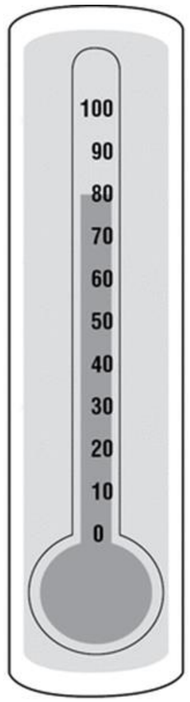
SUDS - Subjective units of distress scale

- Stress/anxiety evaluation
- Continuous one question based method
  - 0-10 or
  - 0-100 scale
- Fast



100 – Highest anxiety/distress that you have ever felt

90 – Extremely anxious/distressed

80 – Very anxious/distressed; can't concentrate. Physiological signs present.

70 – Quite anxious/distressed; interfering with functioning. Physiological signs may be present.

60 – Moderate-to-strong anxiety or distress

50 – Moderate anxiety/distress; uncomfortable, but can continue to function

40 – Mild-to-moderate anxiety or distress

30 – Mild anxiety/distress; no interference with functioning

20 – Minimal anxiety/distress

10 – Alert and awake; concentrating well

0 – No distress; totally relaxed

Note: "SUDS" stands for **"Subjective Units of Distress Scale."** Physiological signs may include, for example, sweating, shaking, increased heart rate or respiration, gastrointestinal distress.

Milosevic, Irena, and Randi E. McCabe, eds. Phobias: The Psychology of Irrational Fear: The Psychology of Irrational Fear. ABC-CLIO, 2015. ISBN 1610695763, 978161069576
http://www.oxfordclinicalpsych.com/view/10.1093/med:psych/9780199334513.001.0001/med-9780199334513-appendix-13

FMS – Fast Motion Sickness Scale

- Sickness evaluation, one question based, verbal
- Discrete 0-20 scale
- Fast
- How (sick) do you feel?
  - 0 (no sickness at all) - 20 (frank sickness)

Keshavarz, B.; Hecht, H. Validating an Efficient Method to Quantify Motion Sickness. Hum. Factors 2011, 53, 415–426.

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VR sickness

User study examples&lessons learnt

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Influence of video content type on users' virtual reality sickness perception and physiological response

Guna, Jože, et al. "Influence of video content type on users' virtual reality sickness perception and physiological response." Future Generation Computer Systems 91 (2019): 263-276.

Co-funded by the Erasmus+ Programme of the European Union

Study overview

- GOALS
  - Determine the influence of video content type on VR sickness
  - Determine the influence of participants' background (demographics, technical experience) on VR sickness
  - VR sickness response assessment by the SSQ, SUDS and physiological response methods
  - Experiment meta-evaluation (NASA-TLX)
- METHOD
  - 26 participants
  - Stimuli: 360-degree videos at:
    - different generations of VR devices (Oculus Rift DK1, DK2 and CV1)
    - Samsung portable display Gear VR
    - 2D widescreen TV screen - reference screen
  - 5 repetitions (counter balanced) views of two 360 videos
  - Relaxing content (beach) and action content (rollercoaster)
  - Objective physiological measurement: skin conductance (GSR, SCR), heart rate and skin temperature; respiration rate
  - Subjective self-assessment questionnaires: SSQ, SUDS, NASA-TLX

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Video content comparison

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Study environment

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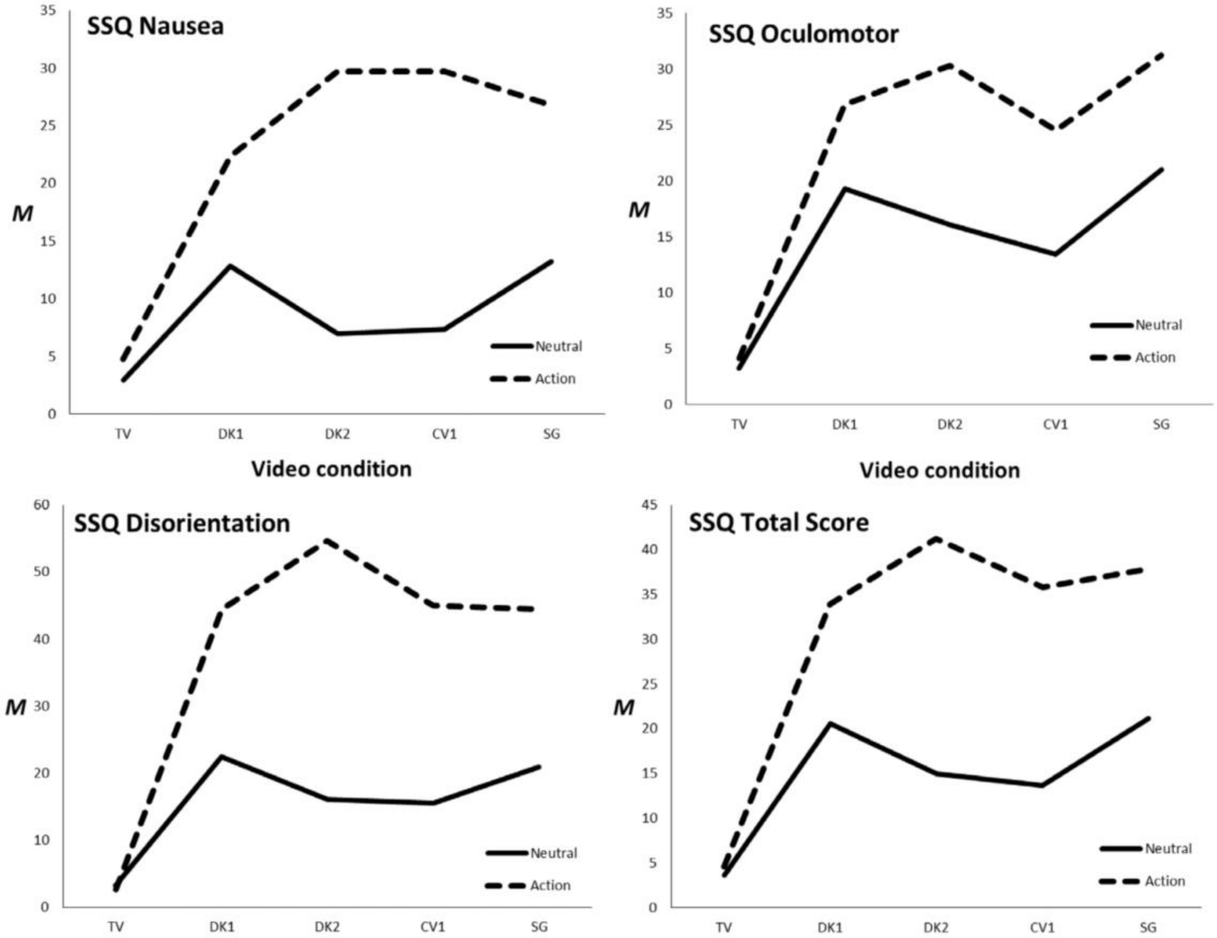
SSQ evaluation



- Highest reported sickness on SSQ-D and SSQ Total Score scale
- Distinct difference in experiencing low and high action content

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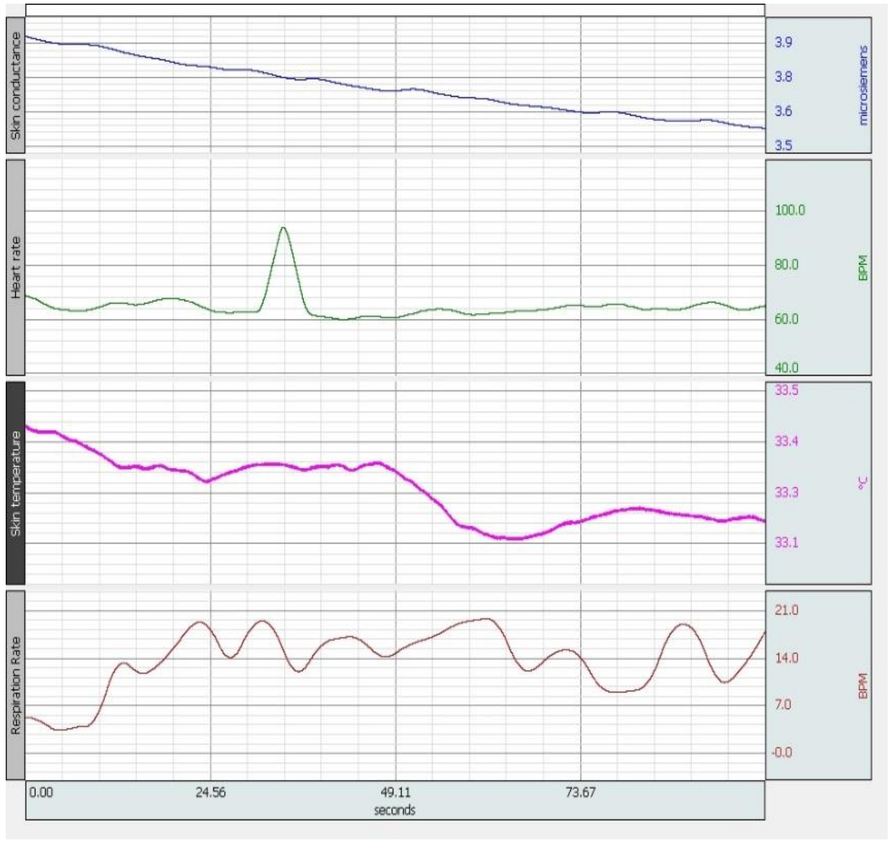
Physiological measurement



Relaxing video stimuli

High-action video stimuli

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Conclusions

- Confirmed content type influence on VR sickness
- Confirmed technology/device influence on VR sickness
- SSQ suitable method for VR sickness evaluation
- Electrodermal activity correlated with VR sickness effects (GSR, SCR)
- Participants' background as influencing factor on VR sickness
  - Higher preference to adrenaline sports -> lower observed VR sickness effects

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Estimating VR Sickness and user experience using different HMD technologies: An evaluation study

A. Somrak, I. Humar, M. S. Hossain, M. F. Alhamid, M. A. Hossain, and J. Guna, "Estimating VR Sickness and user experience using different HMD technologies: An evaluation study," Future Generation Computer Systems, vol. 94, pp. 302–316, May 2019.

Co-funded by the Erasmus+ Programme of the European Union

Study overview

- GOALS
  - Impact of technology on VR sickness
  - Suitability of the SUDS questionnaire for the evaluation of VR sickness
  - The suitability of the UEQ questionnaire for evaluating the user experience
  - Is it sufficient to evaluate VR sickness with SSQ-D subscale only?
- METHOD
  - 14 participants
  - Stimuli: 360-degree videos at:
    - different generations of VR devices (Oculus Rift DK1, DK2 and CV1)
    - Samsung portable display Gear VR
    - 2D widescreen TV screen - reference screen
  - 5 repetitions (counterbalanced) views of two 360 videos
  - Relaxing content (beach) and action content (rollercoaster)
  - Subjective self-assessment questionnaires: SSQ, SUDS, UEQ

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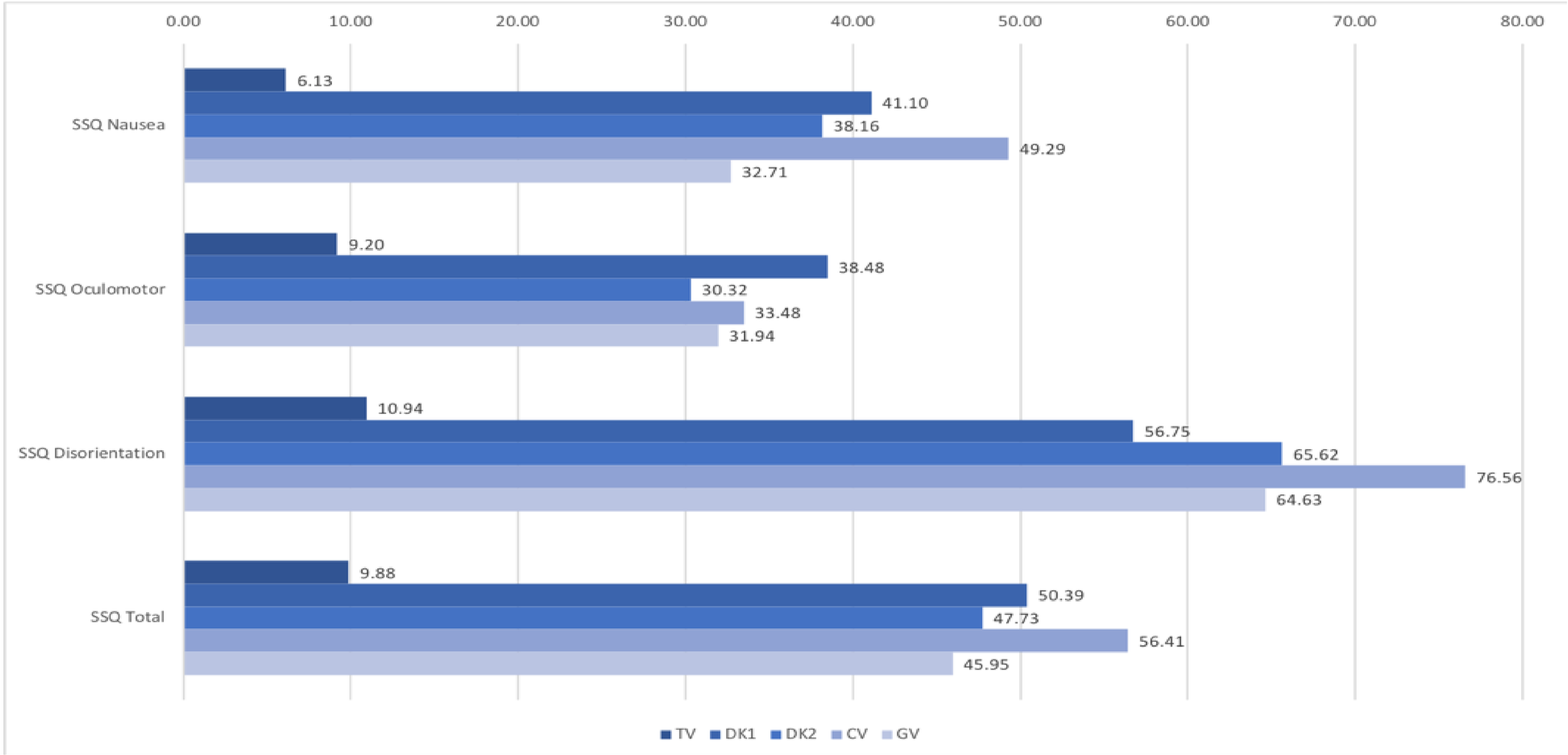
Average SSQ values by display devices



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Correlation matrix for Oculus CV1

- Spearman (ρ) correlation coefficients

Variables		1	2	3	4	5	6	7	8	9	10	11	12	13
1.	SSQ Nausea	1.000												
2.	SSQ Oculomotor	0.864**	1.000											
3.	SSQ Disorientation	0.922**	0.916**	1.000										
4.	SSQ Total	0.954**	0.936**	0.981**	1.000									
5.	SUDS	0.914**	0.863**	0.931**	0.935**	1.000								
6.	UEQ Attractiveness	-0.603*	-0.613*	-0.545	-0.587*	-0.495	1.000							
7.	UEQ Perspicuity	-0.220	-0.347	-0.352	-0.365	-0.271	0.598*	1.000						
8.	UEQ Efficiency	-0.163	-0.341	-0.161	-0.183	-0.039	0.698*	0.635*	1.000					
9.	UEQ Dependability	-0.549	-0.664*	-0.684*	-0.692*	-0.693*	0.520	0.800*	0.329	1.000				
10.	UEQ Stimulation	-0.075	-0.133	0.000	-0.068	0.021	0.669*	0.697*	0.845**	0.406	1.000			
11.	UEQ Novelty	0.069	0.047	0.131	0.106	0.212	0.246	0.482	0.714**	0.171	0.663*	1.000		
12.	UEQ Total Pragmatic	-0.369	-0.539	-0.472	-0.502	-0.382	0.824**	0.931**	0.771**	0.778**	0.785**	0.437	1.000	
13.	UEQ Total Hedonic	0.120	-0.014	0.055	0.023	0.155	0.497	0.677*	0.865**	0.268	0.866**	0.906**	0.671*	1.000

*p<0.05, **p<0.01 (2-tailed significance)

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Conclusions

- Display device type affects VR sickness (statistically significant between TV and VR displays and between DK1 and DK2)
- SUDS as a quick measure for assessing VR sickness can replace the SSQ questionnaire
- SSQ-D sub-scale is suitable for assessing VR sickness with a high
- Symptoms of disorientation are most pronounced and most common among VR users common
- The presence of VR sickness negatively affects the user experience
- UEQ is suitable for assessing user experience in virtual reality systems

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VIRTUAL TECHNOLOGIES @WESTERN BALKAN UNIVERSITIES

Impact of Different Types of Head-Centric Rest-Frames on VRISE and User Experience in Virtual Environments

A. Somrak, M. Pogačnik, and J. Guna, "Impact of Different Types of Head-Centric Rest-Frames on VRISE and User Experience in Virtual Environments, " Applied Sciences, vol. 11, no. 4, p. 1593, Feb.2021

Co-funded by the Erasmus+ Programme of the European Union

Study overview

- GOALS
  - Influence of head-on egocentric reference frames (SROs) on VR sickness, user experience, sense of presence, and gameplay performance
- METHODS
  - 44 participants (10 did not complete due to sickness, 22.7% Dropout rate)
  - Specifically developed 3D VR game (Unity), different scenes (forest, desert, village)
  - High and low action mode games, introductory level (2 min)
  - Two types of RF: glasses, baseball hat
  - VR display: Oculus Rift S HMD
  - 6 repetitions (2x3 repeated measures design, counter balanced)
  - Independent variables: game mode (2 levels), RF (3 levels)
  - Subjective self-assessment questionnaires: SSQ, FMS, VRNQ, UEQ-S, SPES
  - Enough rest time (min 5 min), FMS ≤ 1

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Comparison of game modes

Condition	Mode of the Game	Translation	Rotation	Additional Actions	Rest-Frames
LA_NORF	Low activity	Walking	Slow	No	No rest-frames
LA_RFG	Low activity	Walking	Slow	No	Glasses
LA_RFH	Low activity	Walking	Slow	No	Shield of a baseball hat
HA_NORF	High activity	Running	Fast	Yes, jumping	No rest-frames
HA_RFG	High activity	Running	Fast	Yes, jumping	Glasses
HA_RFH	High activity	Running	Fast	Yes, jumping	Shield of a baseball hat

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Average SSQ values - Users with past VR exp.

VRISE Scale	Condition	N	Mean	SD	Min Value	Max Value
SSQ Total	LA_NORF	17	23.76	19.88	0.00	63.58
	LA_RFG	17	24.42	18.94	3.74	71.06
	LA_RFH	17	31.90	27.77	0.00	93.50
	HA_NORF	17	34.76	33.58	0.00	112.20
	HA_RFG	17	32.12	23.62	3.74	78.54
	HA_RFH	17	27.28	23.42	0.00	67.32
SSQ Disorientation	LA_NORF	17	23.75	24.98	0.00	83.52
	LA_RFG	17	30.30	32.36	0.00	111.36
	LA_RFH	17	33.57	30.36	0.00	97.44
	HA_NORF	17	42.57	39.21	0.00	125.28
	HA_RFG	17	31.93	28.60	0.00	83.52
	HA_RFH	17	30.30	27.06	0.00	83.52
SSQ Nausea	LA_NORF	17	27.49	26.96	0.00	95.40
	LA_RFG	17	23.57	19.99	0.00	57.24
	LA_RFH	17	35.35	34.52	0.00	104.94
	HA_NORF	17	36.48	40.93	0.00	124.02
	HA_RFG	17	37.60	33.30	0.00	114.48
	HA_RFH	17	31.99	34.55	0.00	95.40
SSQ Oculomotor	LA_NORF	17	13.38	12.72	0.00	45.48
	LA_RFG	17	14.27	11.33	7.58	53.06
	LA_RFH	17	18.28	16.31	0.00	53.06
	HA_NORF	17	18.28	18.58	0.00	68.22
	HA_RFG	17	17.84	11.97	0.00	37.90
	HA_RFH	17	13.38	12.14	0.00	37.90

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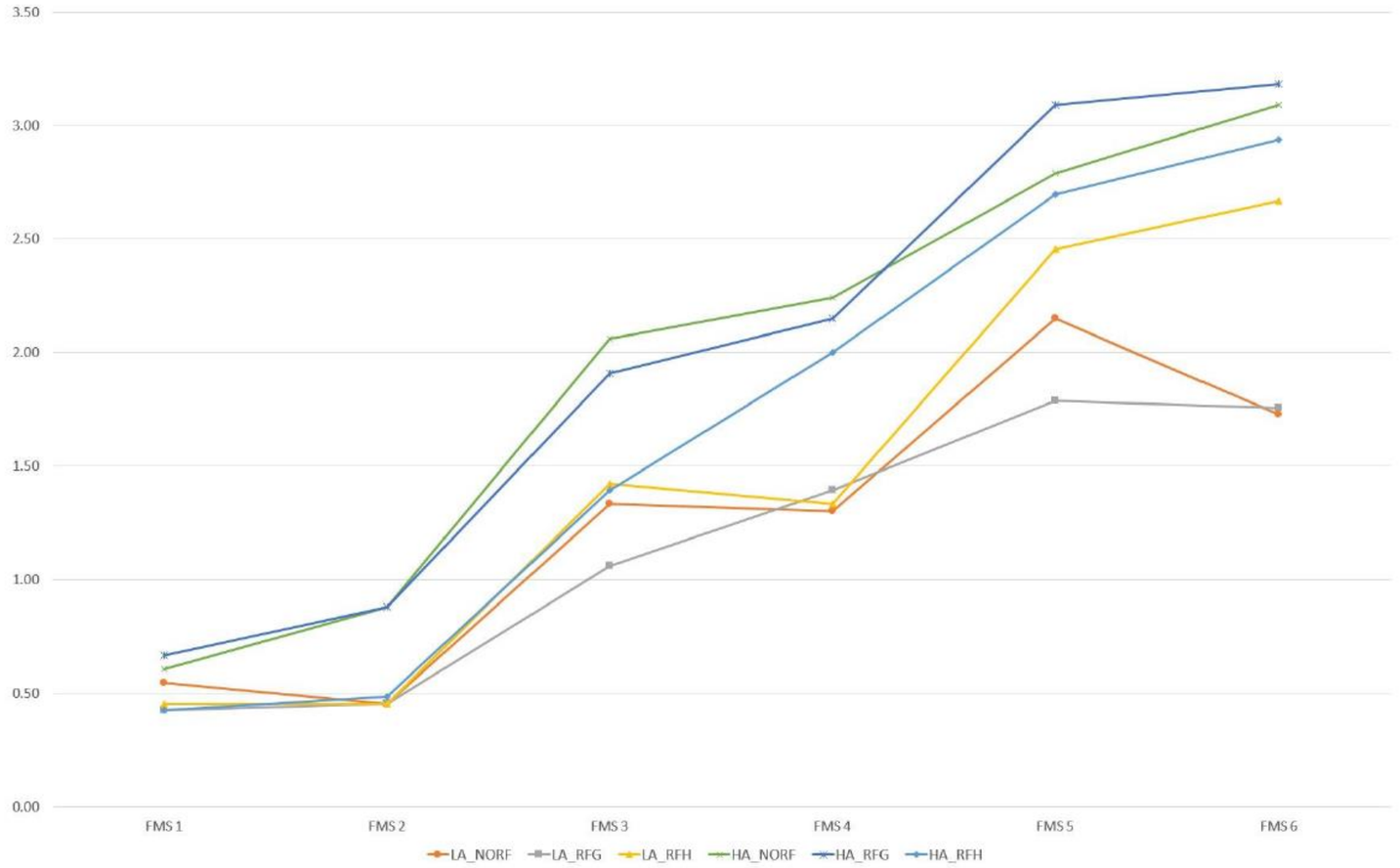
VR sickness over time - FMS questionnaire



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Conclusions

- We did not detect statistically significant differences in user experience and sense of presence, except when using RF glasses in low-action game mode
- RF did not influence user game performance (average score, time)
- RF glasses
  - more suited for users with previous VR experience
  - more suitable for users who wear glasses
  - double glasses (real and virtual) are not suitable
- RF hat is suitable for users who do not wear glasses
- RFs are suitable for use in VR applications, do not affect gaming performance, but have a small impact on the sense of presence and user experience

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Suitability and Comparison of Questionnaires Assessing Virtual Reality-Induced Symptoms and Effects and User Experience in Virtual Environments

A. Somrak, M. Pogačnik, and J. Guna, "Suitability and Comparison of Questionnaires Assessing Virtual Reality-Induced Symptoms and Effects and User Experience in Virtual Environments, " Sensors, vol. 21, no. 4, p. 1185, Feb. 2021,doiStk #: 10.3390 / s21041185.

Co-funded by the Erasmus+ Programme of the European Union

Study overview

- GOALS
  - Evaluation and comparison of standard methodologies for evaluating VR sickness and user experience
  - Suitability of the FMS questionnaire for evaluating VR sickness
  - Suitability of the UEQ-S questionnaire for user experience evaluation
  - Suitability of using the VRNQ questionnaire for evaluating VR sickness and user experience
  - The suitability of using the VRNQ questionnaire to assess the sufficient quality of VR software
- METHOD
  - 33 participants
  - Specifically developed 3D VR game (Unity)
  - High and low action mode games, introductory level (2 min)
  - Two types of RF: glasses, baseball hat
  - VR display: Oculus Rift S HMD
  - 6 repetitions (2x3 repeated measures design, counter balanced)
  - Interactivity - moving along a pre-designed path, picking up coins, jumping, opening doors, sightseeing in a VR environment
  - Subjective self-assessment questionnaires: SSQ, FMS, VRNQ, UEQ-S

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Virtual reality exposure time

- It includes both the playing time of the introductory level as well as all six repetitions of the script
- We compared groups by gender, gaming experience, and VR experience
- Statistically significant differences only between groups with gaming experience (Mann-Whitney test, Z = -2.621, p = 0.009)

(sub)Group	N	Mean	Minimum	Maximum	SD
All participants	32	18 min 39 s	14 min 21 s	27 min 17 s	3 min 13 s
Gender—males	24	18 min 15 s	14 min 21 s	25 min 32 s	3 min 7 s
Gender—females	8	19 min 52 s	15 min 53 s	27 min 17 s	3 min 25 s
Gaming experience—Yes	14	16 min 55 s	14 min 42 s	20 min 29 s	1 min 44 s
Gaming experience—No	18	20 min 0 s	14 min 21 s	27 min 17 s	3 min 30 s
VR experience—Yes	16	18 min 13 s	14 min 21 s	23 min 21 s	2 min 19 s
VR experience—No	16	19 min 5 s	14 min 42 s	27 min 17 s	3 min 57 s

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Average VR sickness for all 6 scenarios

VRISE Scale	N	Mean	SD	Min Value	Max Value
SSQ Total	33	26.86	22.09	0.00	84.77
SSQ Disorientation	33	28.82	26.09	0.00	95.12
SSQ Nausea	33	28.86	26.72	0.00	93.81
SSQ Oculomotor	33	15.81	15.34	0.00	78.33
FMS Average	33	1.57	1.85	0.00	6.64
VRNQ—VRISE subscale	32	31.36	3.61	20.33	35.00

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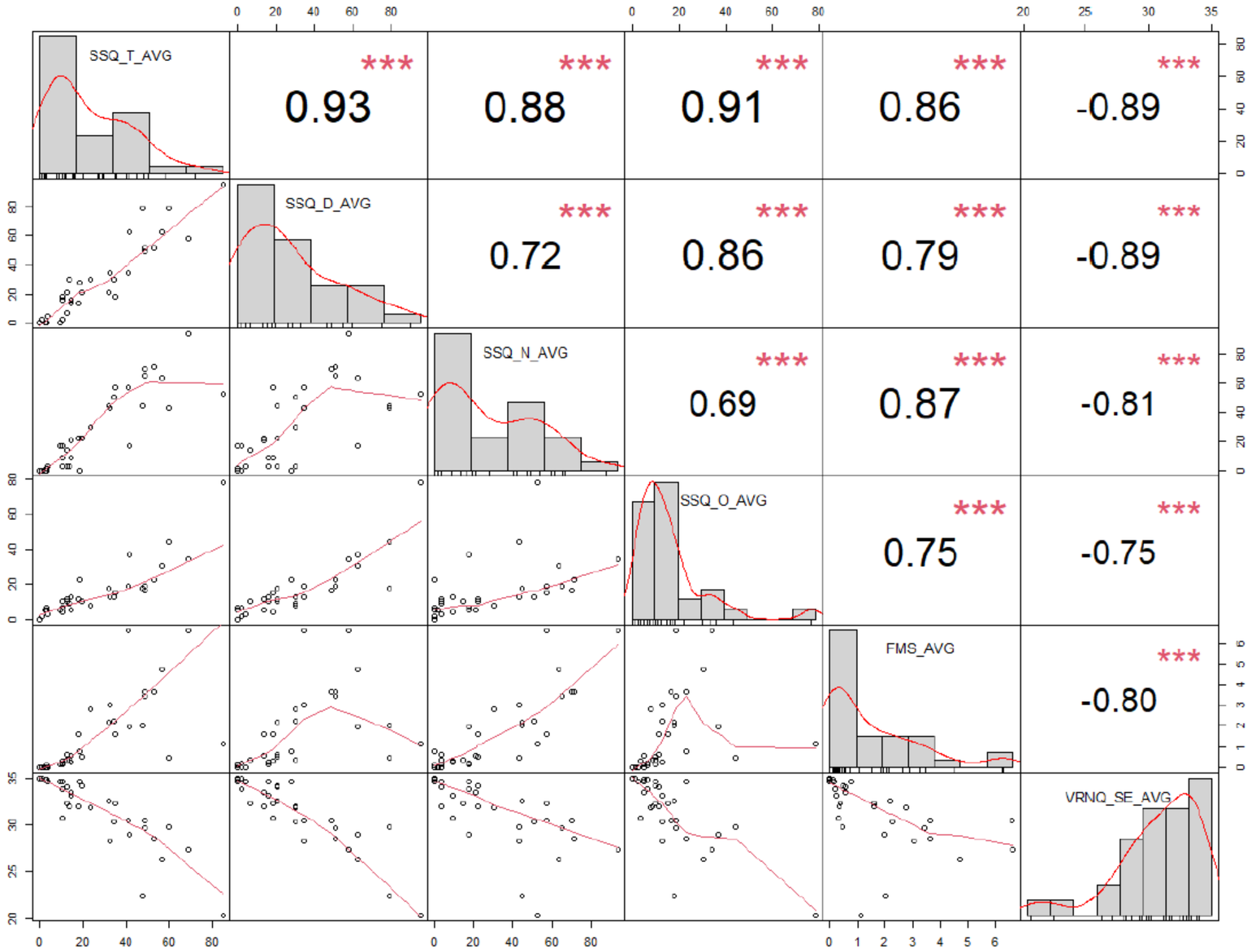
Correlation matrix for VR sickness

Spearman (ρ)



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Average user experience values for all 6 scenarios

User Experience Scale	N	Mean	SD	Min Value	Max Value
UEQ-S Overall	33	1.39	0.82	−0.15	3.00
UEQ-S Pragmatic Quality	33	1.75	0.72	0.33	3.00
UEQ-S Hedonic Quality	33	1.03	1.24	−1.71	3.00
VRNQ—User Experience subscale	33	24.19	4.06	17.00	31.67

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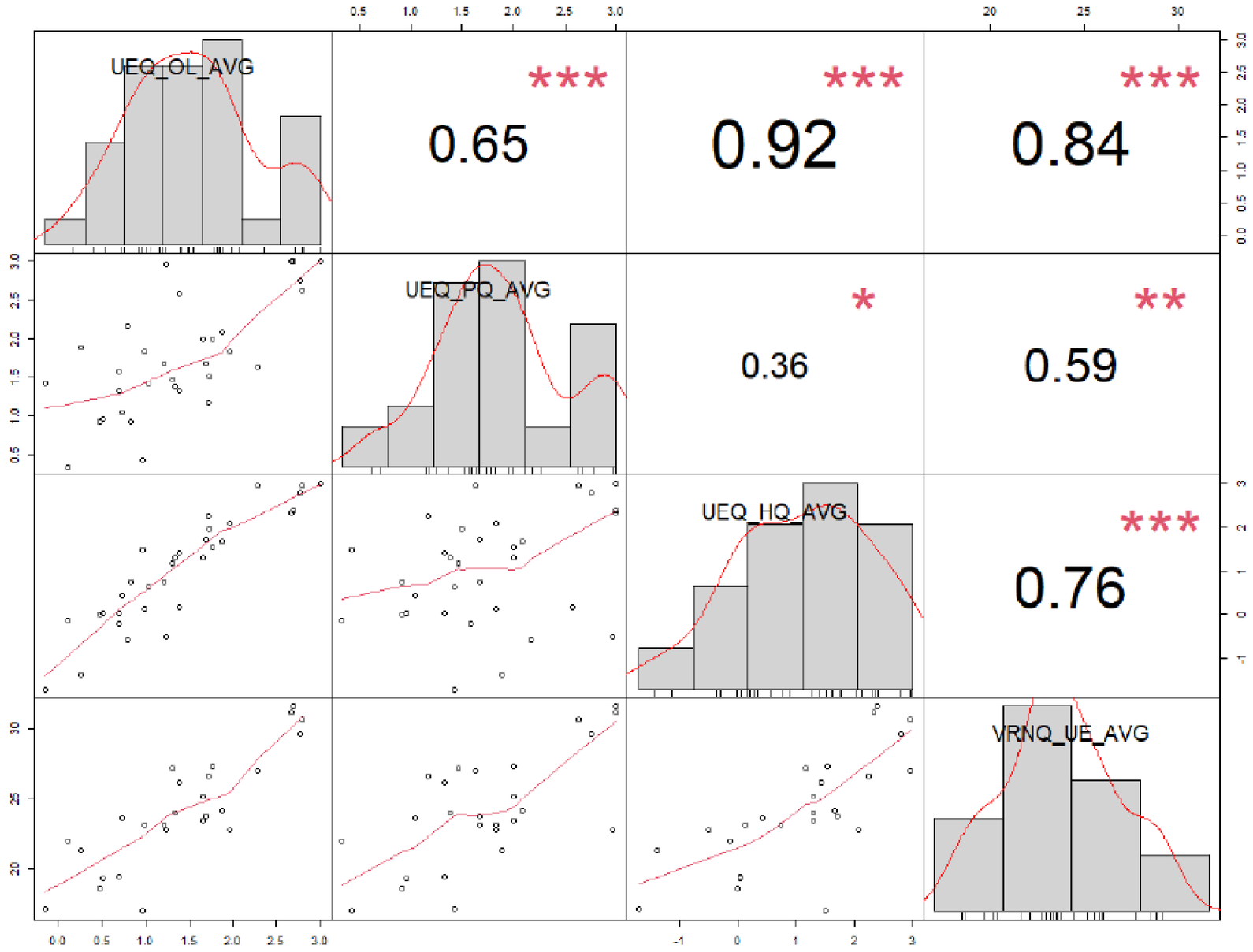
Correlation matrix for user experience



Spearman (ρ)

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Conclusions

- The FMS questionnaire is suitable for evaluating VR sickness and does not break presence/immersion
- VRNQ is suitable for the evaluation of VR sickness (VRISE subscale) and user experience (User Experience subscale)
- VRNQ is suitable for assessing sufficient software quality
- UEQ-S is suitable for evaluating the user experience in virtual reality (pragmatic and hedonic quality)

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Trends & Challenges

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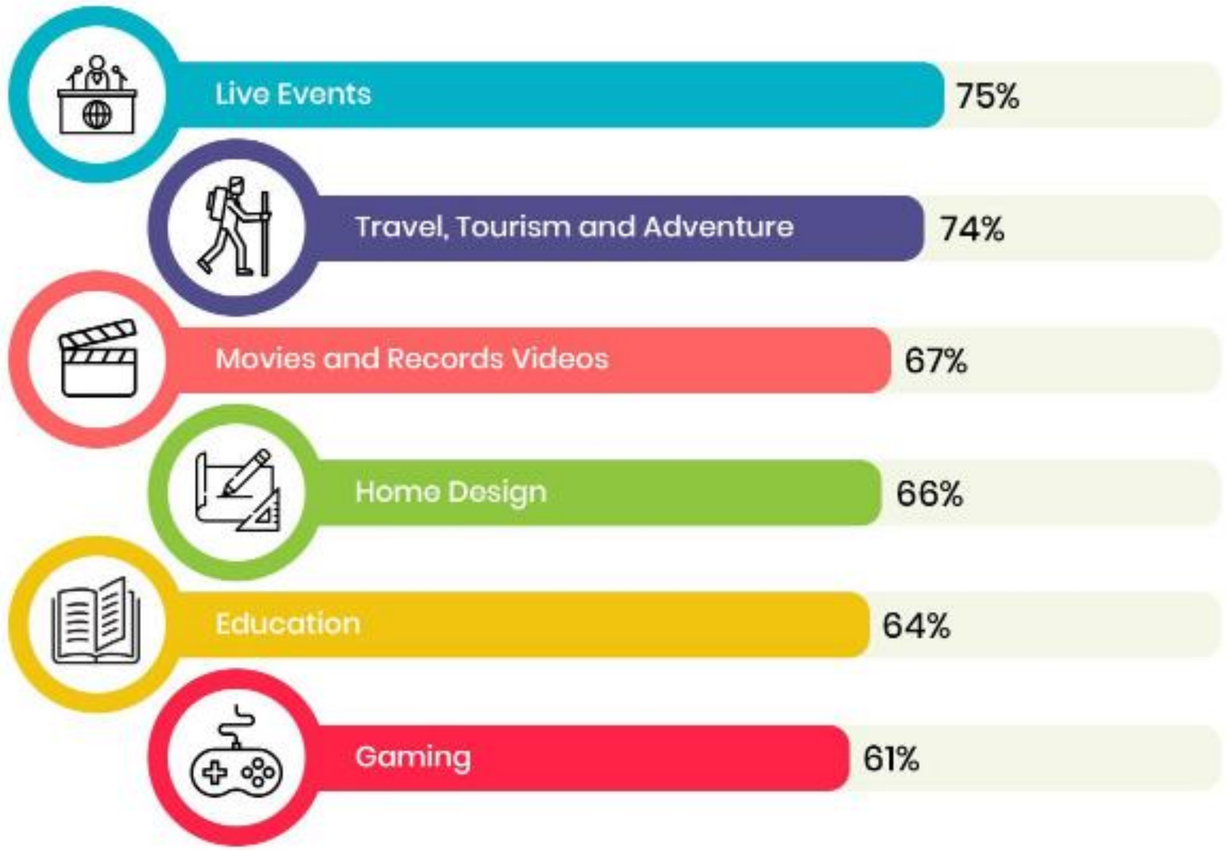
Trends

- More of everything
  - Resolution -> 4k+, 8k+
  - Framerate -> 60/90/120 Hz+
  - New display tech
- No wires – freedom of movement
- Eye-tracking
- VR and AR convergence
- Interactions & haptics
- Social multiplayer experiences
- Web VR/AR/MR
- CONTENT!!!



https://techtrends.tech/infographic/infographic-the-future-of-virtual-reality/

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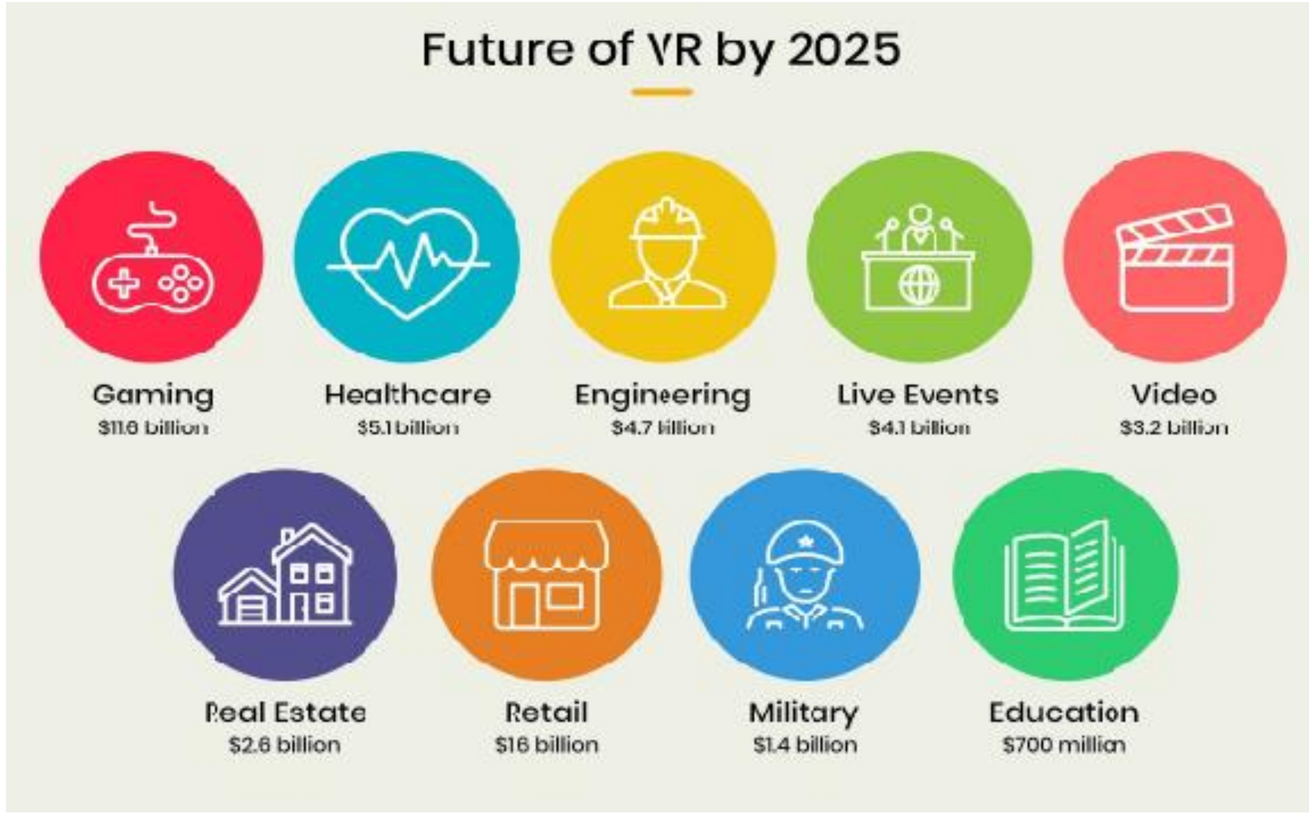
Challenges

„VR is like the first iPhone – a small number of people are extremely excited about it, but it's true power still hasn't been created"

- Well-being/medical effects
- Social effects (e.g. hikikomori)
- New UX design guidelines
- VR sickness
- Content&Apps
- …
- Do we actually need all this?



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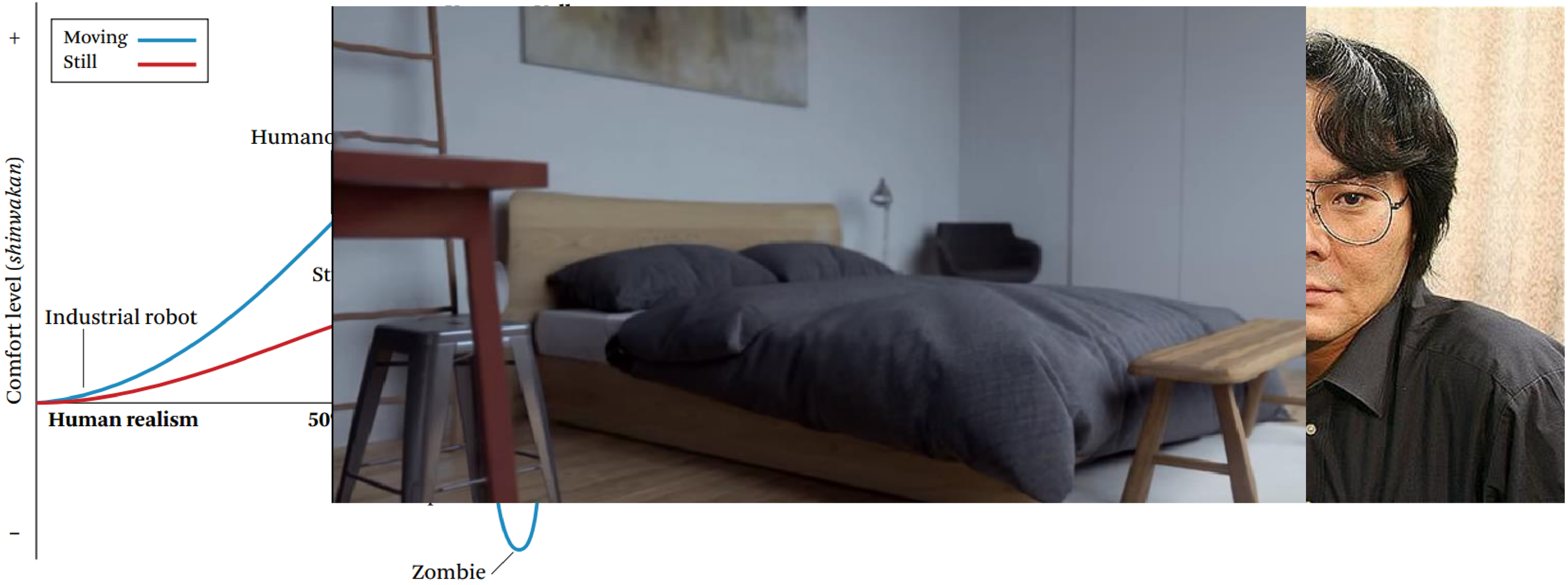
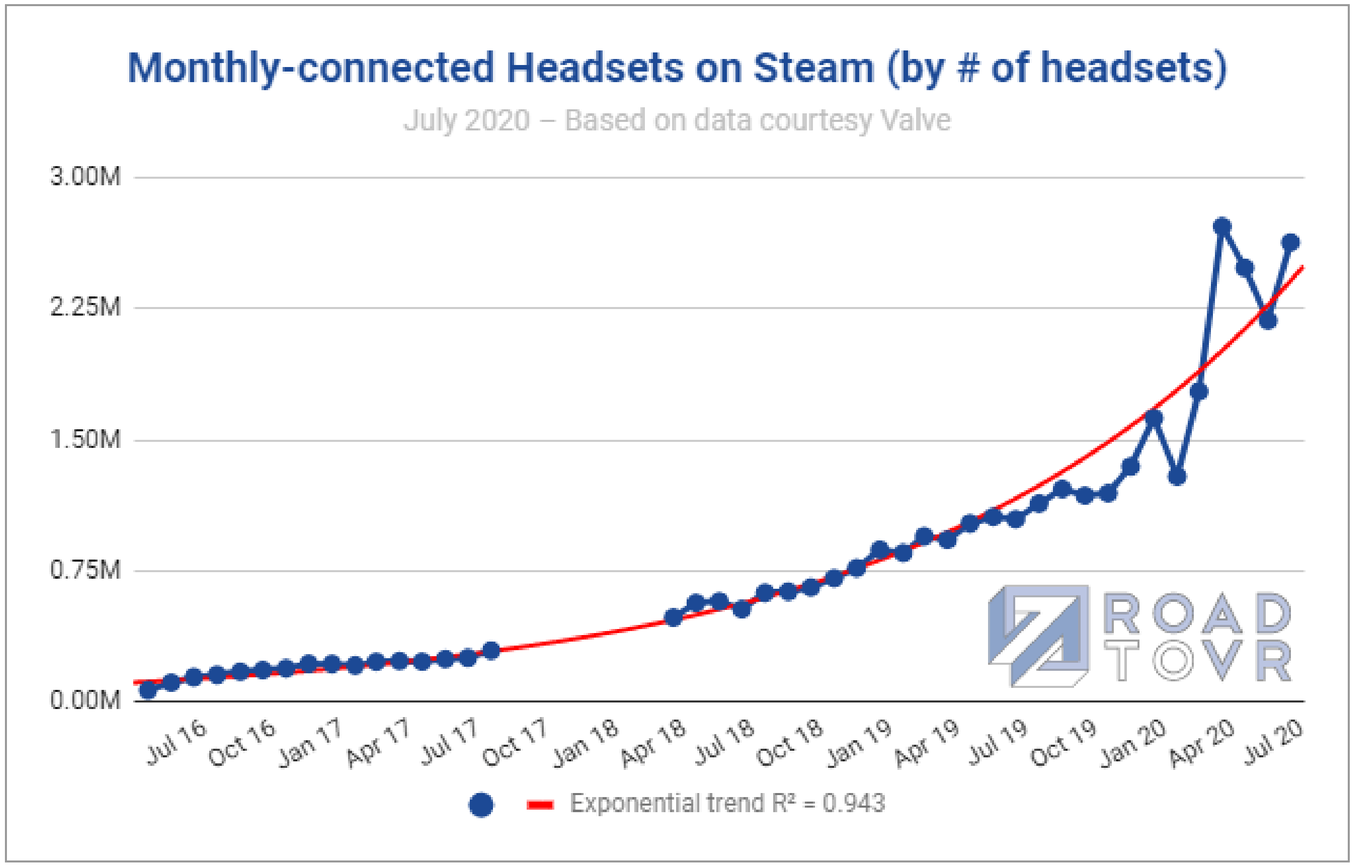
„Uncanny valley“



Ho and MacDorman 2010

Prof. Hiroshi Ishiguro

VR market data for 2020



https://www.roadtovr.com/steam-survey-vr-headset-growth-august-2020/

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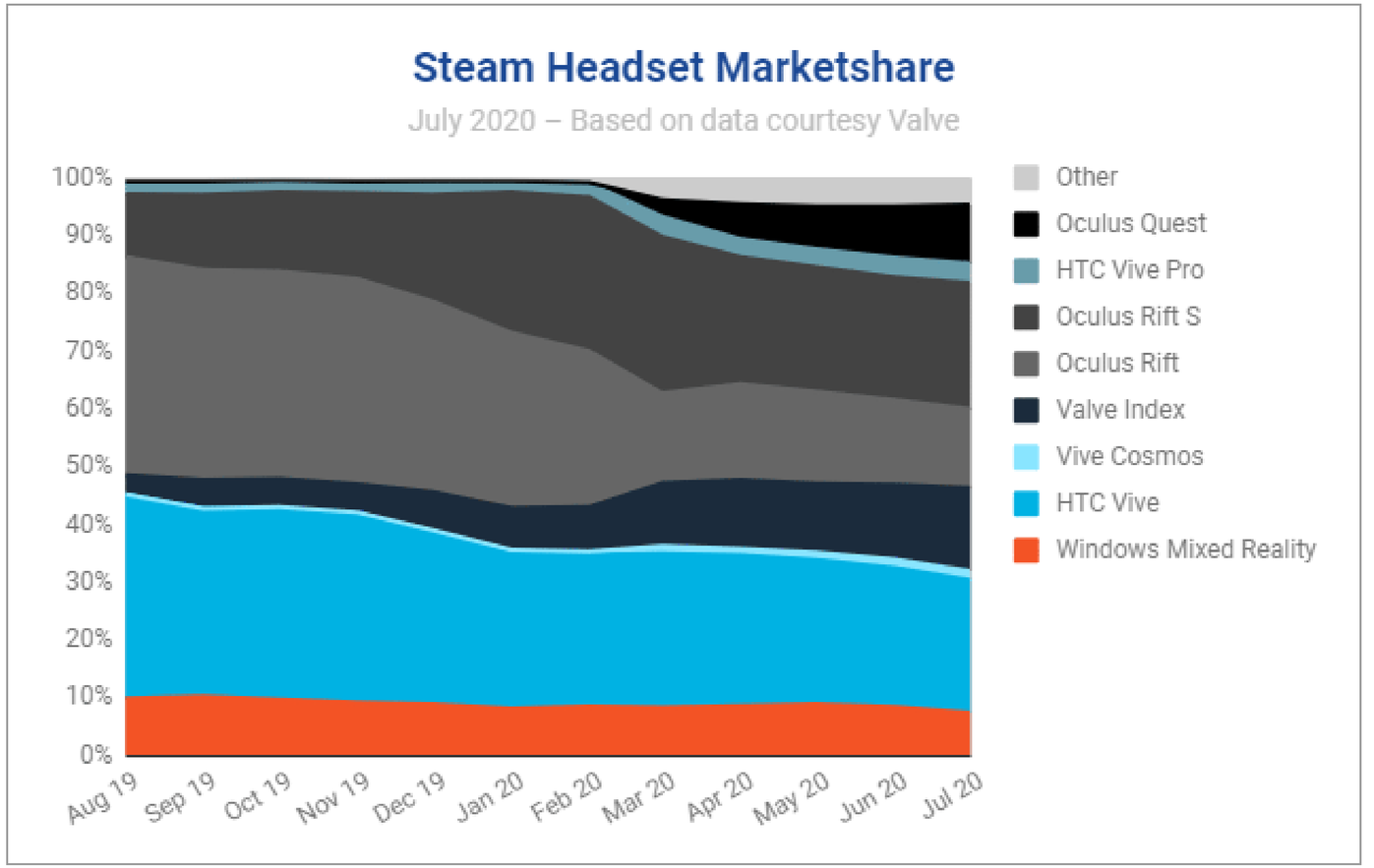
VR market data for 2020



https://www.roadtovr.com/steam-survey-vr-headset-growth-august-2020/

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Varjo Workspace

https://varjo.com

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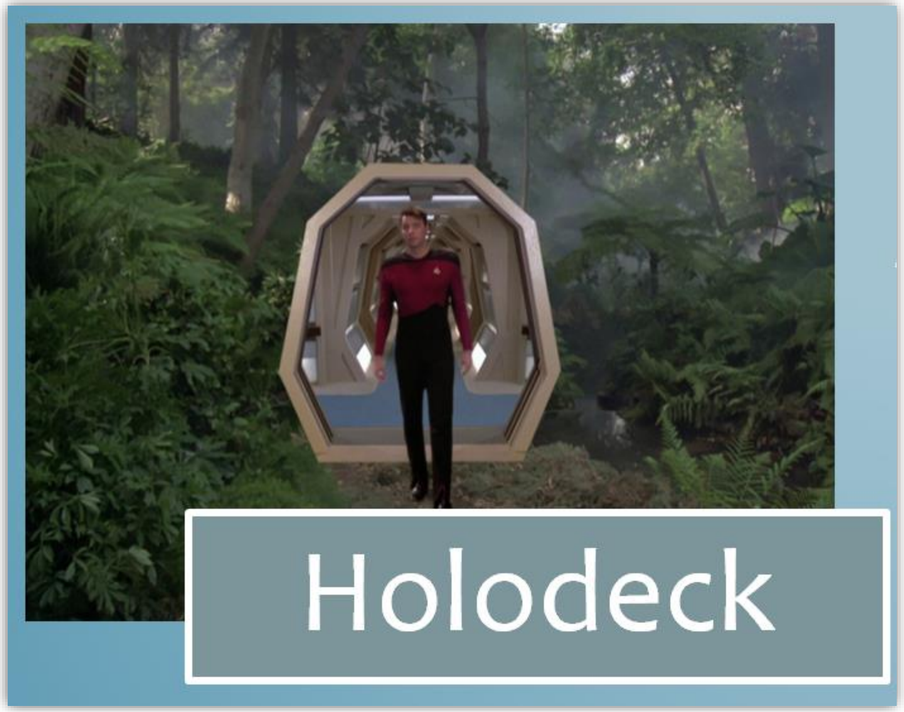
The Future?



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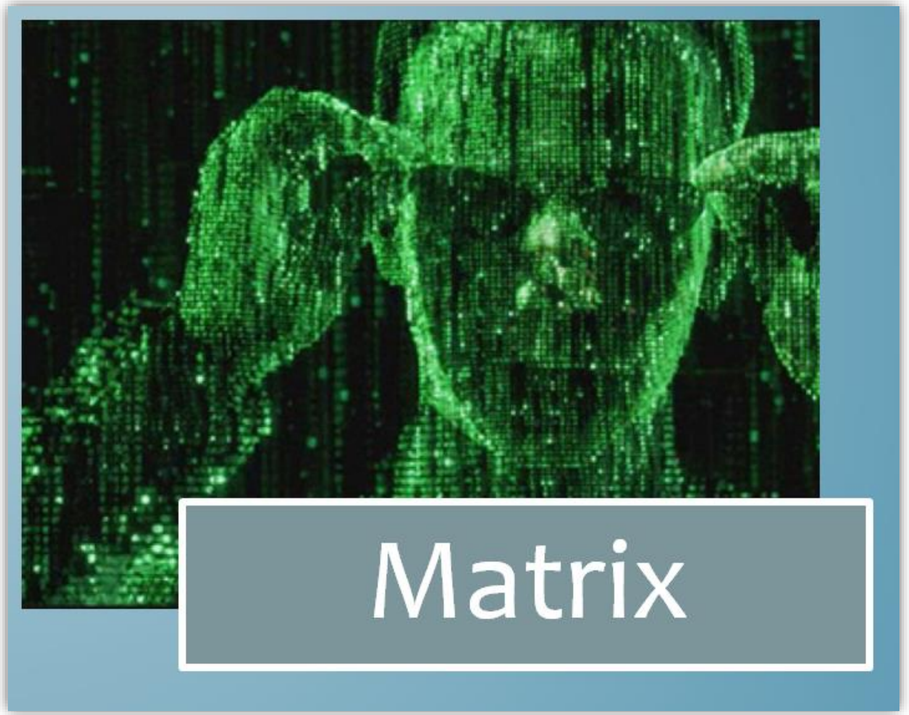

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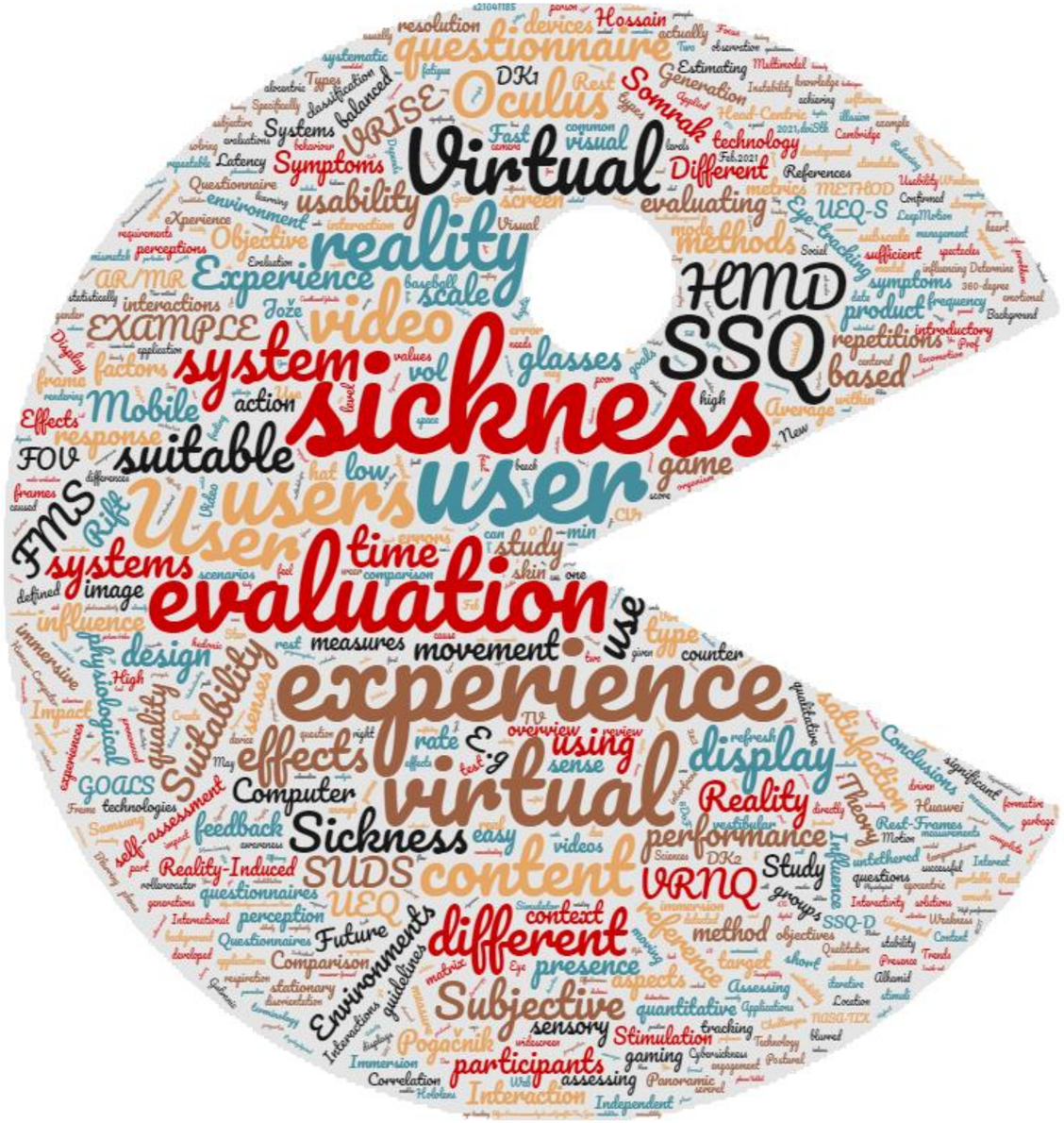

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Discussion

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