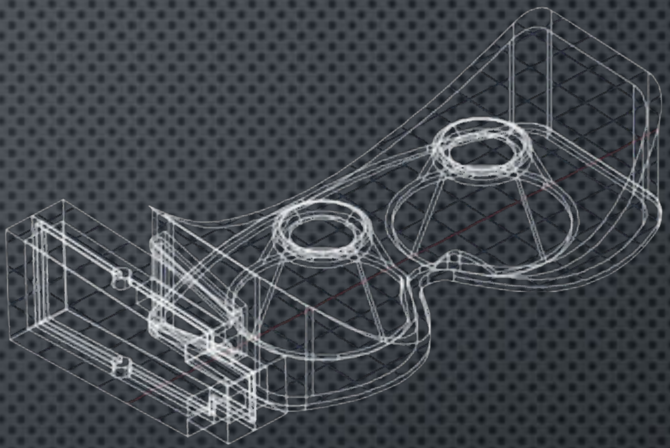
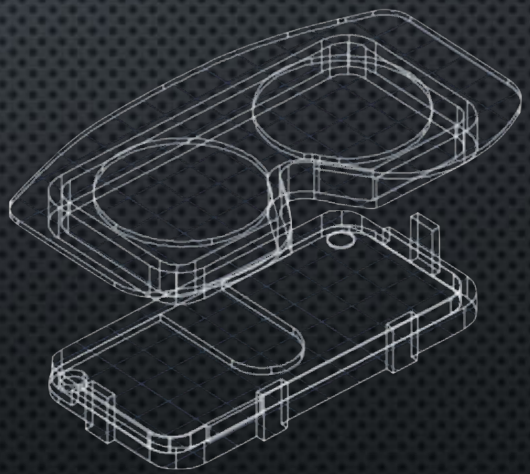
DESIGN & EVALUATION OF UBIQUITOUS WEARABLE VIRTUAL REALITY





DISSERTATION DEFENSE

ARYA BASU

COMMITTEE:

- DR. KYLE JOHNSEN
- DR. WALTER D. POTTER
- DR. KHALED RASHEED
- DR. TIANMING LIU

OVERVIEW

<u>Part I</u>

The Problem

<u>Part II</u>

The case for Ubiquitous VR

<u>Part III</u>

Contributions made

<u>Part IV</u>

Path forward

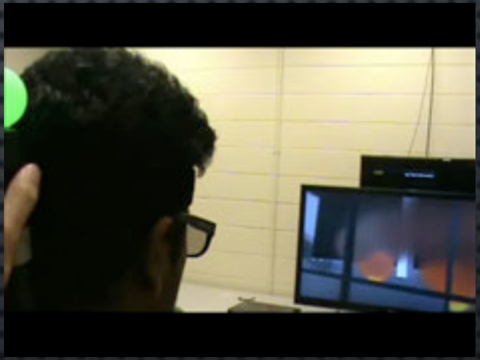
PART I

The Problem

Difficult Inputs

Un-Immersive Displays

Infrastructure



THE PROBLEM

Infrastructure

- Setup space is a constraint
- Heavy on maintenance
- Interfacing with the tech has a steeper learning curve
- Lacks mobility and steep deployment curve
- Low scalability
- Lack of standardization

V6 HMD

OptiTrack Flex 3

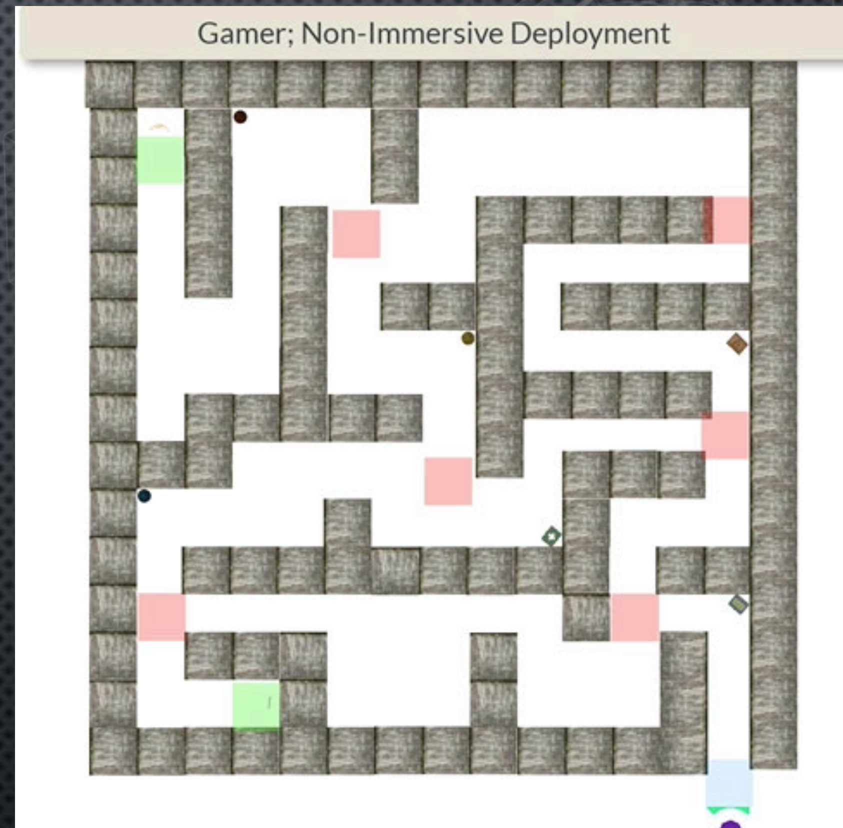
eMagin z800 3D Visor; Razer Hydra

Sensics zSight

THE PROBLEM

- Potential usability bias

Non-Immersive Deployment
Gamer vs. Non-gamer



PART II

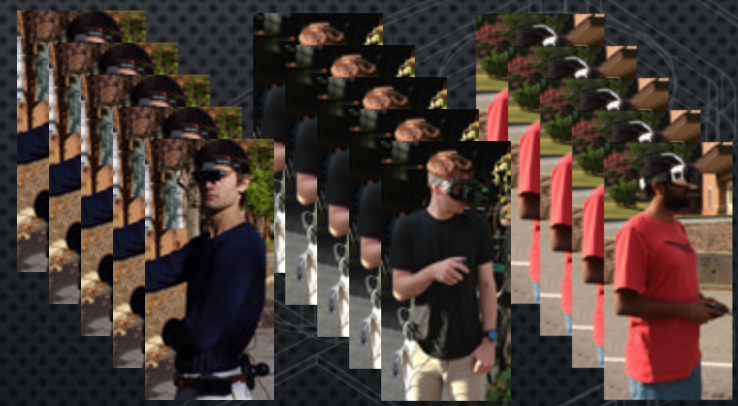
The case for Ubiquitous Virtual Reality

- Consumer level ubiquitous devices and smart phones are becoming more and more accessible.

- These devices are mobile and have standardized interfaces.

- In terms of computing ability these devices are capable of rendering sophisticated interfaces and graphics.

- These devices together create their own network and can connect to other existing networks.

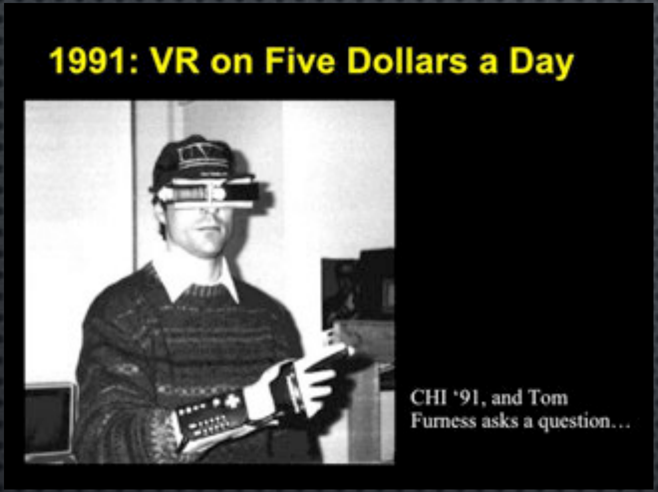


Nearly 384 million smartphones were sold in the first quarter of 2018*

* https://www.gartner.com/newsroom/id/3876865

PREVIOUS WORK

Pausch's inexpensive VR System – [Pausch, Randolph et al. 1991]



"The field of virtual reality research is in its infancy, and will benefit greatly from putting the technology into as many researchers' hands as possible."
- R. Pausch

System components:

- 80386 IBM-PC™
- Polhemus 3Space Isotrak™
- Private Eye™ displays
- Mattel Power Glove™

Research findings:

- Quality of graphics not important
- Interaction latency matters
- Stereoscopy is not essential
- Ground plane is required for ref

Randy Pausch. Virtual reality on five dollars a day. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '91, pages 265–270, New York, NY, USA, 1991a. ACM. ISBN 0-89791-383-3. doi: 10.1145/108844.108913. URL http://doi.acm.org/10.1145/108844.108913.

PREVIOUS WORK

Pausch's comparative study (HMD vs. Stationary Displays) – [Pausch, Randolph et al. 1993]

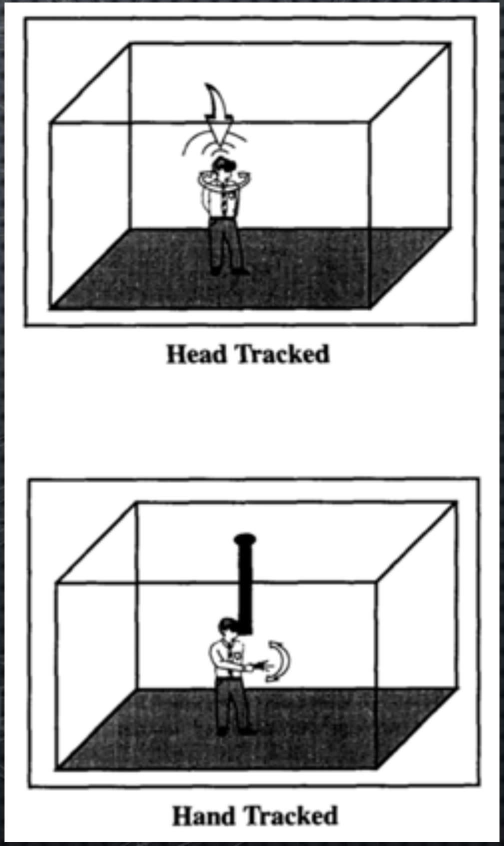
System components:

- VPL Eyephone™
- Polhemus 3Space Isotrak™

Study* findings:

- Using head tracking reduced task time by 42% over hand tracking

- Subjects performed the task 23% faster using hand tracking if they had first used head tracking



Head Tracked

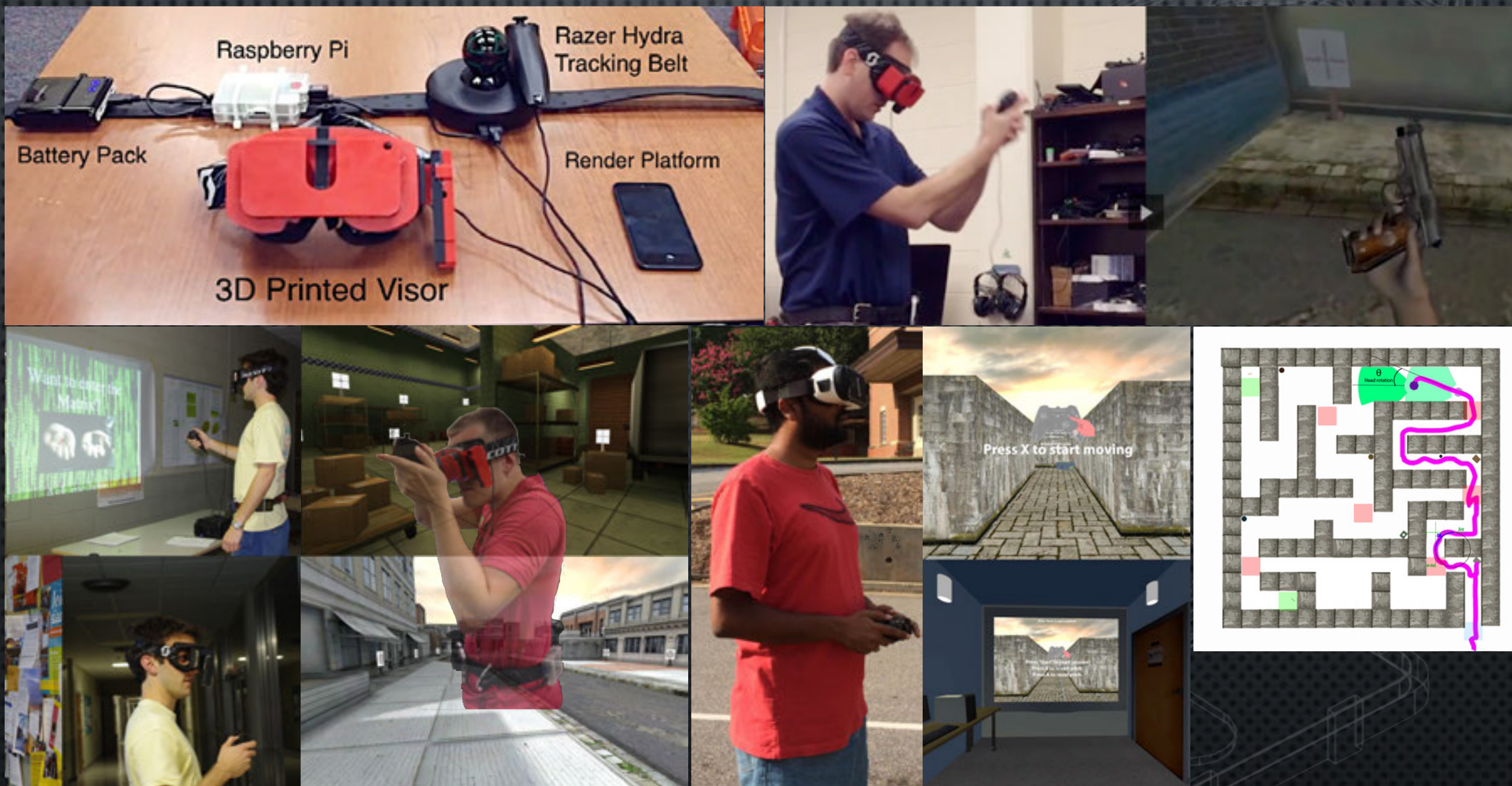
Hand Tracked

**Study demographics: 14 Males and 14 Females participated*

Randy Pausch, M Anne Shackelford, and Dennis Proffitt. A user study comparing head- mounted and stationary displays. In Virtual Reality, 1993. Proceedings., IEEE 1993 Sym- posium on Research Frontiers in, pages 41–45. IEEE, 1993.

PART III

Contributions made



UBIQUITOUS VR SYSTEM - UCAVE

- Prototype I

System components:

- Apple iOS device – 4th Gen iPod Touch™
- Vuzix Wrap 920 Eyewear™
- Elastic Headband

Findings:

- Power is an issue
- Lack of open source alternatives
- Form factor could be better
- Device (HMD) latency is an issue
- Missing interactive interface

https://www.bhphotovideo.com/c/product/803999-REG/Vuzix_Corp_329T00011_Wrap_920.html

UBIQUITOUS VR SYSTEM - UCAVE

- Prototype II, III

System components:

- Apple iOS device – 4th Gen iPhone™
- Razer Hydra™
- Single board computer (Beagleboard XM, Raspberry Pi Rev B)
- 3D Printed Visor
- Leather Belt

Findings:

- E-m tracker suffers from interference
- The wearable belt design is usable
- The ski-goggle design is not well insulated from light
- Self-contained tracking works well

UBIQUITOUS VR SYSTEM - UCAVE

- Final design

STUDY I

The ergonomic impact of a *perceived tether* in Ubiquitous Immersive VR

Q: If there is a significant impact on successful completion time of the maze under the presence of a 'fake' USB tether (perceived tether)?

- Study design

STUDY I

The ergonomic impact of a *perceived tether* in Ubiquitous Immersive VR

- Study population, Environment, and Measures

Treatment:

- Untethered (Category 1)
- Tethered (Category 2)

Qualitative Data:

- Demographic data
    - *Age, Gender, and Prior gaming experience index (self-reported)*
- *Simulator Sickness Score*[1]
- *Presence Score*[2]

Quantitative Data:

- Participants' data
    - Position (x,y)
    - Head gaze (rotation; quaternion)
    - Total time of completion
    - Total turns taken inside maze

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	38	17	60	24.87	8.857
Gaming Experience Index (Scale: 0.0-10.0)	37	.00	9.50	3.0243	2.32058
Presence Questionnaire Index (scale -21:21)	38	-9	16	7.29	6.971
Time to complete 2D Maze (secs)	38	25.2	225.0	105.850	45.6542

Driftmier Engineering Center, UGA

1) Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The International Journal of Aviation Psychology, 3(3):203–220, 1993. doi: 10.1207/s15327108ijap0303 3.

2) Martin Usoh, Ernest Catena, Sima Arman, and Mel Slater. Using presence questionnaires in reality. *Presence: Teleoperators & Virtual Environments*, 9(5):497–503, 2000.

STUDY I

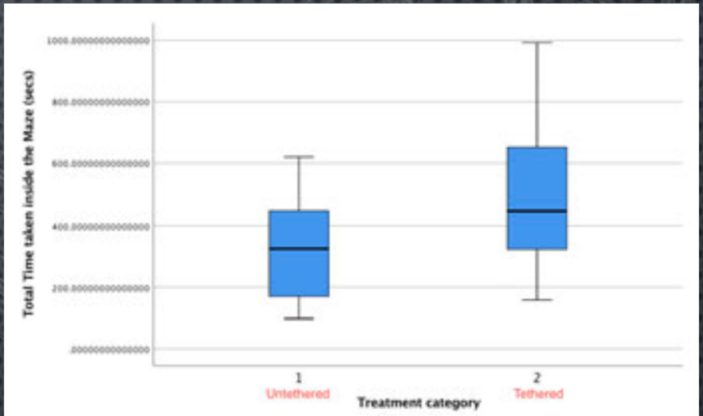
The ergonomic impact of a *perceived tether* in Ubiquitous Immersive VR

- Analyses and Results

Report

Treatment category		Total Time taken inside the Maze (secs)	Total Turns inside the Maze in degrees
Untethered	N	28	28
	Mean	319.167893	10276.6469
	Std. Deviation	160.098073	5509.15277
Tethered	N	10	10
	Mean	499.706153	16032.3638
	Std. Deviation	268.397044	8570.27363
Total	N	38	38
	Mean	366.677961	11791.3093
	Std. Deviation	206.682100	6827.25072

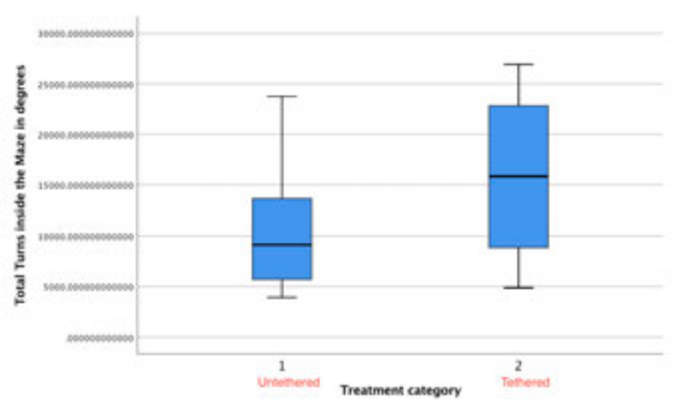
Descriptive Statistics (within group)



Total time taken (un-tethered vs. tethered)

		F	Sig.	t	df
Total Time taken inside the Maze (secs)	Equal variances assumed	4.616	.038	-2.540	36
	Equal variances not assumed			-2.004	11.371
Total Turns inside the Maze in degrees	Equal variances assumed	9.892	.003	-2.436	36
	Equal variances not assumed			-1.983	11.767

Independent samples T-test (tethered vs. un-tethered)



Total turns taken (un-tethered vs. tethered)

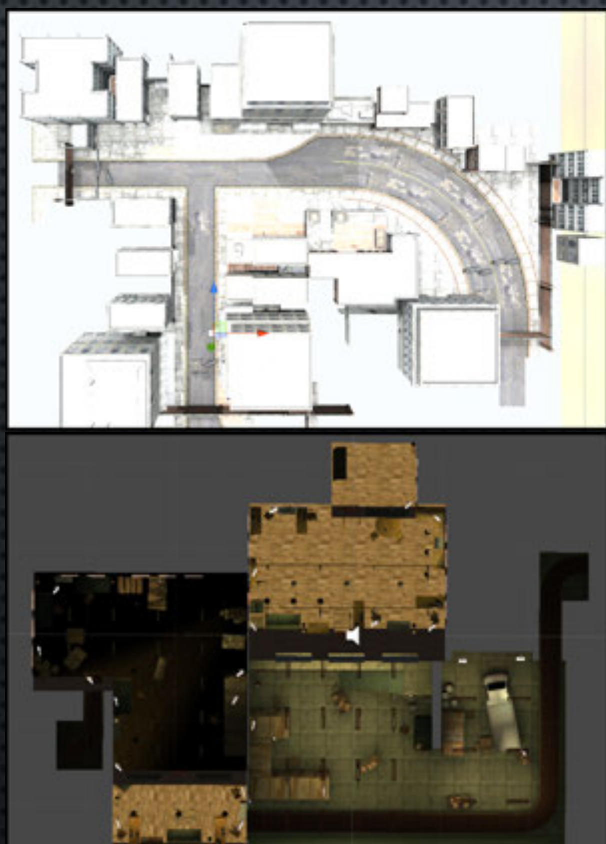
There is a significant impact on successful completion time of the maze under the presence of a 'fake' USB tether (perceived tether).

STUDY II

The *environmental* impact on user performance in Ubiquitous Immersive VR

Q: If there is a significant difference between shooting score in matched vs unmatched configuration of Virtual Environment and the Physical Space?

- Study design



STUDY II

The *environmental* impact on user performance in Ubiquitous Immersive VR

- Study population, Environment, and Measures

Treatment (2x2 cross over):

- Group 1
  - Inside (physical) – Indoors (Virtual)
  - Inside (physical) – Outdoors (Virtual)
- Group 2
  - Outside (physical) – Indoors (Virtual)
  - Outside (physical) – Outdoors (Virtual)

Qualitative Data:

- *Simulator Sickness Score*[1]
- *Presence Score*[2]

Quantitative Data:

- Participants' trajectory data
  - Position (x,y)
  - Head gaze (rotation; quaternion)
- Participants' performance data
  - Raw Score (virtual indoor)
  - Raw Score (virtual outdoor)

1) Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The International Journal of Aviation Psychology, 3(3):203–220, 1993. doi: 10.1207/s15327108ijap0303 3.

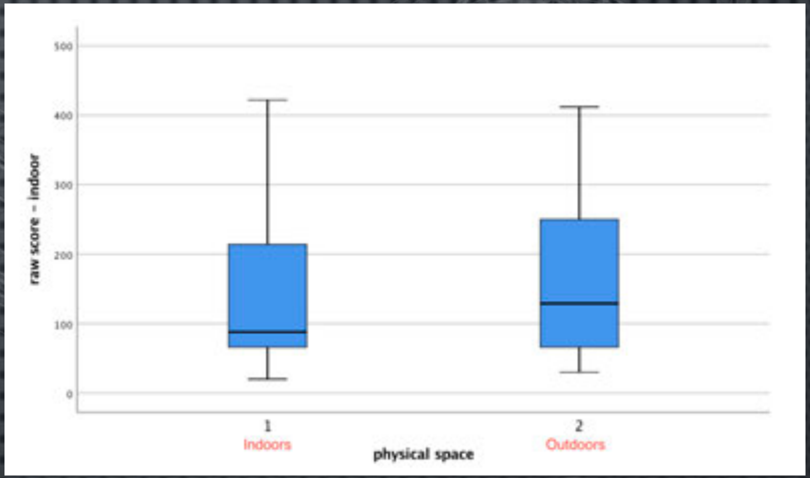
2) Martin Usoh, Ernest Catena, Sima Arman, and Mel Slater. Using presence questionnaires in reality. *Presence: Teleoperators & Virtual Environments*, 9(5):497–503, 2000.

STUDY II

The *environmental* impact on user performance in Ubiquitous Immersive VR

- Analyses and Results

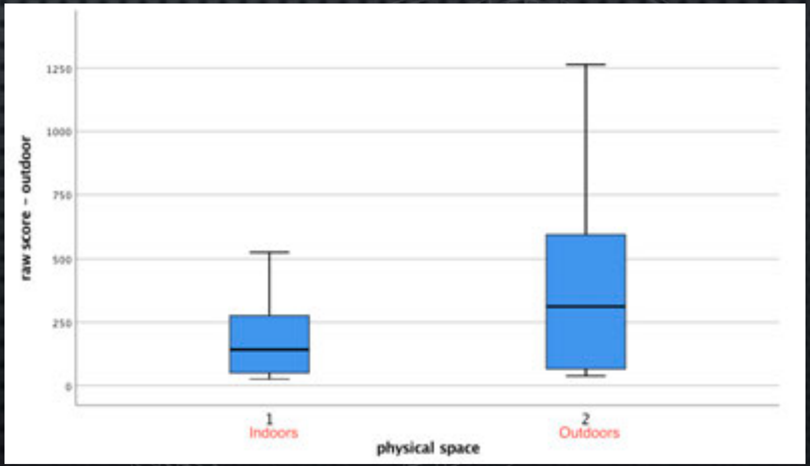
Treatment (2x2 cross over):
- Group 1
  - Inside (physical) – Inside (Virtual)
  - Outside (physical) – Inside (Virtual)
- Group 2
  - Inside (physical) – Outside (Virtual)
  - Outside (physical) – Outside (Virtual)



Raw score - Indoor (virtual)

condition		raw score - indoor	raw score - outdoor
indoor - matched	N	10	10
	Mean	124.00	194.60
	Std. Deviation	114.298	183.616
indoor- unmatched	N	7	7
	Mean	167.71	152.29
	Std. Deviation	137.542	135.629
outdoor - matched	N	7	7
	Mean	112.86	237.14
	Std. Deviation	65.776	229.921
outdoor - unmatched	N	7	7
	Mean	224.00	544.57
	Std. Deviation	151.499	421.551
Total	N	31	31
	Mean	153.94	273.68
	Std. Deviation	122.640	287.862

Descriptive Statistics (within group)



Raw score - Outdoor (virtual)

STUDY II

The *environmental* impact on user performance in Ubiquitous Immersive VR

- Analyses and Results

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
virtual_environement	Pillai's Trace	.296	11.325[b]	1.000	27.000	.002
	Wilks' Lambda	.704	11.325[b]	1.000	27.000	.002
	Hotelling's Trace	.419	11.325[b]	1.000	27.000	.002
	Roy's Largest Root	.419	11.325[b]	1.000	27.000	.002
virtual_environement * first_matched	Pillai's Trace	.020	.551[b]	1.000	27.000	.464
	Wilks' Lambda	.980	.551[b]	1.000	27.000	.464
	Hotelling's Trace	.020	.551[b]	1.000	27.000	.464
	Roy's Largest Root	.020	.551[b]	1.000	27.000	.464
virtual_environement * physical_space	Pillai's Trace	.203	6.878[b]	1.000	27.000	.014
	Wilks' Lambda	.797	6.878[b]	1.000	27.000	.014
	Hotelling's Trace	.255	6.878[b]	1.000	27.000	.014
	Roy's Largest Root	.255	6.878[b]	1.000	27.000	.014
virtual_environement * first_matched * physical_space	Pillai's Trace	.118	3.610[b]	1.000	27.000	.068
	Wilks' Lambda	.882	3.610[b]	1.000	27.000	.068
	Hotelling's Trace	.134	3.610[b]	1.000	27.000	.068
	Roy's Largest Root	.134	3.610[b]	1.000	27.000	.068

a. Design: Intercept + first_matched + physical_space + first_matched * physical_space
Within Subjects Design: virtual_environement

b. Exact statistic

Tests of Within-Subjects Contrasts

Measure: raw_score

Source	virtual_environement	Type III Sum of Squares	df	Mean Square	F	Sig.
virtual_environement	Linear	236513.514	1	236513.514	11.325	.002
virtual_environement * first_matched	Linear	11499.522	1	11499.522	.551	.464
virtual_environement * physical_space	Linear	143646.580	1	143646.580	6.878	.014
virtual_environement * first_matched * physical_space	Linear	75393.175	1	75393.175	3.610	.068
Error (virtual_environement)	Linear	563859.629	27	20883.690		

Repeated measures analysis

		F	Sig.	t	df
raw score - indoor	Equal variances assumed	.054	.819	-.591	29
	Equal variances not assumed			-.589	27.508
raw score - outdoor	Equal variances assumed	9.199	.005	-2.182	29
	Equal variances not assumed			-2.040	17.247

Independent samples T-test (VE = indoors vs. outdoors)

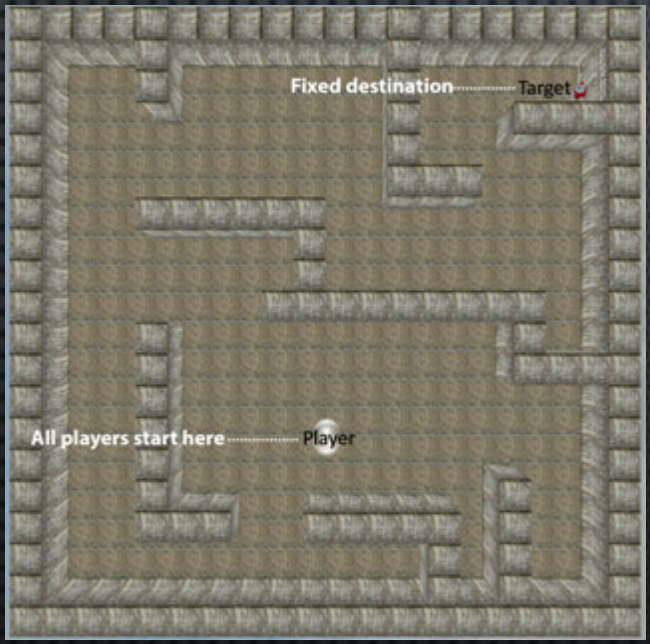
- *The state of the VE (warehouse indoors vs urban outdoors) does significantly impact users' performance inside immersive VR*
- *There is a partially significant impact on shooting score by matched vs unmatched configuration of VE and the physical space.*
- *We found that a matched outdoor setting (outdoor as physical space and outdoor as the VE) seems to be the best performing setting for our participants.*

STUDY III

The *human factor* impact on user performance in Ubiquitous Immersive VR

Q: If there is a positive correlation between self-reported physical fitness score and maze completion time?

- Study design



STUDY III

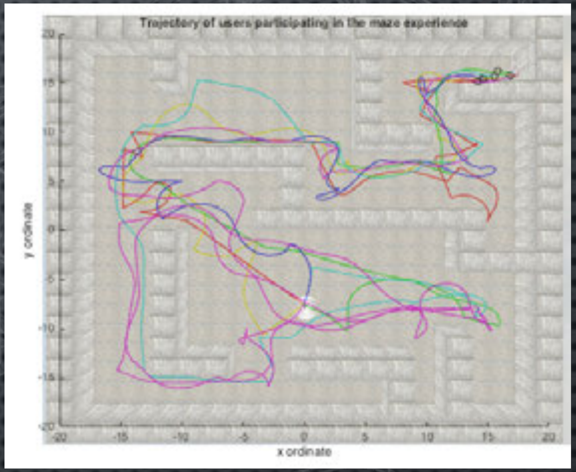
The *human factor* impact on user performance in Ubiquitous Immersive VR

- Study population, Environment, and Measures

  Treatment:
  - *N/A*

  Qualitative Data:
  - Demographic data
    - *Age, Gender, 20/20 vision, Self-reported athletic score, and Self-reported gaming hours score*
  - *Simulator Sickness Score*[1]
  - *Presence Score*[2]

  Quantitative Data:
  - Participants' data
    - Position (x,y)
    - Head gaze (rotation; quaternion)
    - Total time of completion of the maze



Ramsey Student Center, UGA

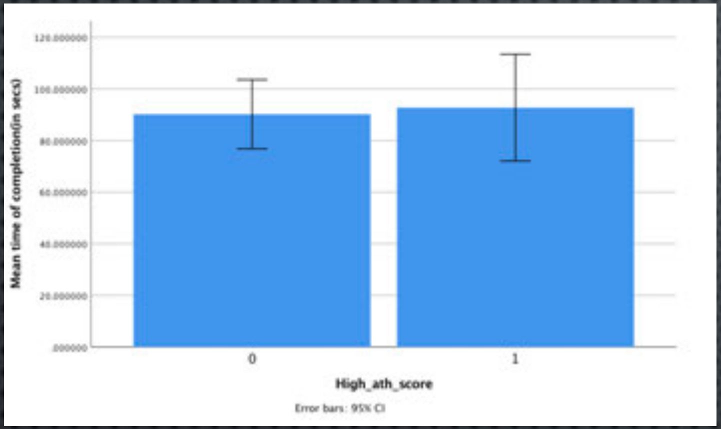
1) Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The International Journal of Aviation Psychology, 3(3):203–220, 1993. doi: 10.1207/s15327108ijap0303 3.

2) Martin Usoh, Ernest Catena, Sima Arman, and Mel Slater. Using presence questionnaires in reality. *Presence: Teleoperators & Virtual Environments*, 9(5):497–503, 2000.

STUDY III

The *human factor* impact on user performance in Ubiquitous Immersive VR

- Analyses and Results

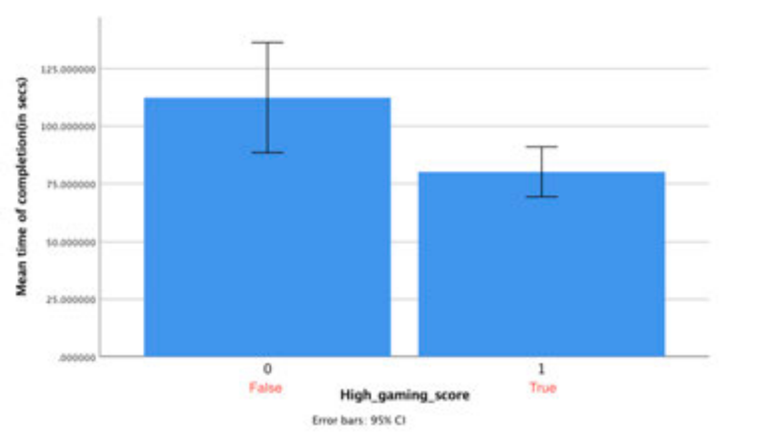


Time of completion of the maze by group (high athletic score; binned)

time of completion(in secs)

High_ath_score	N	Mean	Std. Deviation
0	62	90.1798733	52.6436595
1	32	92.7350218	57.3217160
Total	94	91.0497111	53.9862188

Descriptive Statistics (within group; athletic score)



Time of completion of the maze by group (high gaming hours score; binned)

time of completion(in secs)

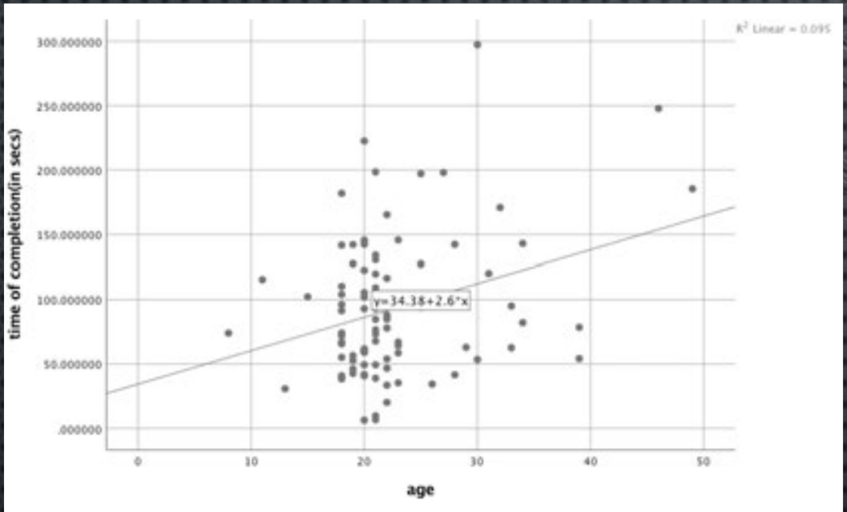
High_gaming_score	N	Mean	Std. Deviation
0	32	112.377347	66.5625832
1	62	80.0418990	42.7791240
Total	94	91.0497111	53.9862188

Descriptive Statistics (within group; gaming score)

STUDY III

The *human factor* impact on user performance in Ubiquitous Immersive VR

- Analyses and Results



Scatter plot

Correlations

		time of completion(in secs)	Low_gaming_score	High_gaming_score	High_ath_score
time of completion(in secs)	Pearson Correlation	1	.285**	-.285**	.023
	Sig. (2-tailed)		.005	.005	.829
	N	94	94	94	94
Low_gaming_score	Pearson Correlation	.285**	1	-1.000**	-.042
	Sig. (2-tailed)	.005		.000	.685
	N	94	94	94	94
High_gaming_score	Pearson Correlation	-.285**	-1.000**	1	.042
	Sig. (2-tailed)	.005	.000		.685
	N	94	94	94	94
High_ath_score	Pearson Correlation	.023	-.042	.042	1
	Sig. (2-tailed)	.829	.685	.685	
	N	94	94	94	94

**. Correlation is significant at the 0.01 level (2-tailed).

Pearson Correlation Matrix

- *Athletic score is not found to be significantly correlated to the dependent variable (time of completion of the maze).*
- *We found that gaming profile of immersive VR users is a more important metric that seems to affect immersive VR performance significantly.*
- *We see a positive correlation scatterplot between the time of completion of the maze (in seconds) and the age of the participants.*

STUDY IV

The *technical factor* impact on user performance in Ubiquitous Immersive VR

Q: If there a significant impact on users' behavioral ability to successfully navigate a 3D maze under the influence of technical factors such as immersive, non- immersive 3DUIs?

- Study design

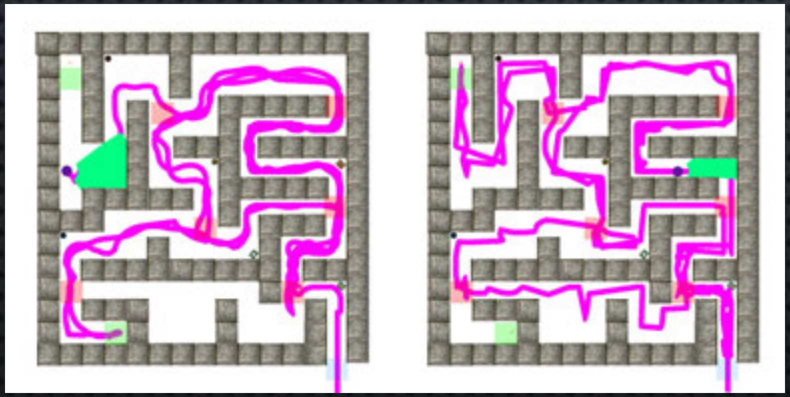
ECDS, Emory University

STUDY IV

The *technical factor* impact on user performance in Ubiquitous Immersive VR

- Study population, Environment, and Measures

Treatment (2x2 cross over):
- Condition 1
  - Immersive deployment (first)
  - Non-Immersive deployment (second)
- Condition 2
  - Non-Immersive deployment (first)
  - Immersive deployment (second)



Qualitative Data:
- Demographic data
  - *Age, Gender, 20/20 vision, Self-reported athletic score, and Self-reported gaming hours score*
- *Simulator Sickness Score*[1]
- *Presence Score*[2]

Quantitative Data:
- Participant data
  - Position (x,y)
  - Head gaze (rotation; quaternion)
  - Total time of completion of the maze

1) Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The International Journal of Aviation Psychology, 3(3):203–220, 1993. doi: 10.1207/s15327108ijap0303 3.

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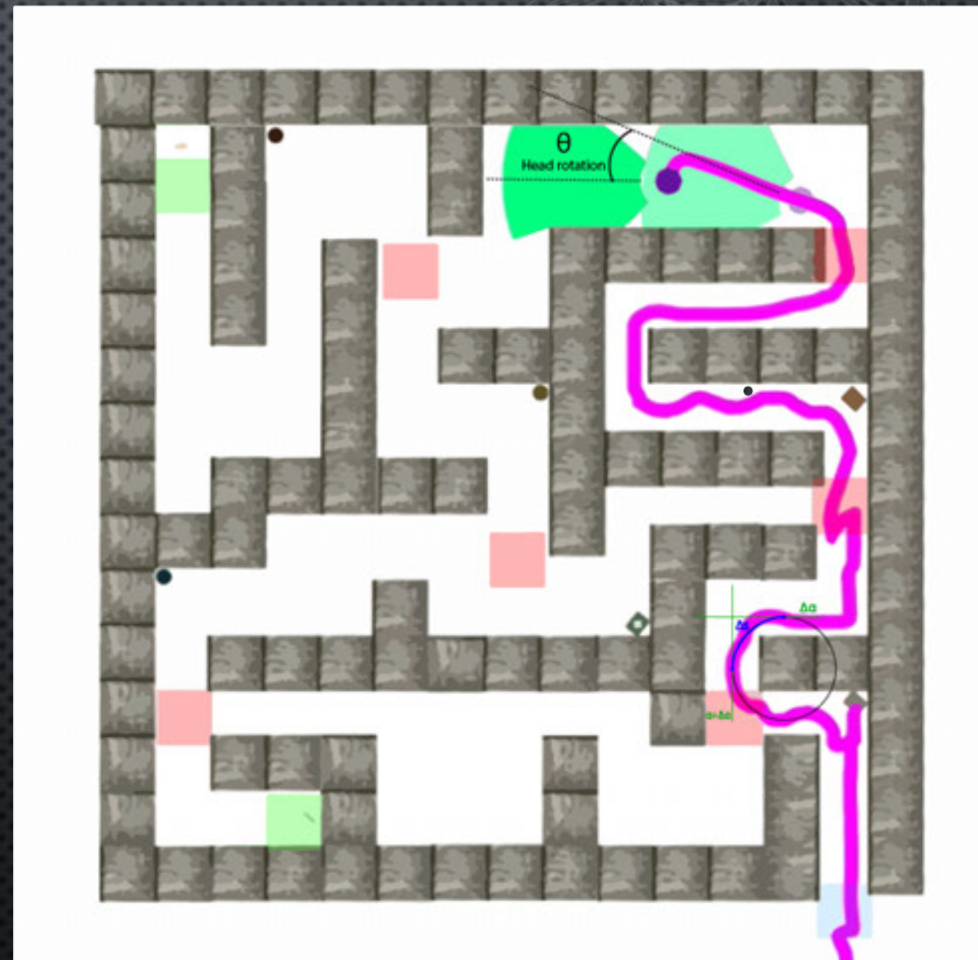
STUDY IV

The *technical factor* impact on user performance in Ubiquitous Immersive VR

- Features of user trajectory

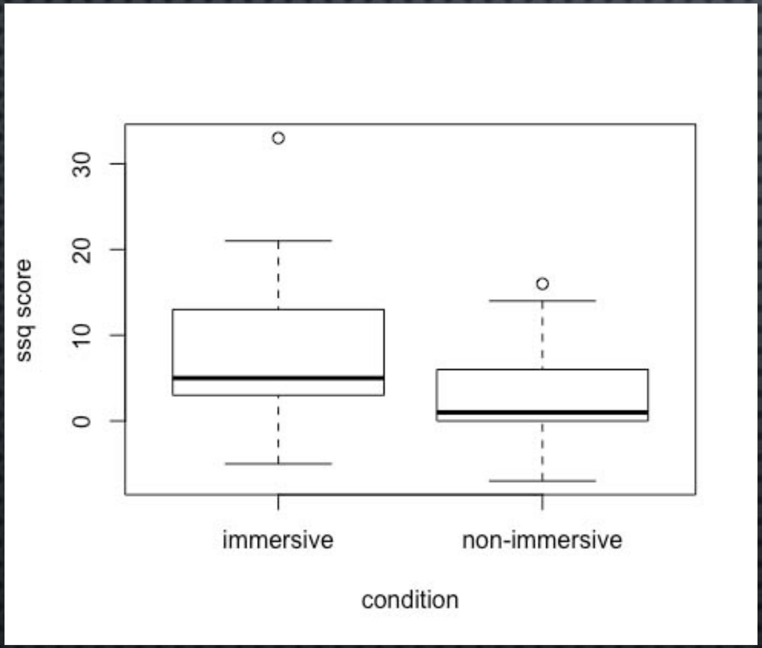
Features	Definition
Distance traveled	It is the total length of the path traveled between two positions.
Coverage	Total number of unit cubes covered (area).
Number of decision points reached	Total number of decision points covered in the maze.
Positional Curvature	The signed angle of curvature between two consecutive position vectors.
Head rotation amount	The unsigned head rotation angle between two consecutive rotation transforms.



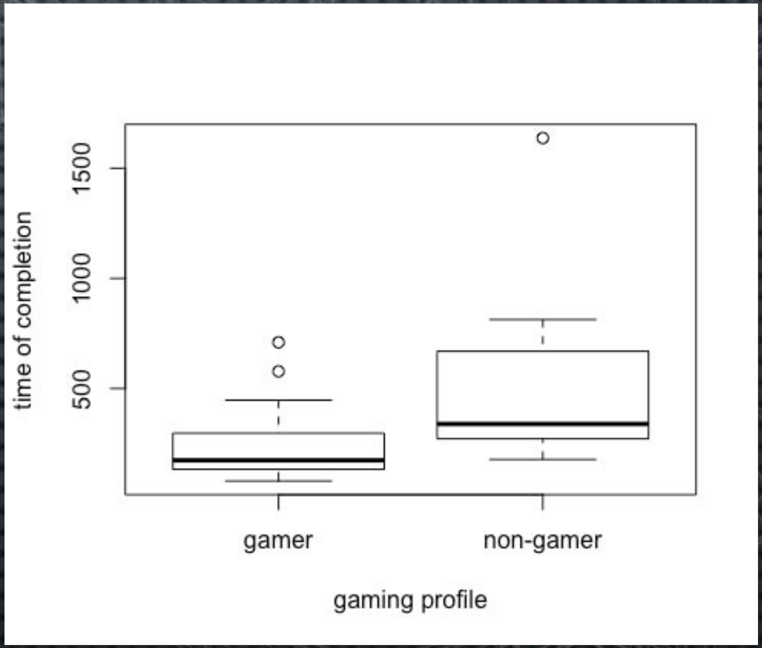
STUDY IV

The *technical factor* impact on user performance in Ubiquitous Immersive VR

- Analyses and Results



SSQ score is higher in immersive mode of avatar control



Time of completion is significantly less for participants who self-reported their gaming profile as gamers

STUDY IV

The *technical factor* impact on user performance in Ubiquitous Immersive VR

- Analyses and Results

Tests of Within-Subjects Effects

Multivariate[a,b]

Within Subjects Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
treatment	Pillai's Trace	.699	4.651[c]	6.000	12.000	.011	.699
	Wilks' Lambda	.301	4.651[c]	6.000	12.000	.011	.699
	Hotelling's Trace	2.325	4.651[c]	6.000	12.000	.011	.699
	Roy's Largest Root	2.325	4.651[c]	6.000	12.000	.011	.699
treatment * Condition	Pillai's Trace	.652	3.742[c]	6.000	12.000	.025	.652
	Wilks' Lambda	.348	3.742[c]	6.000	12.000	.025	.652
	Hotelling's Trace	1.871	3.742[c]	6.000	12.000	.025	.652
	Roy's Largest Root	1.871	3.742[c]	6.000	12.000	.025	.652

a. Design: Intercept + Condition
Within Subjects Design: treatment

b. Tests are based on averaged variables.

c. Exact statistic

Tests of Within-Subjects Contrasts

Source	Measure	treatment	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
treatment	distance	Linear	408755.139	1	408755.139	1.453	.245	.079
	toc	Linear	32143.609	1	32143.609	1.044	.321	.058
	decpts	Linear	92.778	1	92.778	1.174	.294	.065
	pos_curve	Linear	39.773	1	39.773	2.421	.138	.125
	rot_amount	Linear	.725	1	.725	.328	.574	.019
	coverage	Linear	256.976	1	256.976	2.771	.114	.140
treatment * Condition	distance	Linear	224768.859	1	224768.859	.799	.384	.045
	toc	Linear	63187.696	1	63187.696	2.052	.170	.108
	decpts	Linear	48.567	1	48.567	.614	.444	.035
	pos_curve	Linear	62.681	1	62.681	3.815	.067	.183
	rot_amount	Linear	.132	1	.132	.060	.810	.003
	coverage	Linear	3.818	1	3.818	.041	.842	.002
Error(treatment)	distance	Linear	4782595.05	17	281329.121			
	toc	Linear	523460.773	17	30791.810			
	decpts	Linear	1343.801	17	79.047			
	pos_curve	Linear	279.319	17	16.431			
	rot_amount	Linear	37.630	17	2.214			
	coverage	Linear	1576.392	17	92.729			

Repeated measures analysis

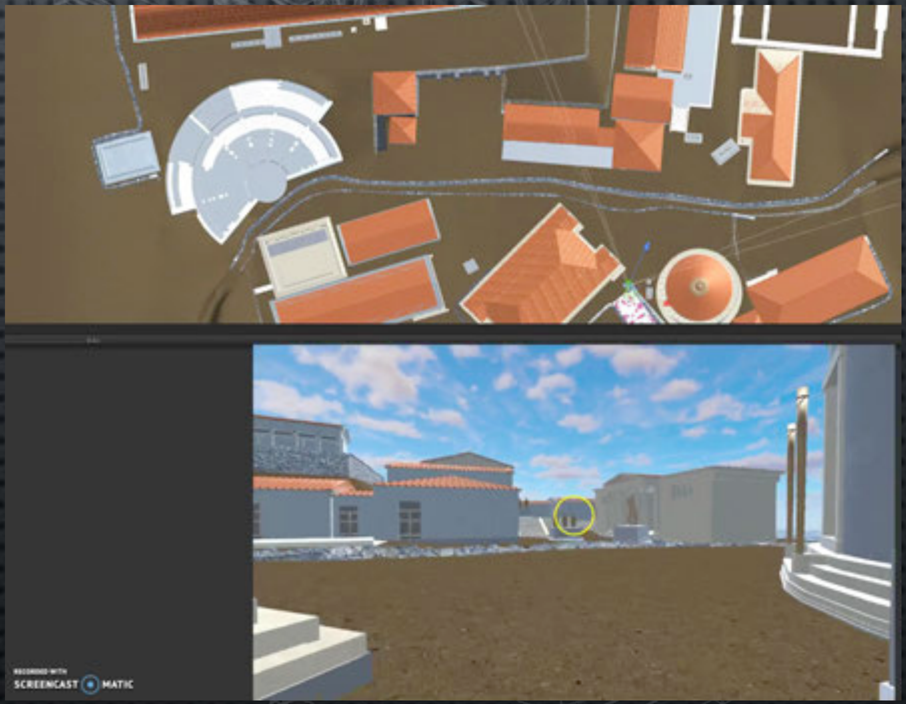
- *We found significant main effect of treatment (difference between immersive and non-immersive) and an interaction effect of treatment * condition.*

- *We found significant difference between groups of means between gaming profile type and time of completion.*

PART IV

Path forward

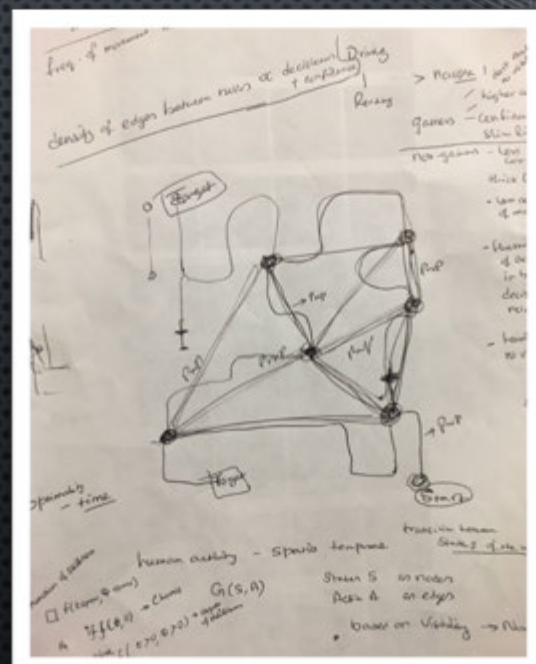
- ❑ Validation of current findings of all studies combined in other pedagogically valid setting
  - ❑ Samothrace – 200 BCE
  - ❑ Rome – 17th century CE



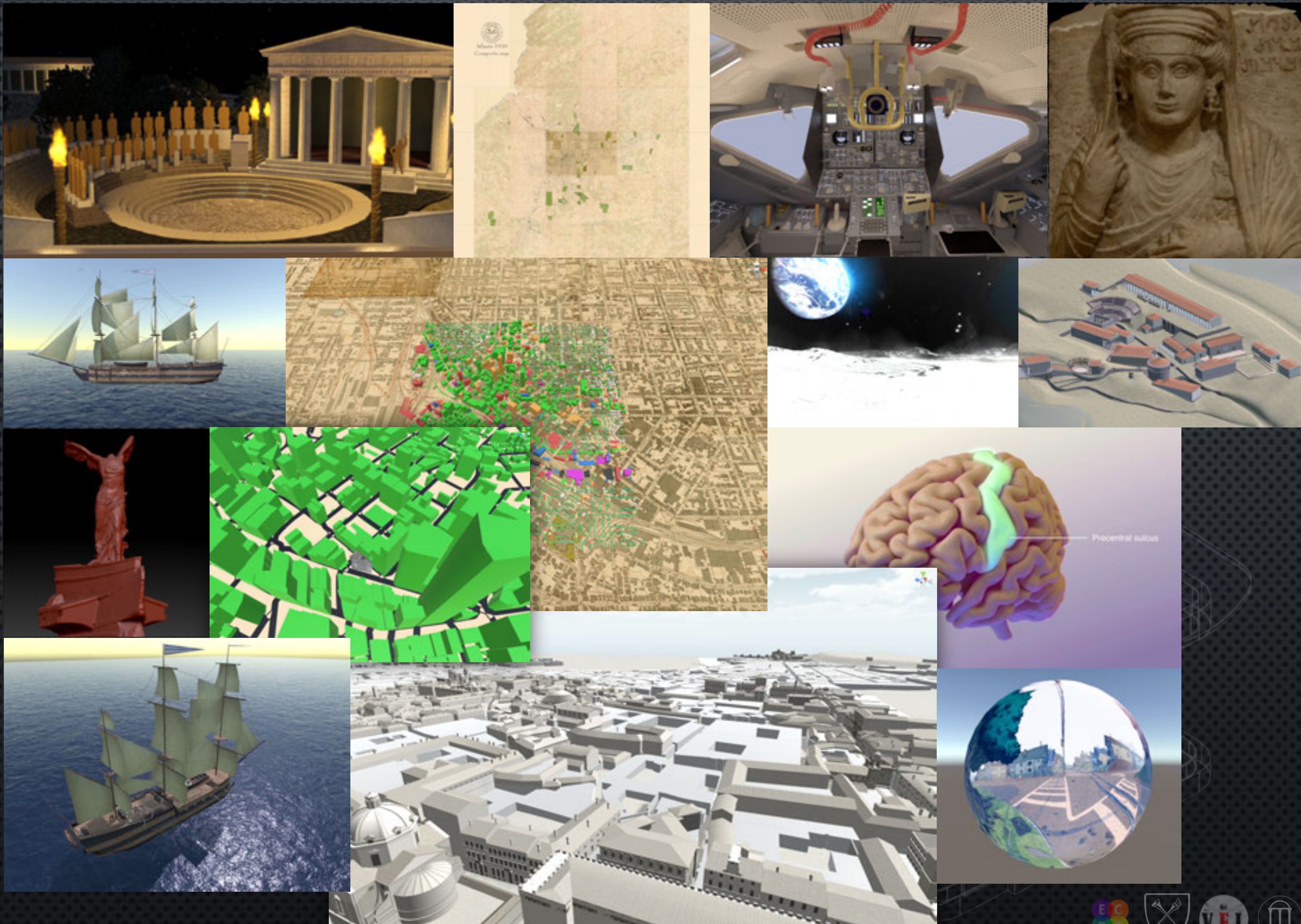
PART IV

Path forward

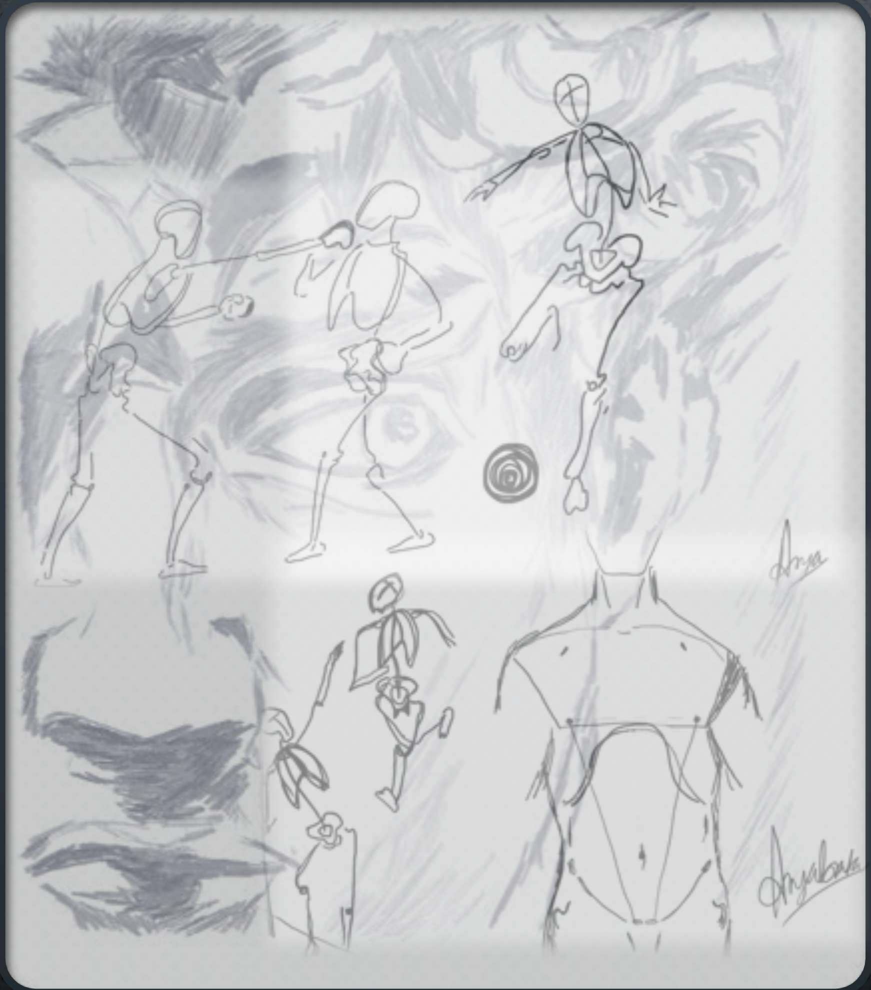
- ❑ Develop a generalized model of human spatial navigation
  - ❑ Recording and creating a library of maze navigation trajectories
  - ❑ Work on defining more features of spatial navigation trajectory



Natura Naturans.


Precentral sulcus

QUESTIONS ?



THANK YOU!