Cognition-Driven Display for Navigation Activities (Cog-DNA): Personalized Spatial Information System for Firefighters

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Fire-related accidents in the US

FEMA (2018) and NFPA (2017) data:

- **1,319,500** fire-related accidents (one fire accident every 25 seconds)
- **>3,400** deaths
- **>14,670** injuries
- **$23 billion** property loss
- **68,085** firefighter injuries in the line of duty
- **1,056,200** firefighters (**65%** volunteers)

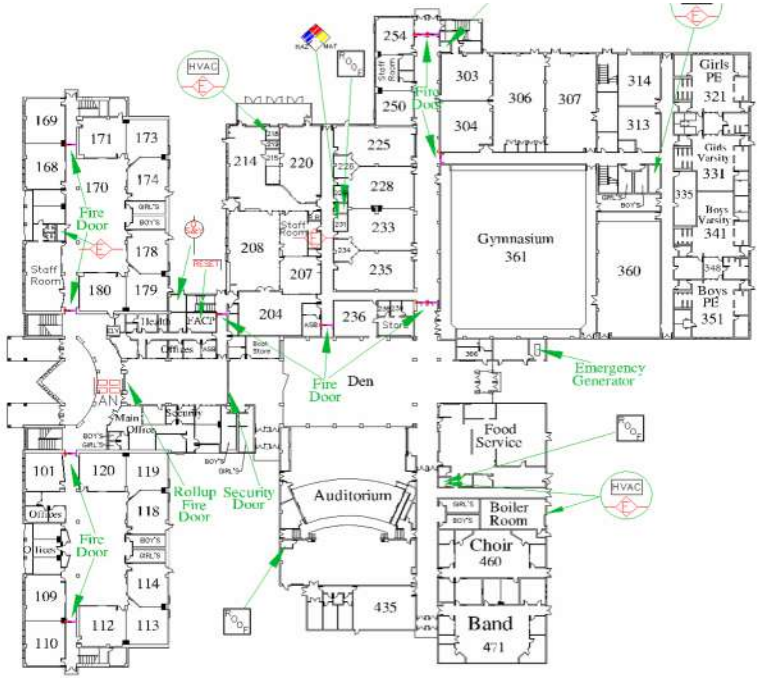
Disorientation is a major cause of injuries and fatalities for firefighters

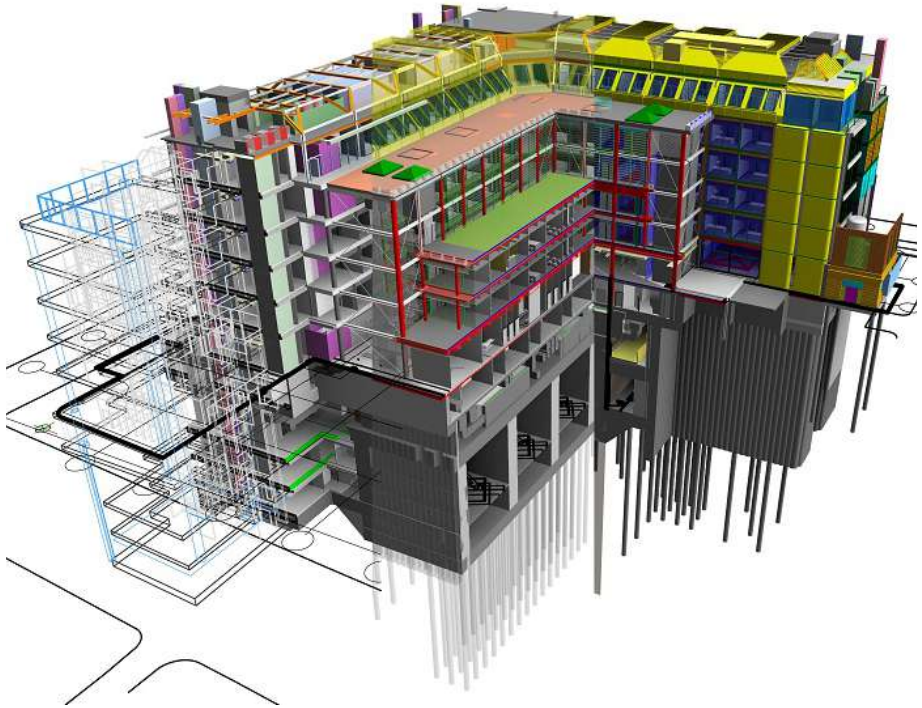
- Failure of the emergency response team to conduct timely and accurate assessments on the affected environment is a major contributor of casualties and property destruction.
- About 43.6% of firefighters' injuries were related to it.
- Challenge of firefighters' safety is the difficulty with retreat, i.e., finding the way out.


CHANGE
CHANGE
$10,741.35

1,115 GAMING FLOOR SLOTS*
58 BAR TABLE SLOTS
102 NON SMOKING SLOTS
59 HIGH LIMIT SLOTS
1,330 SLOTS TOTAL
24 TABLE GAMES
4 HIGH LIMIT TABLE GAMES
28 HIGH LIMIT TABLE GAMES

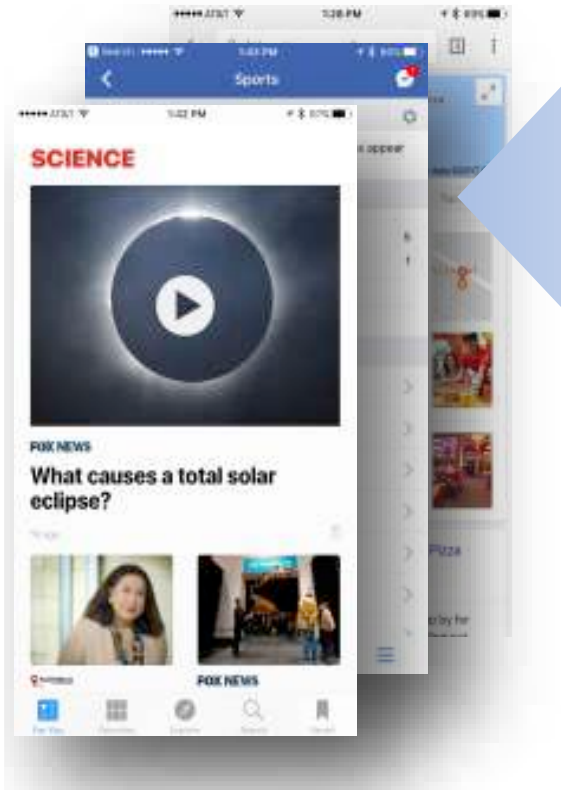
Problem: Complex Buildings and Information Overload





- Modern buildings with increasing complexity can cause cognitive overload for firefighters in wayfinding;
- It remains unclear how new information visualization methods (e.g., 3D models and virtual reality) affects the spatial cognition of firefighters.

Problem (cont'd): Same Information for Everybody

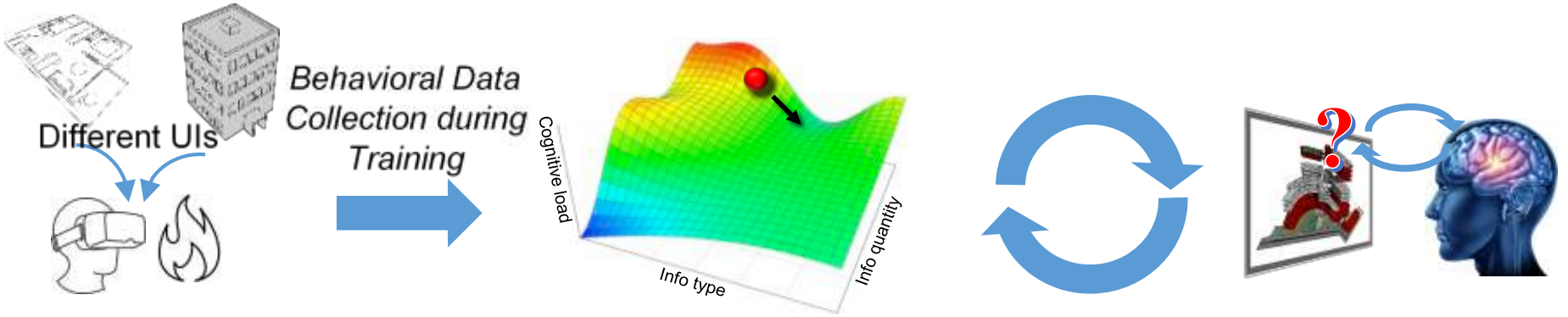


Personalized Info Systems
(different to everyone) are popular in daily life (e.g., Google personalized search result, Facebook friend news, News Feeds etc.)

Universal Info Systems
(same to everyone) are still heavily used in public wayfinding (e.g., maps, signage, instructions etc.)

Research Goal and Objectives

To develop and test a personalized UI system (Cog-DNA) to control the real-time cognitive load of firefighters in emergency wayfinding, and to reflect individual difference in information preference, i.e., “information personality”.



Step1: Firefighter Virtual Reality Training

Step 2: Develop info personality model that reflects repetitive pattern of information taking behavior based on training data

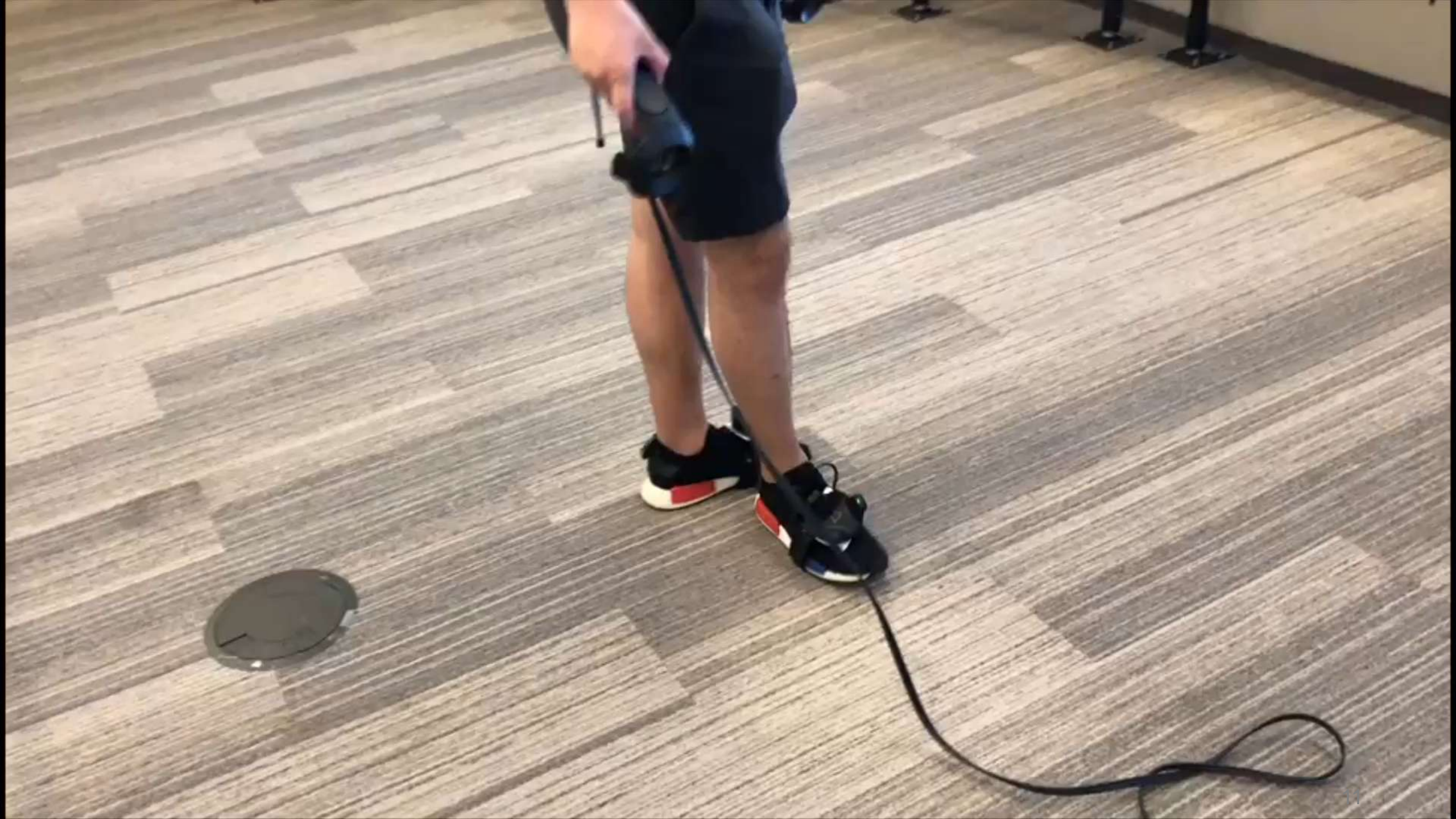
Step 3: Dynamically adjust UI based on info personality under different levels of cognitive load

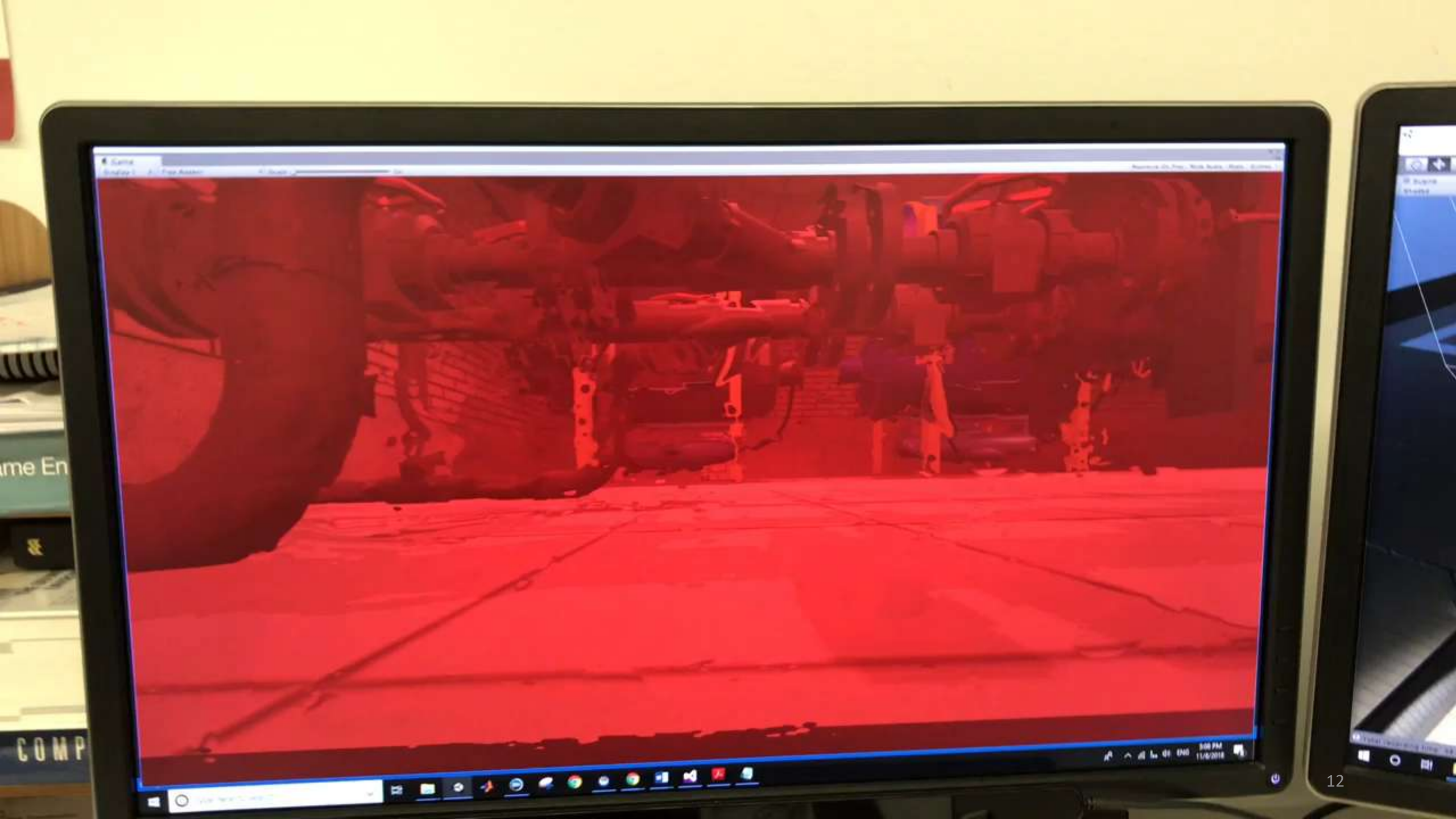
The Cog-DNA Conceptual Map

Objective 1: VR Training Platform and UI Design

a. Training mode with body motion tracking and simulation of hazardous environment

b. Review mode for post-training analysis – lines indicate gaze focus and body movement trajectories

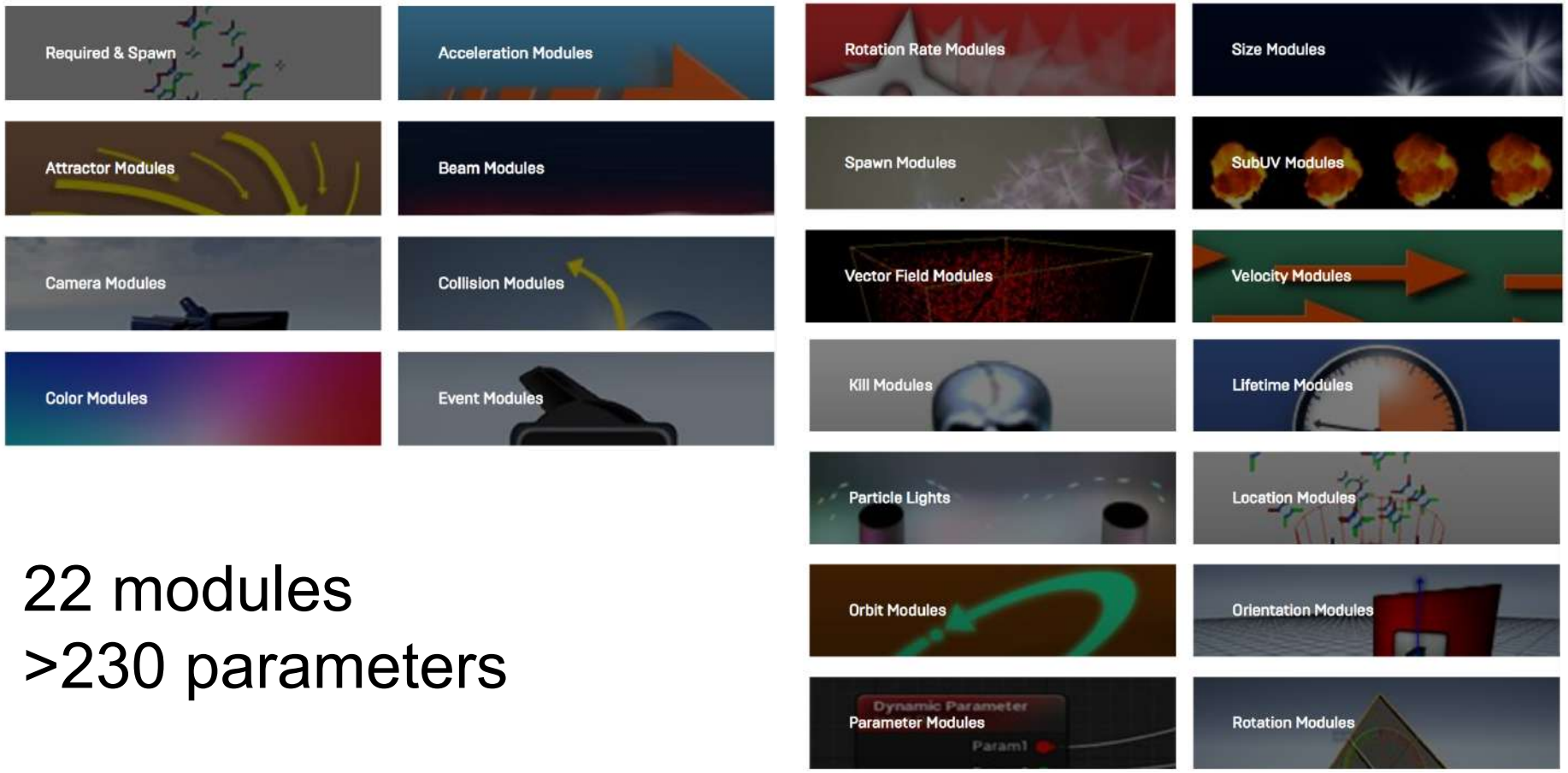




Workflow of a participatory fire simulation

Convergence of both parameter list and parameter values

List of particle parameters



22 modules
>230 parameters

Fire scene categorization

Catalogue	Class	Description
Fuel	A	Ordinary combustible materials, such as wood, cloth, paper, rubber and many plastics.
	B	Flammable liquids (burn at room temperature) and combustible liquids (require heat to ignite).
	C	Fuels that would be A or B except that they involve energized electrical equipment.
	D	Combustible metals, such as magnesium, titanium, zirconium, sodium, lithium and potassium.
	E	Fires in cooking appliances that involve combustible cooking media (vegetable or animal oils and fats).
Stages	Ignition	Fuel, oxygen and heat join together in a sustained chemical reaction.
	Growth	With the initial flame as a heat source, additional fuel ignites.
	Fully developed	Fire has spread over much if not all the available fuel; temperatures reach their peak, resulting in heat damage. Oxygen is consumed rapidly.
	Decay	The fire consumes available fuel, temperatures decrease, fire gets less intense.
Spread	Conduction	The passage of heat energy through or within a material because of direct contact, such as a burning wastebasket heating a nearby couch, which ignites and heats the drapes hanging behind, until they too burst into flames.
	Convection	The flow of fluid or gas from hot areas to cooler areas. The heated air is less dense, and rises, while cooler air descends. A large fire in an open area produces plume or column of hot gas and smoke high into the air. But inside a room, those rising gases encounter the ceiling. They travel horizontally along the ceiling forming a thick layer of heated air, which then moves downward.
	Radiation	Heat traveling via electromagnetic waves, without objects or gases carrying it along. Radiated heat goes out in all directions, unnoticed until it strikes an object. Burning buildings can radiate heat to surrounding structures, sometimes even passing through glass windows and igniting objects inside.

Evolutional Parameter Selection

Assume that X is the set of parameters defined for the simulator interface and C_k is a subset of X in *k-th* literation: $C_k \quad = \quad \{x|x \subset X\}$.

Randomly generating m parameters in the dataset X.

Value change of each parameter is $\triangle x_i = \parallel x_i^k - x_i^o \parallel^2$,where x_i^o denotes the original value of parameter x_i, and x_i^k denotes the value after adjusting by experts in *k-th* literation.

Find $x^* = \underset{k}{argmax}\{\triangle x\}$

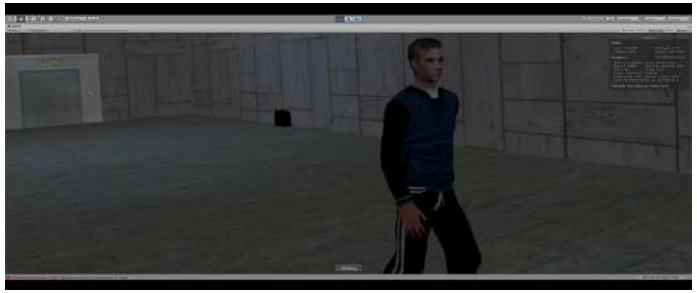
Calculate the score of x_i by the function as $S_i = R^{\frac{1}{w_i}}$, where w_i denotes the weight of item x_i, and R denotes a random number generated from $random(0, 1)$.

Select the m largest items with the largest score S_i as a set with a weighted random sample until we reach a fixed set

It converges if $\underset{i=1}{\overset{n}{max}}\{w_i\} \geq \epsilon$, where n is the total of all parameters and ϵ is the convergence threshold.

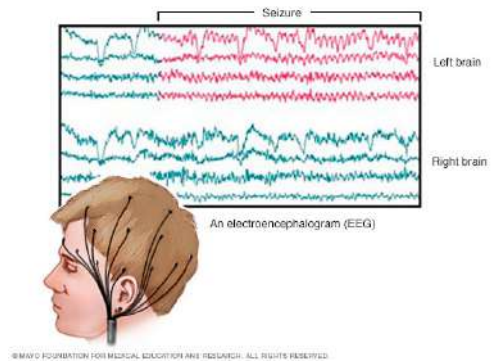
WRS (Weighted random sampling) (Efraimidis and Spirakis 2006)

More real scale VR models

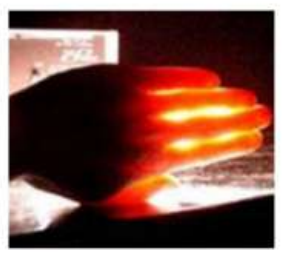


Objective 2: Experiments to Model Info Personality

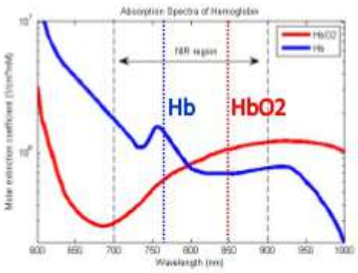
Electroencephalogram (EEG)



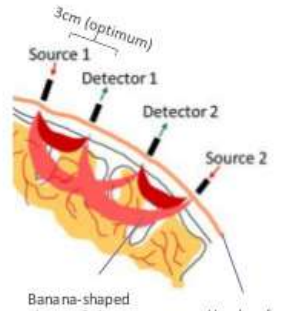
functional Near Infrared Spectroscopy (fNIRS)



Red light penetrating in biological tissue

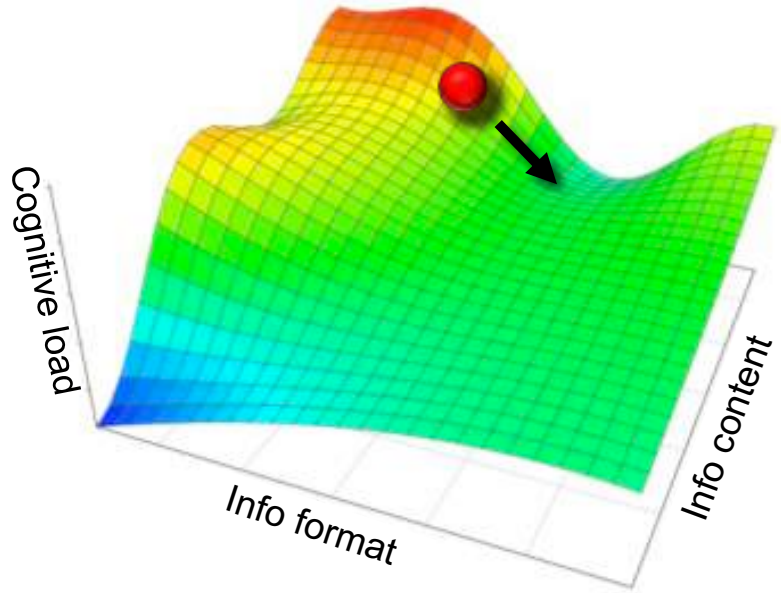


Absorption spectra of Hb

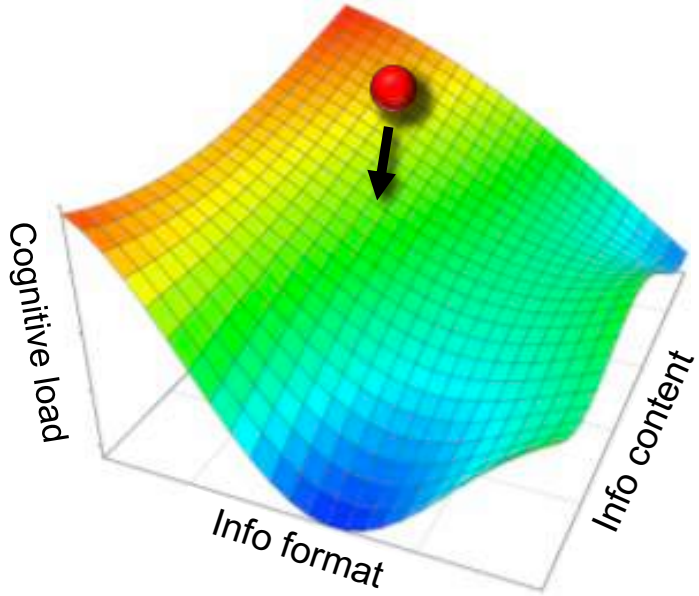


What is “Information Personality”?

A cognitive profile of information intake preference and behavioral patterns at the individual level



Information personality of Eric



Information personality of Ryan

What to control? – Content and Format

Multimedia Learning Theory (sensory processing)

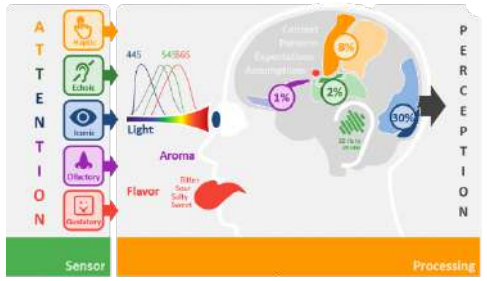
Mixed

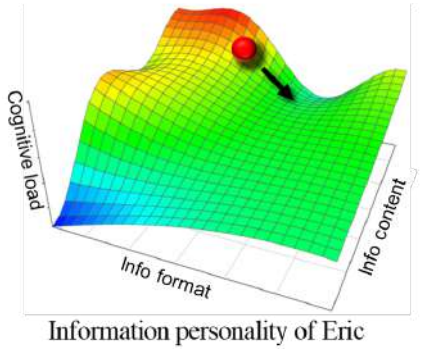
Other sensory

Spatial

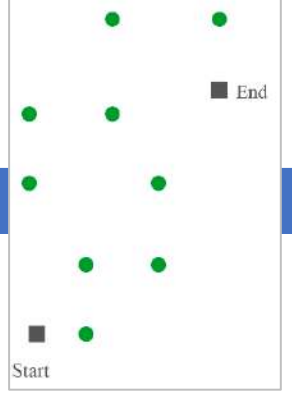
Visual

Phonological

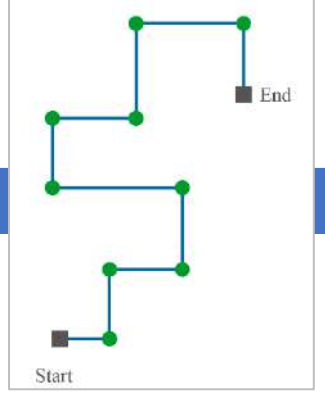




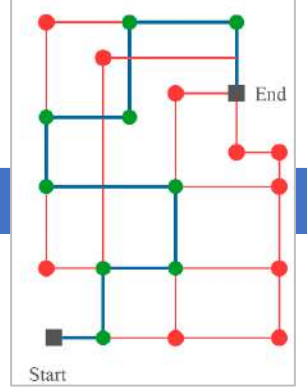
Landmark



Route



Survey

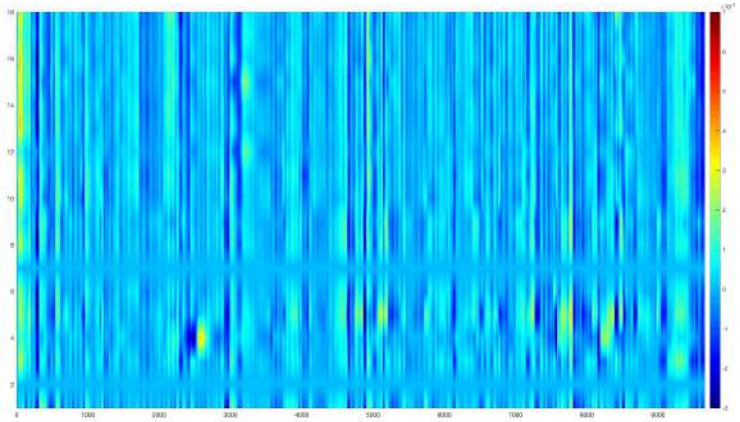


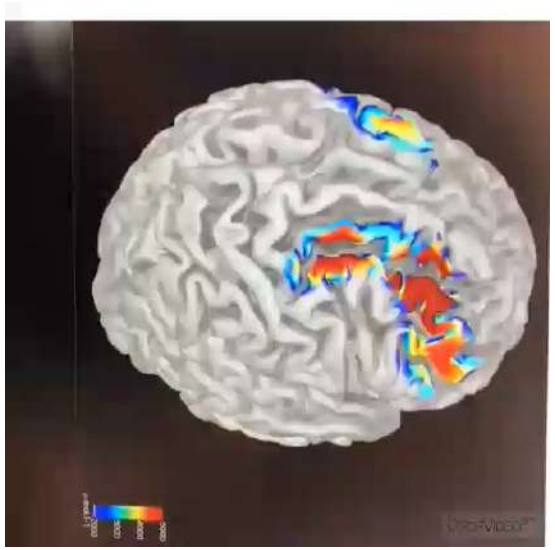
Spatial Knowledge Theory

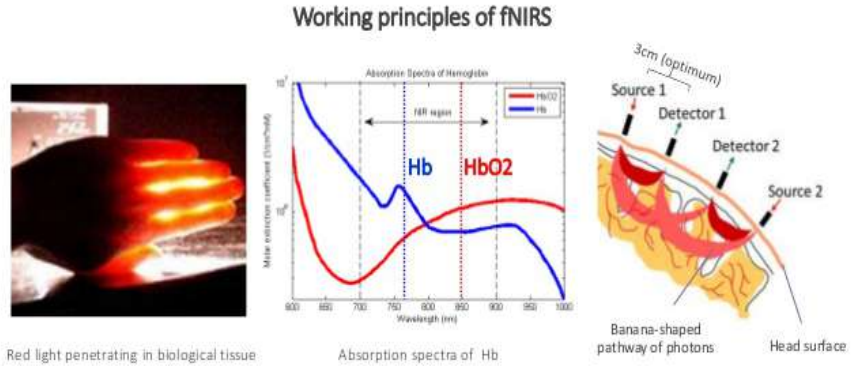
What to measure? – Cognitive Load and Task Performance

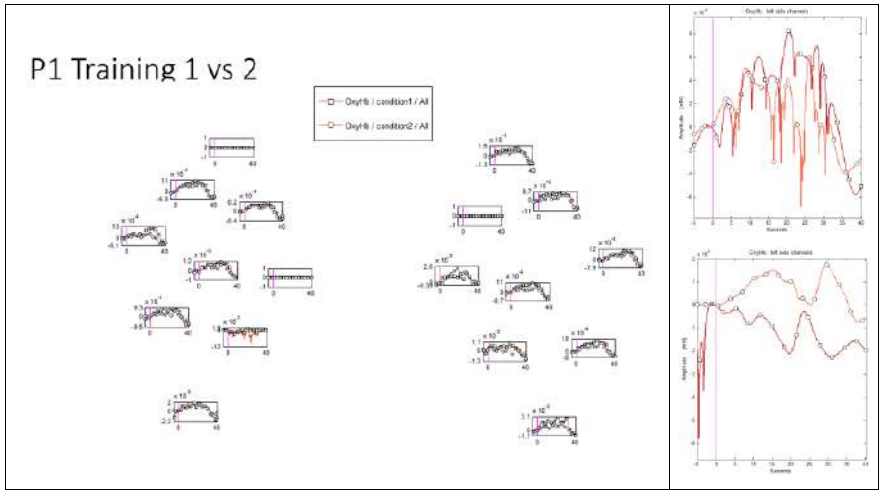
Category	Real-Time Cognitive Load Metrics
Brain Activities	1. Electroencephalogram (EEG): *Certain EEG signals relate to extraneous cognitive load (e.g., cognitive load induced by verbal, visual, textural info)*
Physiology	2. Pupillary Dilation (PD): *Task-invoked pupillary response in diameter change* 3. Eye Movement Frequency (EMF): *Pixels moved per second* 4. Eye Blink Rate (EBR): *Eye blinks per minute* 5. Electrocardiogram (ECG): *The electrical activity of the heart* 6. Respiratory (RES): *Total volume and respiratory rate* 7. Galvanic Skin Response (GSR): *Electrical resistance change of the skin* 8. Heat Flux Rate (HFR): *Rate of skin heat transfer* 9. Electromyography (EMG): *Muscle activities* 10. Heart Rate-Blood Pressure Product (RPP): *Heart rate and systolic blood pressure*
Ergonomics	11. Tapping Frequency (TF): *The tapping frequency of feet and fingers* 12. Gait Features (GF): *Gait variability such as change to stride length*

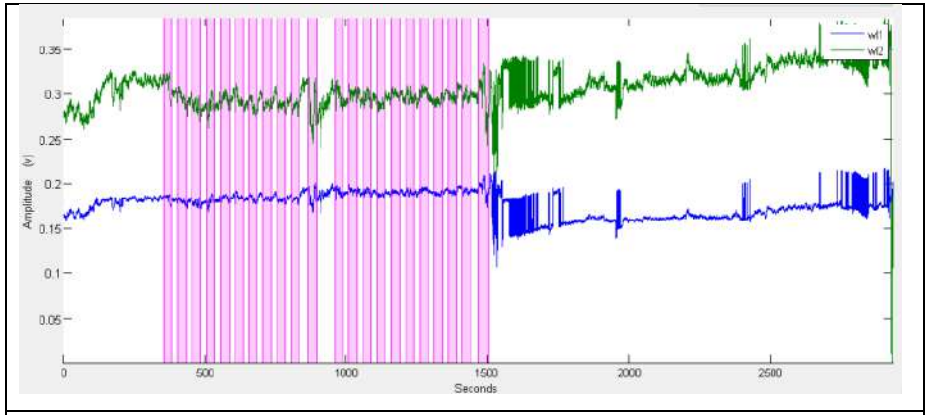
Category	Wayfinding Performance Metrics
Objective	1. Speed or Average Time (m/s): The average travel speed between two waypoints 2. PAO (% above optimal path): The distance that was travelled additionally to the optimal route 3. Directional Error (°): Average deviation from the optimal direction in open areas 4. Wrong Turns (n): Average number of wrong turns at critical intersections 5. Intentional Stops (n): Average number of intentional stops for wayfinding 6. Intentional Stop Time (s): Average intentional stop time for wayfinding 7. Backtracking (n): Average number of backtracking
Subjective	8. Reported Lost (n): Average number of reported lost by subjects 9. Verbal Comments: Subjects' verbal comments about difficulty, landmarks etc.
Cognitive Mapping	10. Sketch Map Accuracy: Statistical measure of the accuracy of memorized map



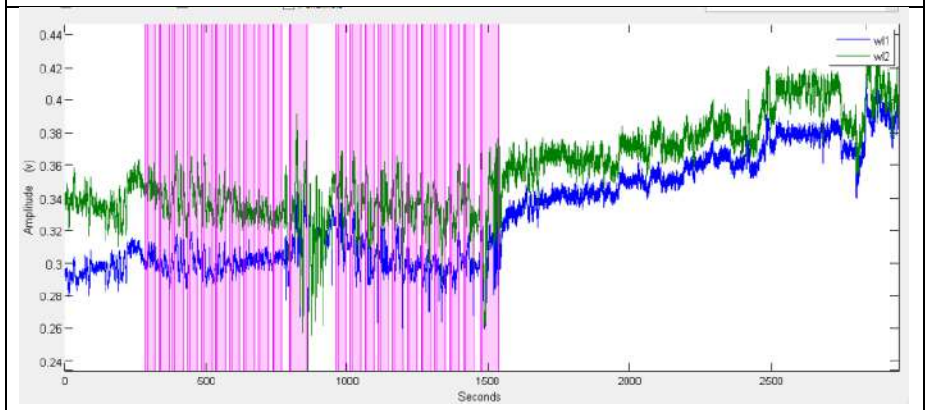








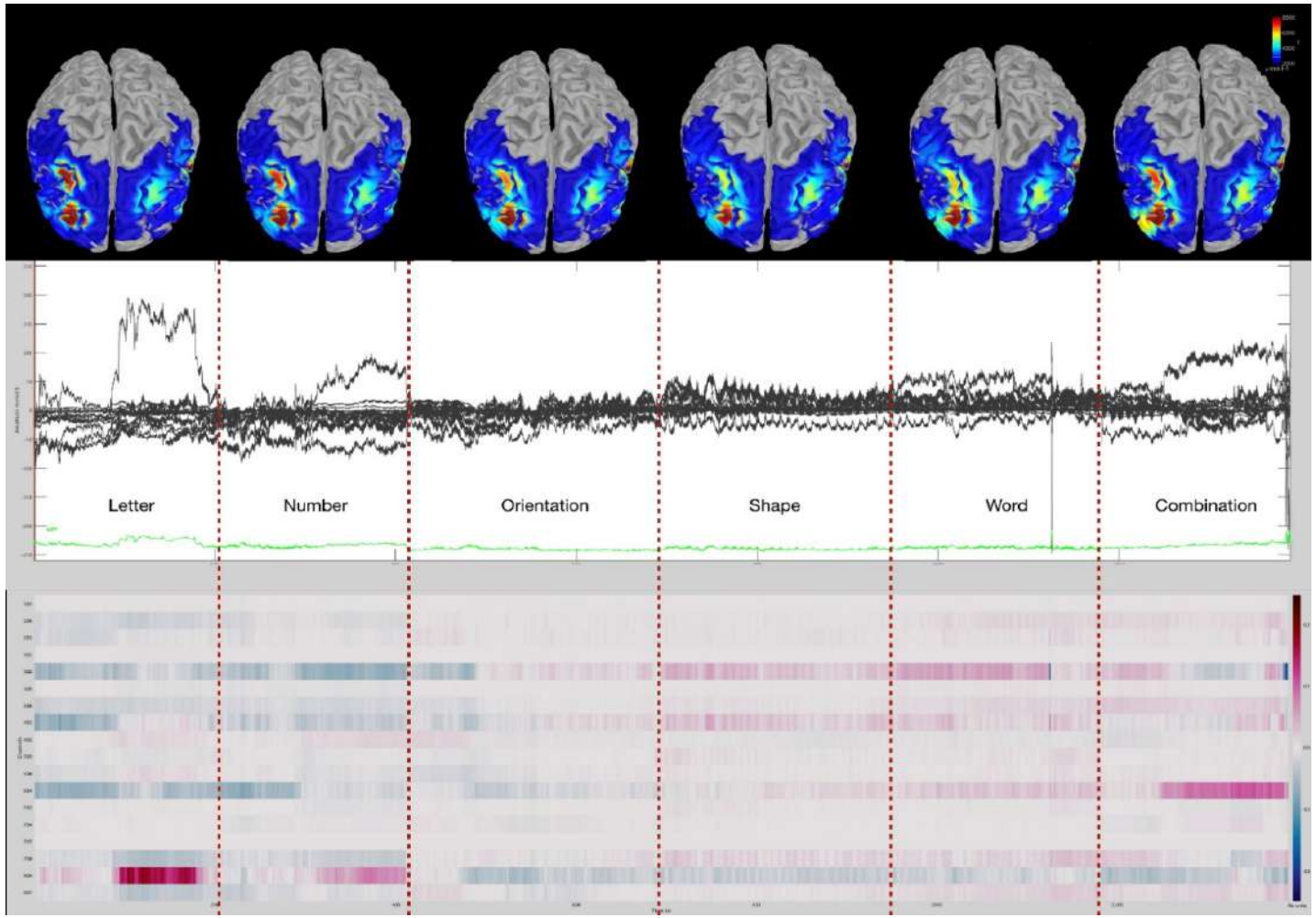
Aggregated oxygen consumption change of subject 05 over one hour



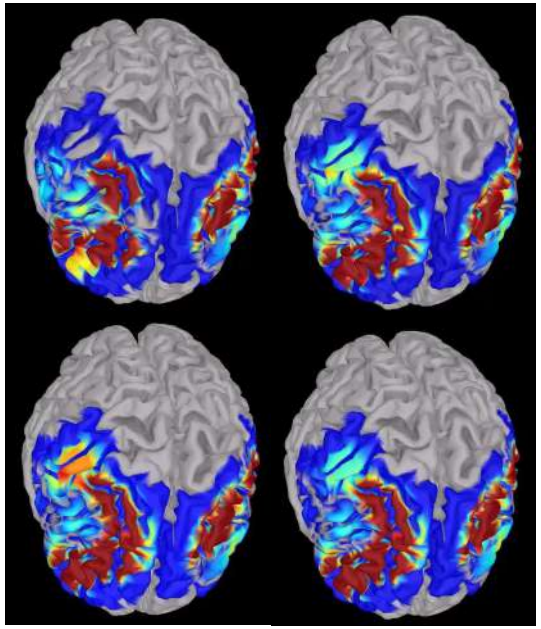
Aggregated oxygen consumption change of subject 08 over one hour

fNIRS: Hemodynamic response as an indicator

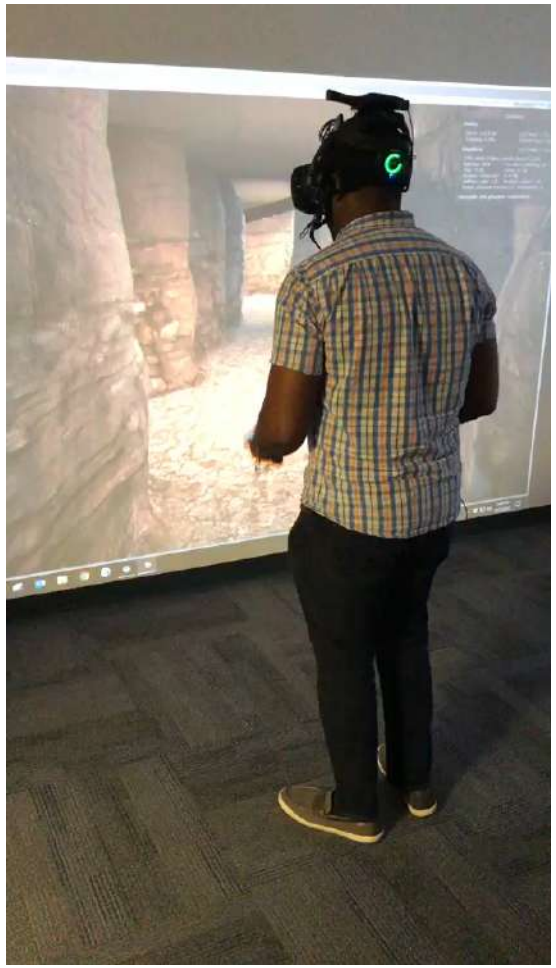
Info Format: Base stimuli (BS) and Base neural responses (BNR)



Subject ID	Percent Misclassified	-2LogLokelihood
1	7.284%	50.6144
2	6.662%	7.92326
3	8.596%	80.4007
4	4.636%	45.8853
5	5.298%	75.4885
6	4.636%	56.6448
7	6.662%	6.53595
8	8.609%	84.3487
9	4.636%	43.1822
10	9.272%	170.38
11	7.947%	105.973
12	9.986%	18.8986
13	3.3112%	57.2329
14	6.6225%	72.2801

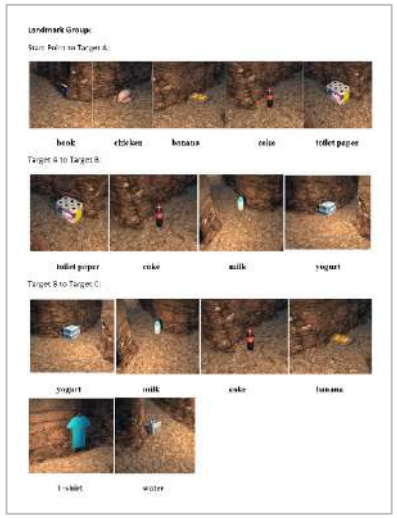


Info Content: what spatial knowledge is the best?



Which group was the best?

A. Landmarks
B. Routes
C. Survey (map)



Route Group:

One and only one instruction is ought to be performed on every crossroads and corners.

Start Point to Target A:

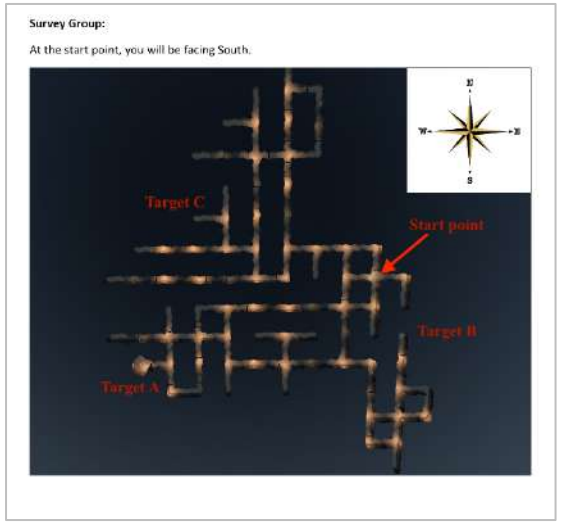
Left, right, left, right, left, left, right, left, right

Target A to Target B:

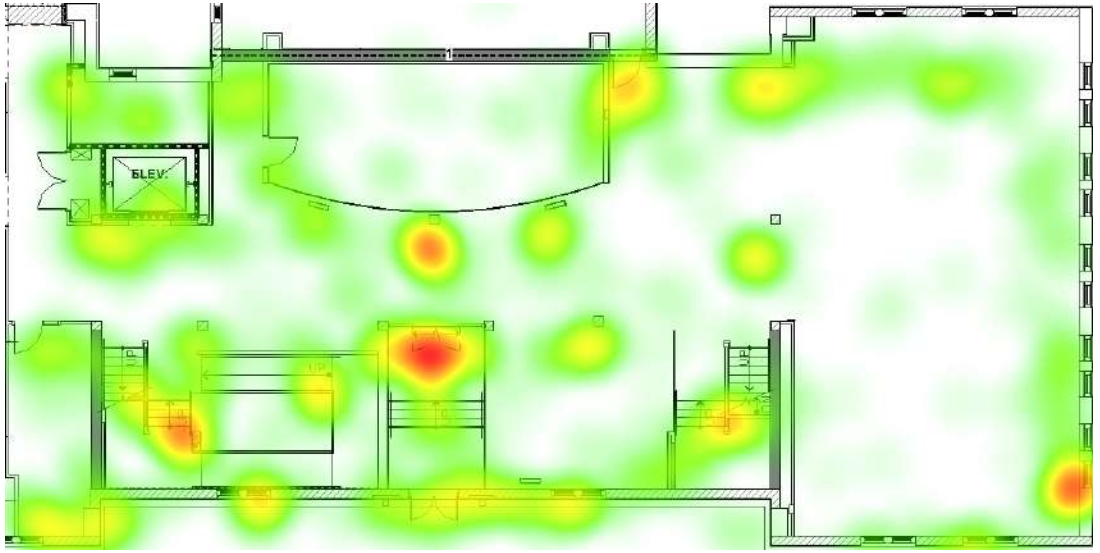
Turn around, left, right, left, right, right, left, forward, left, left

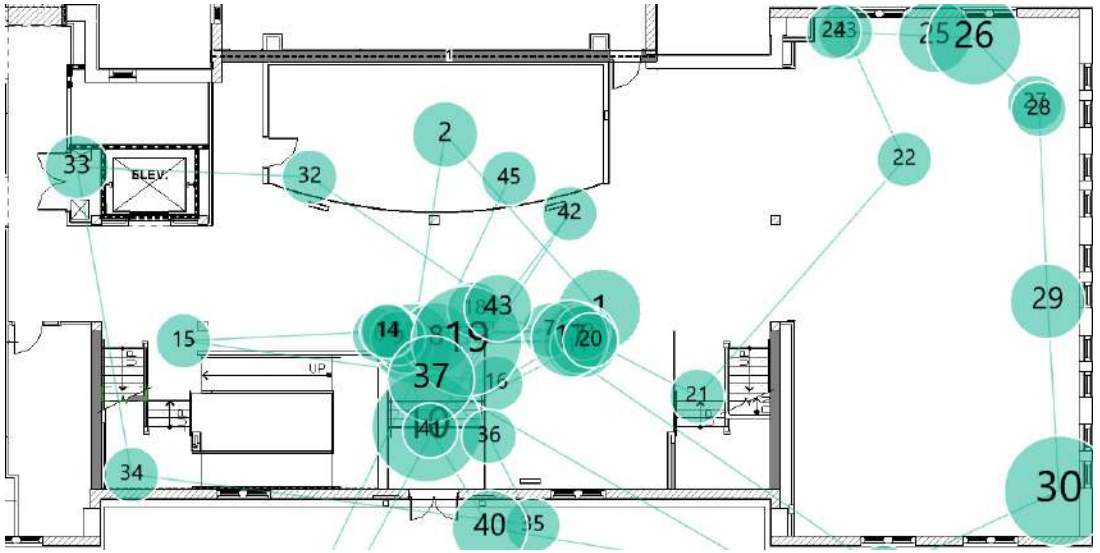
Target B to Target C:

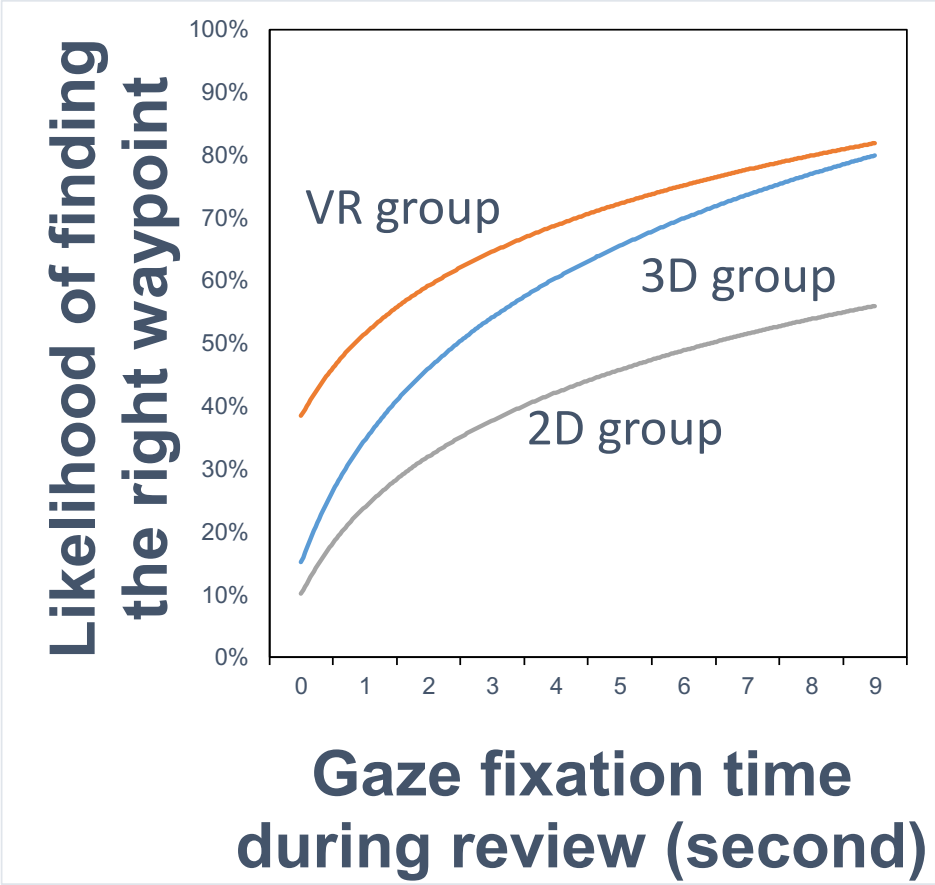
Turn around, right, right, left, left, right, right, left, right, left



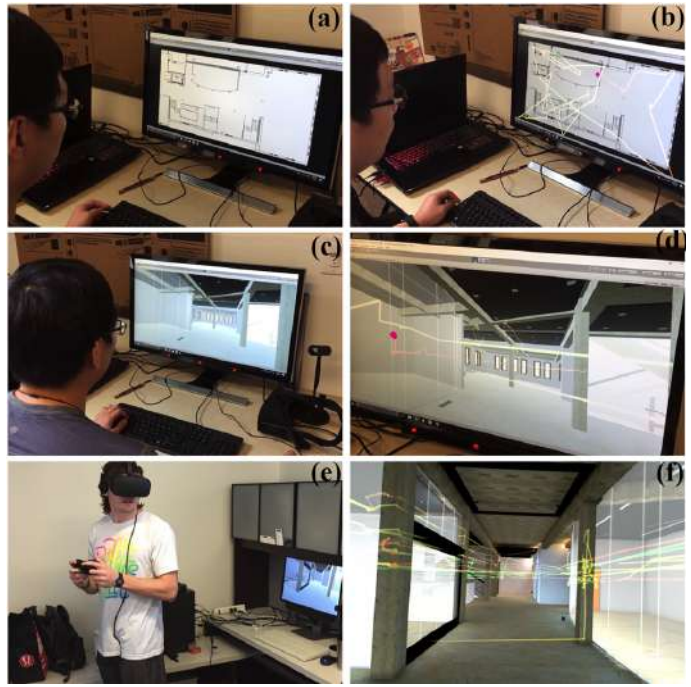
Unexpected #1: Mixed Impacts of Info Content and Info Format

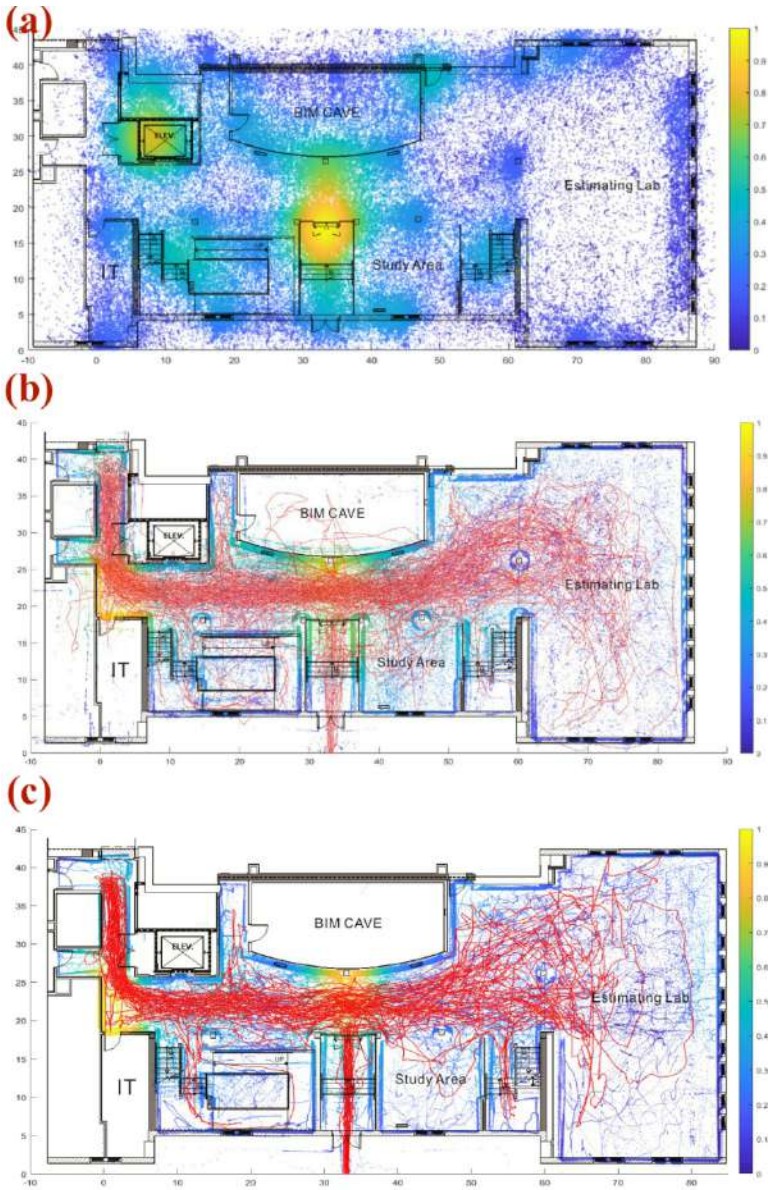


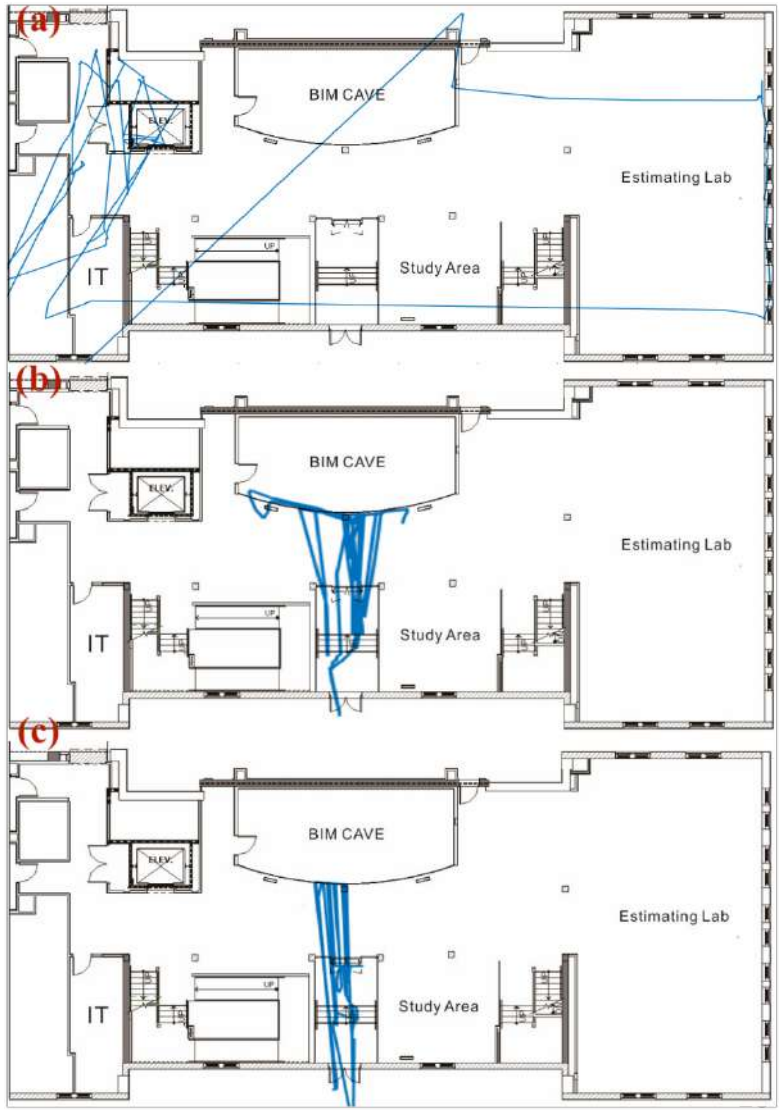




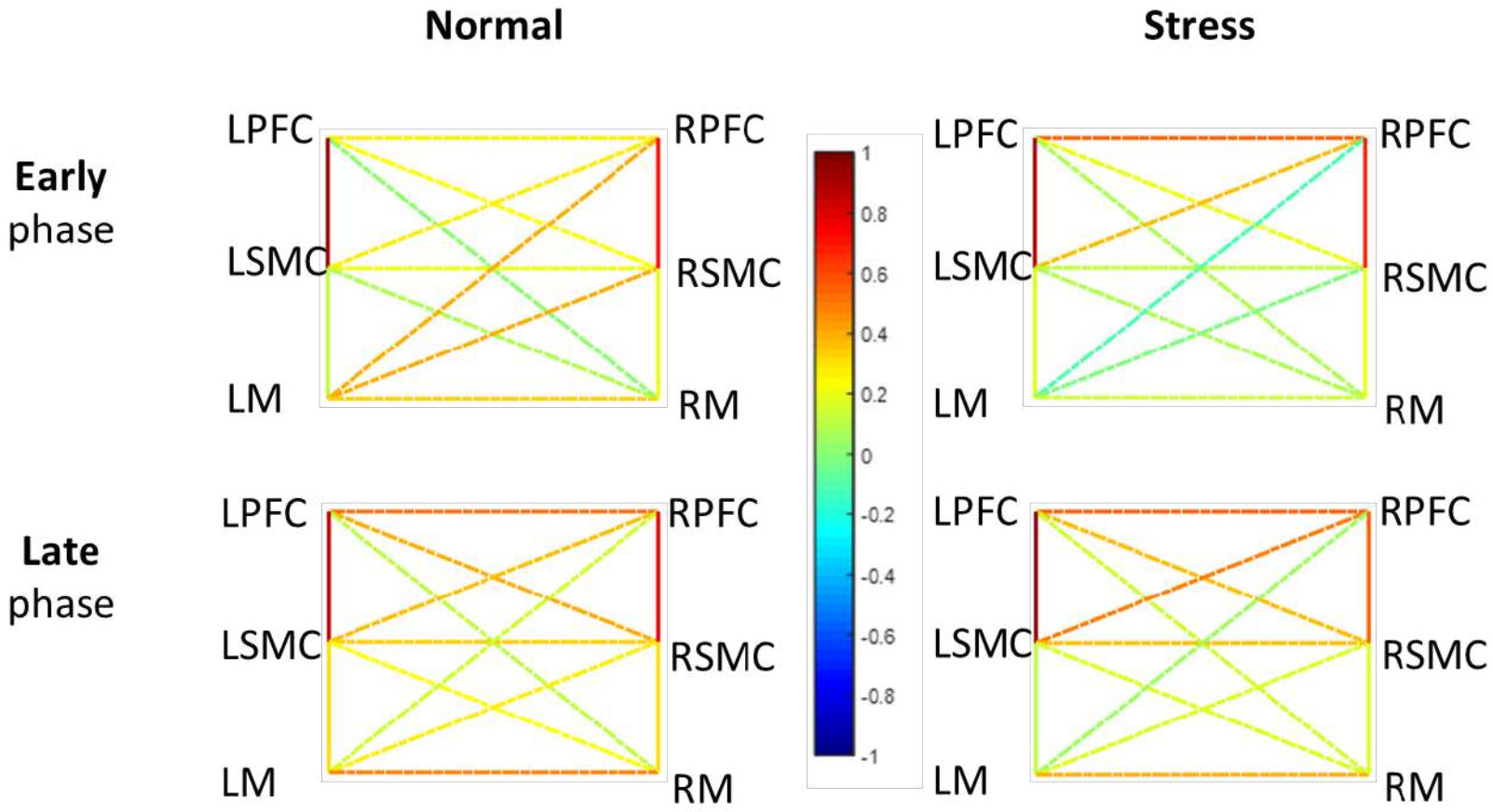
Mixed Impacts of Info Content and Info Format (cont'd)



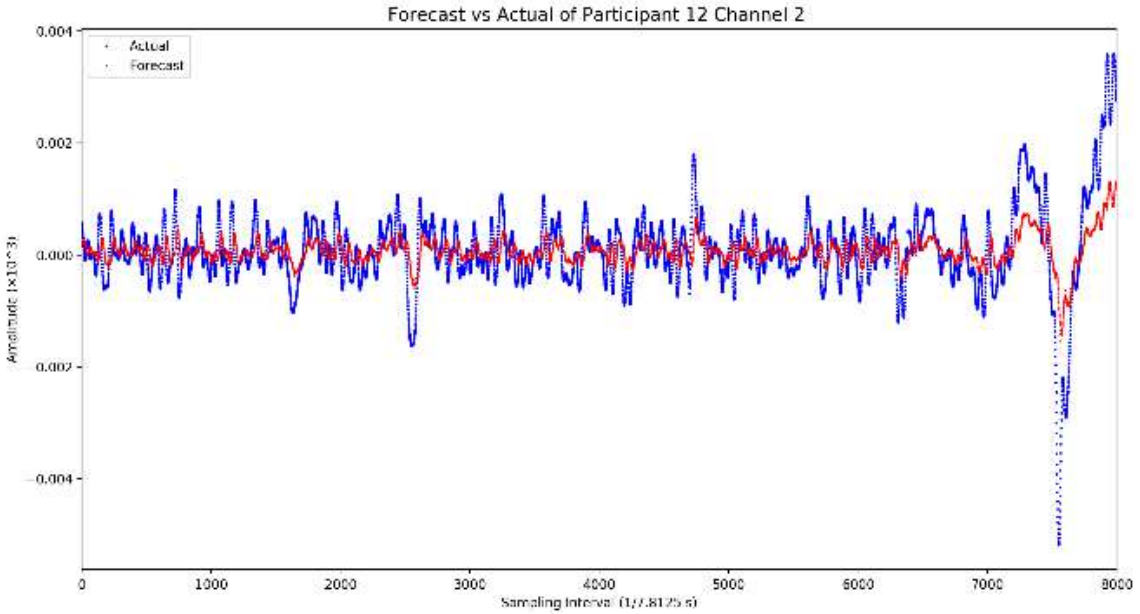


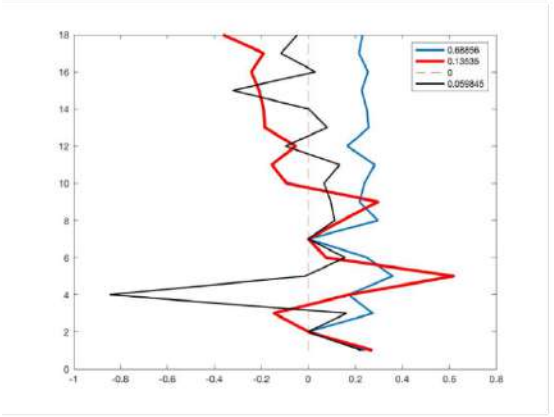


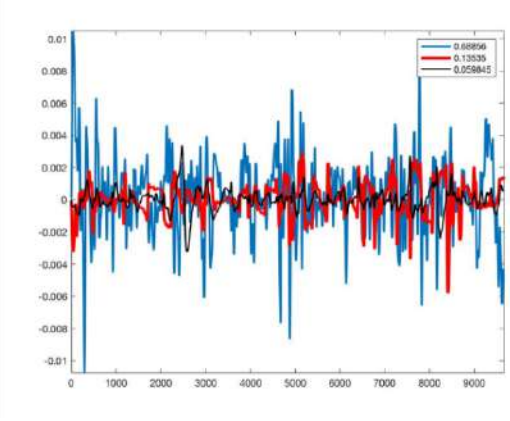
Unexpected #2: Stress is another contributing factor



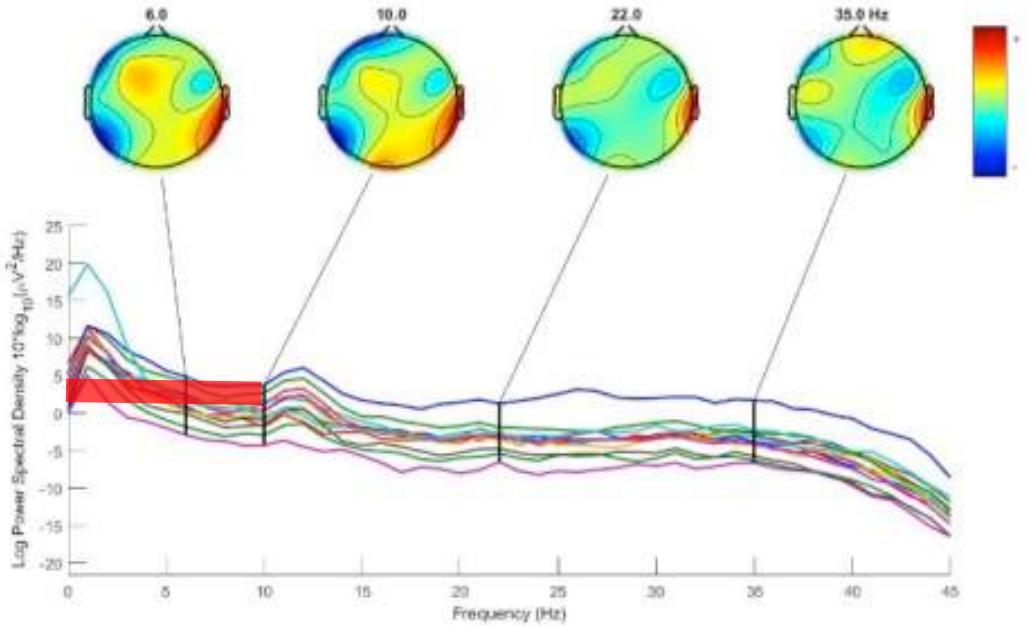
Predicting tipping point of cognitive status



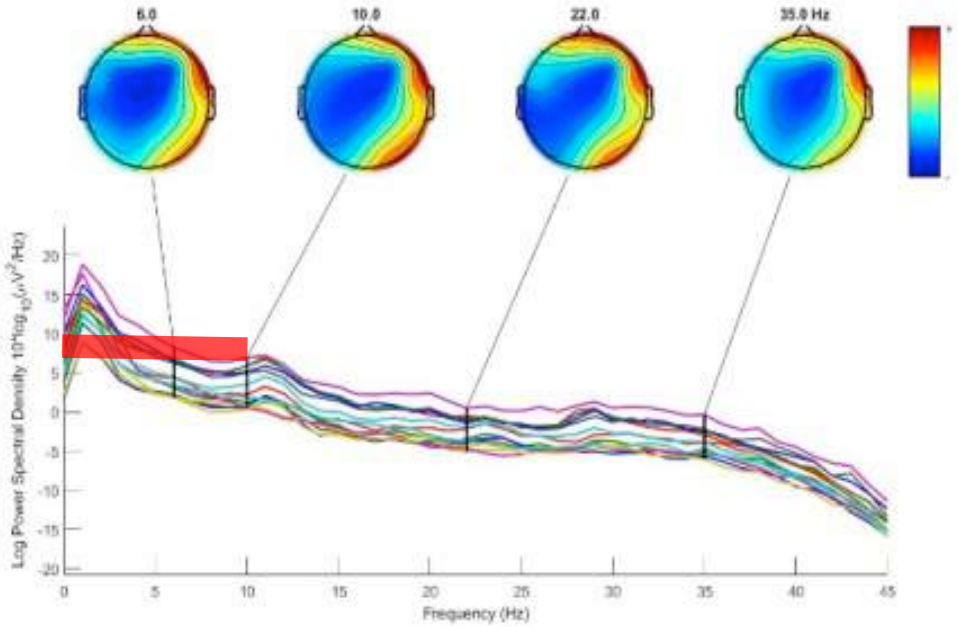




EEG results

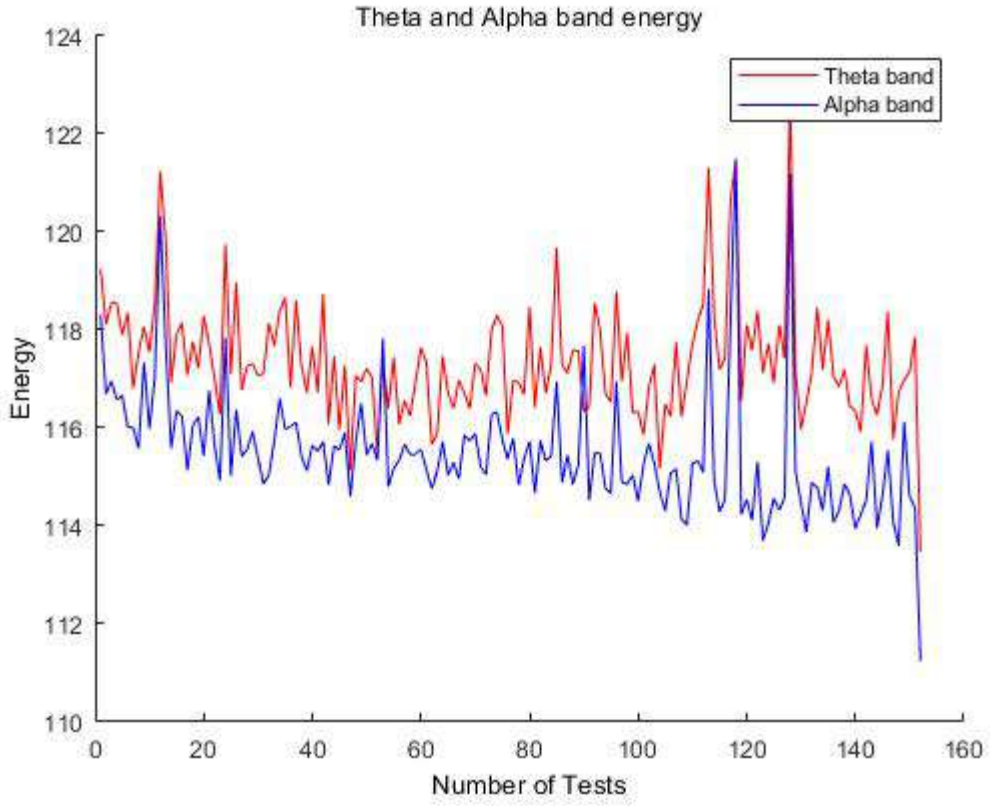


2D map



3D computer model

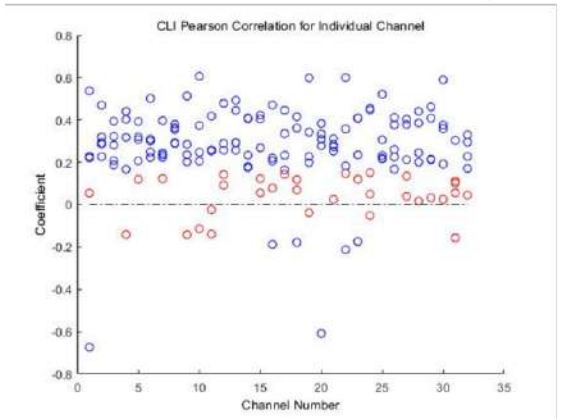
Cognitive load measure

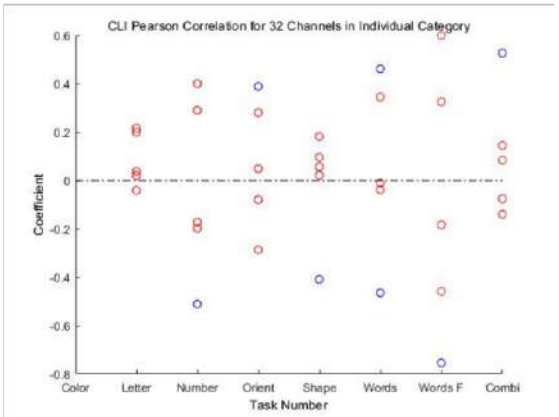


Cognitive Load Index

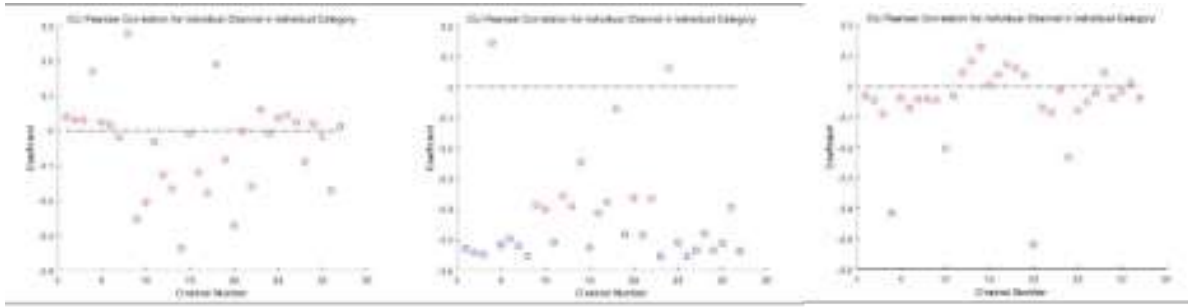
$$CLI = \frac{Theta\ Band\ Energy}{Alpha\ Band\ Energy}$$

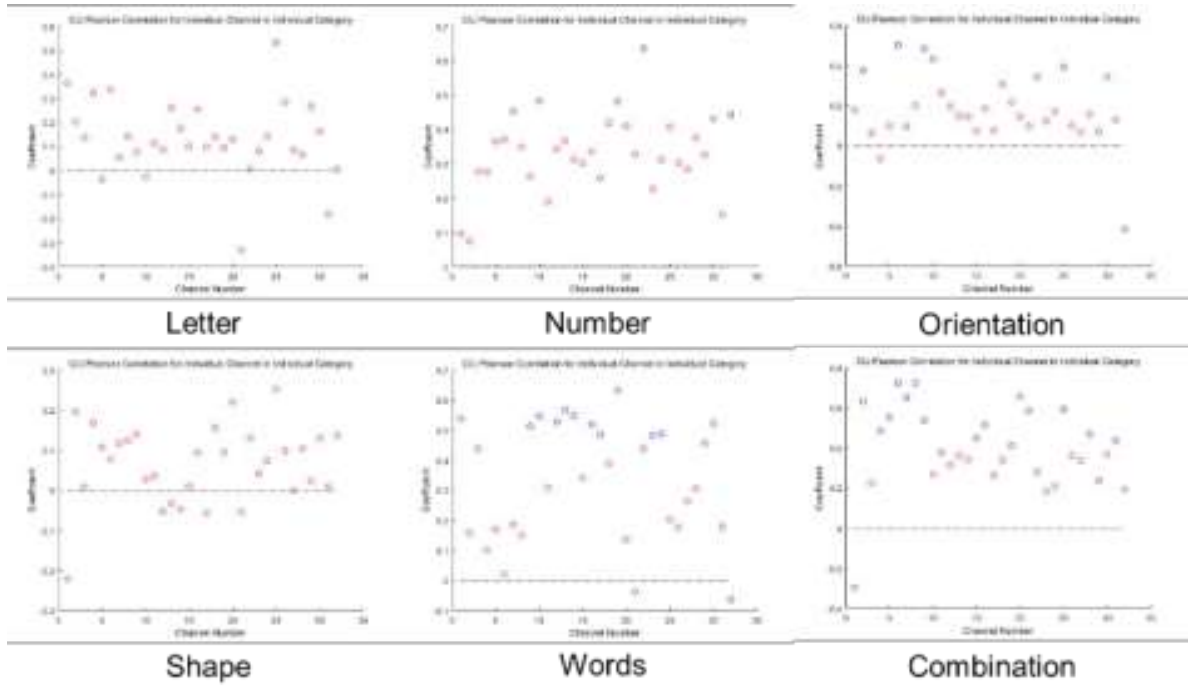
Blue: $p < 0.05$



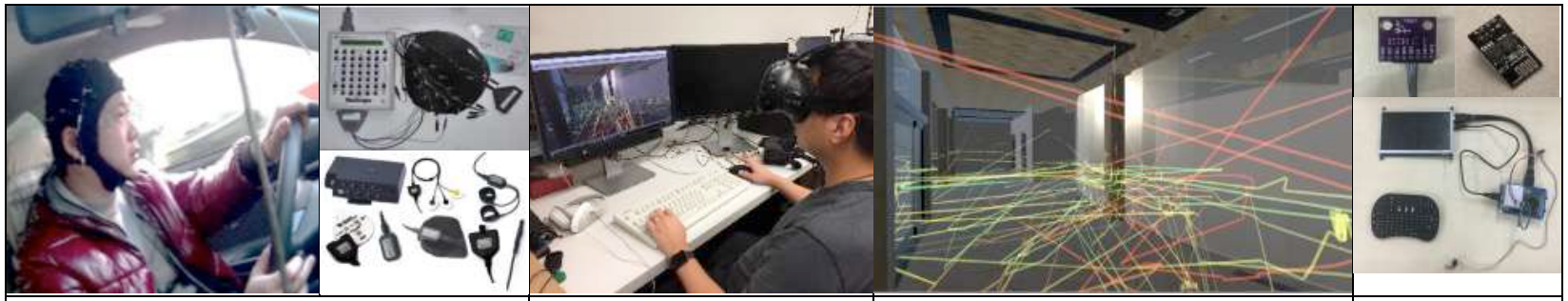


Cognitive load based on two bands

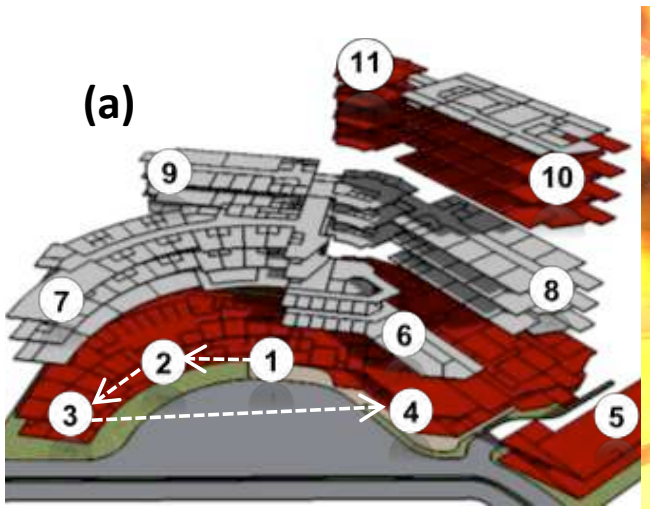




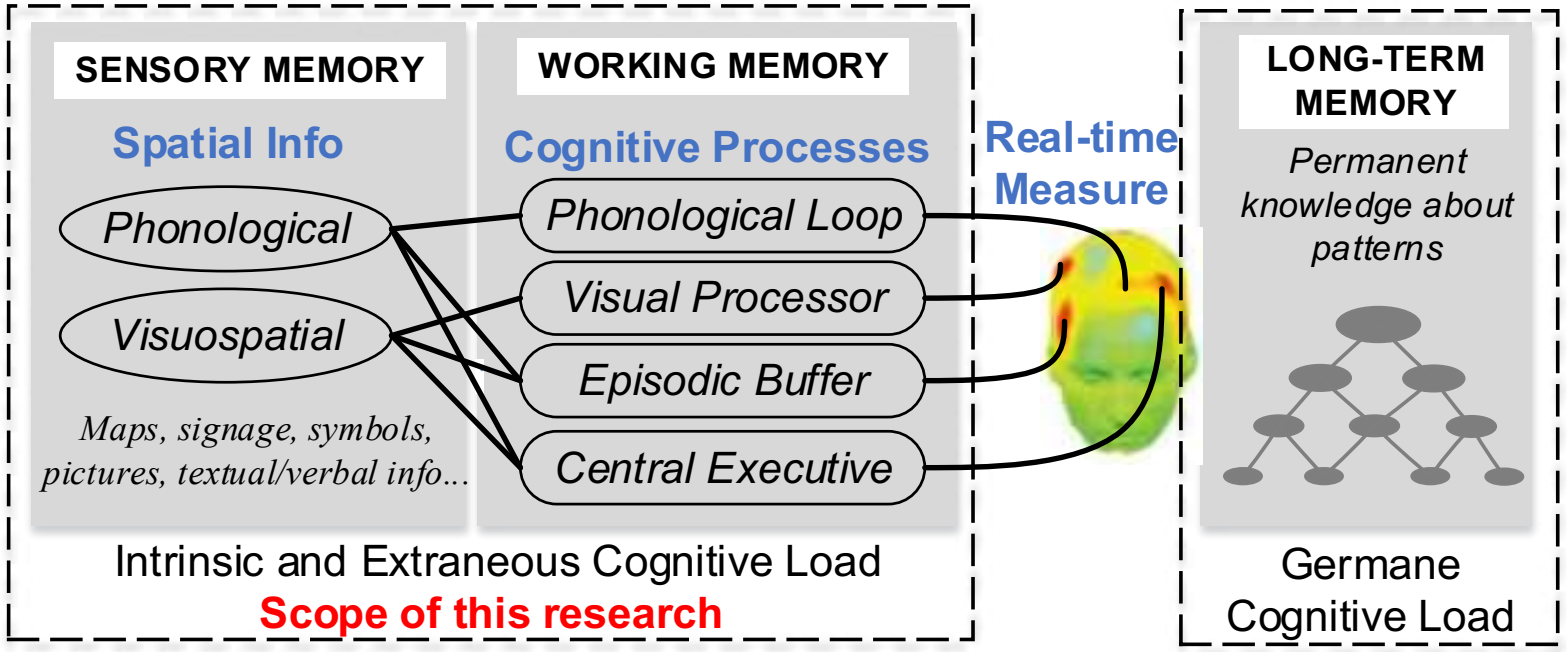
Objective 3: Develop and Validate Cog-DNA



a. Mobile cognitive tracking system by Co-PI Lin for driver studies	**b.** Eye tracker integrated with HTC VIVE headset	**c.** Gaze focus movement in VR visualized in green/red lines	**d.** Raspberry Pi 3 as core

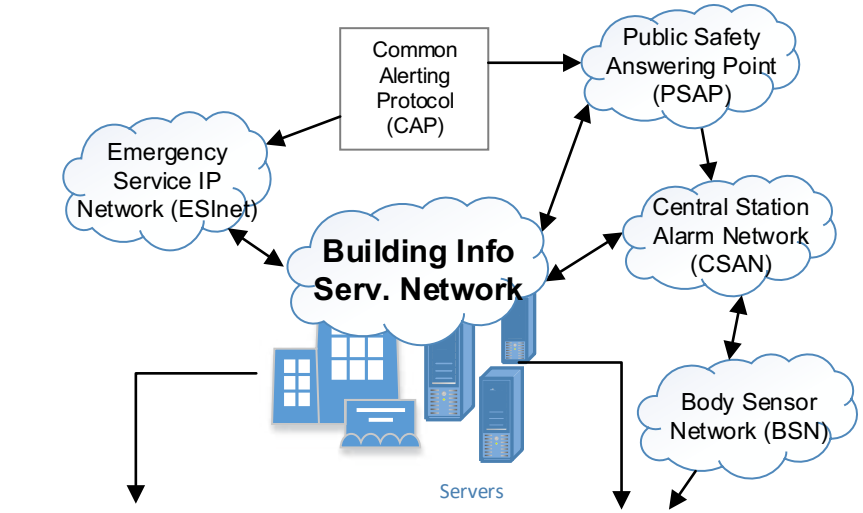


We must recognize the complexity of cognitive load



Cognitive load is not “one thing” – it is many things. Different types of information (2D, 3D, immersive, verbal…) trigger different areas of a brain. Display can be fine tuned.

Relevant Information in Emergency Wayfinding



PERMANENT DATA

Building Metadata
(e.g., use, age, contacts)

Spatial Data
(e.g., floor plan, 3D model, exits)

Fire Response Features
(e.g.,water access, areas of refuge, utility shutoffs)

Emergency Serv. Features
(e.g.,hazardous materials)

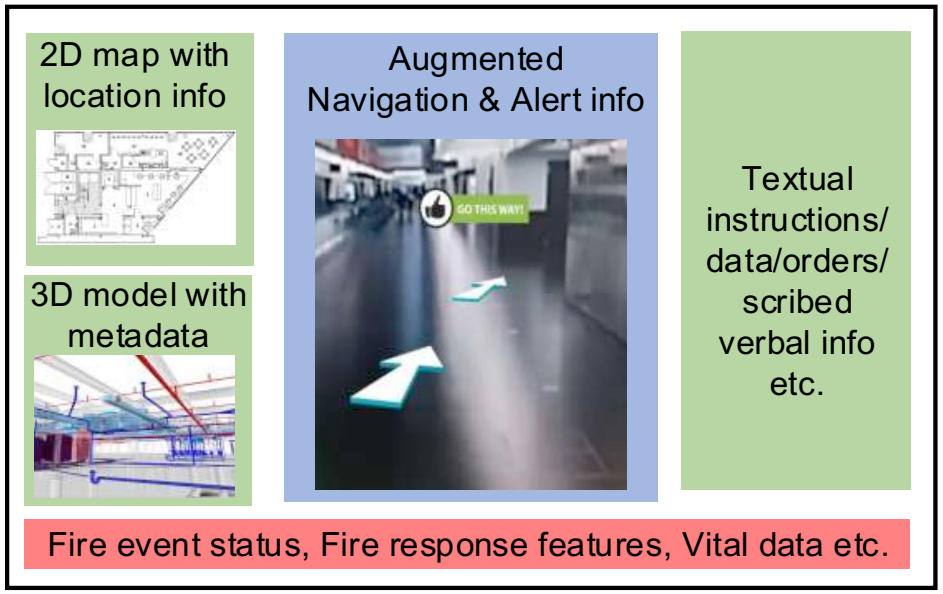
Site Features
(e.g.hydrants, egress path)

DYNAMIC DATA

Building System Status
(e.g.,visibility, alarm, occupancy, sensor status, utility sys)

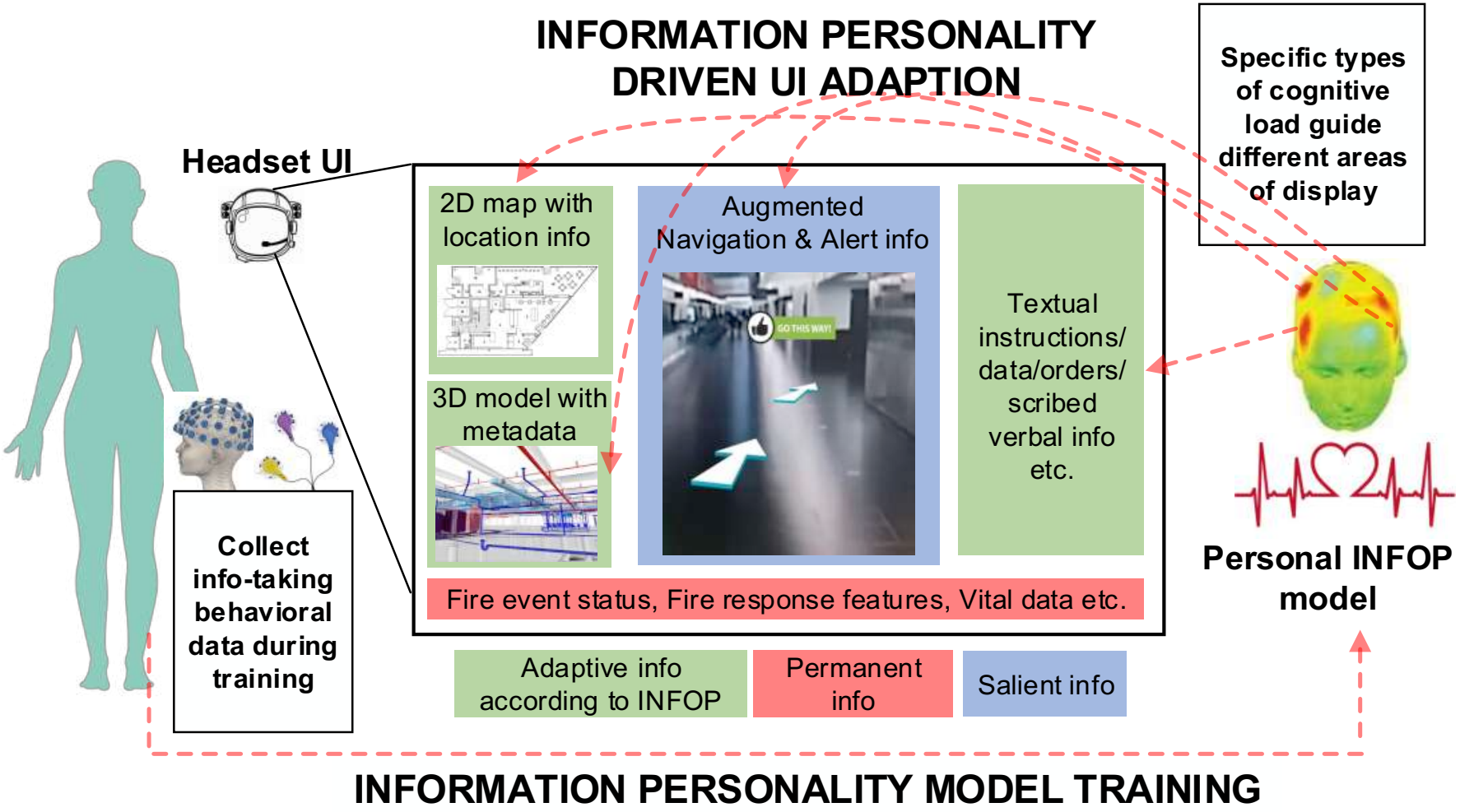
Firefighter Status
(e.g.,location, physiological condition, airpack time)

Control Function
(e.g., elevator control, silence notification appliance, reset alarm, smoke control, activate emergency voice)



NIST standards such as NIST Technical Note 1648; Building Information Exchange for First Responders Workshop: Proceedings; NISTIR 7314

UI and Information Display should be fine-tuned



Special Thanks to Our Collaborating Partners!

DoD Fire Academy
17th Training Wing
Goodfellow Airforce Base

Boston Fire Department

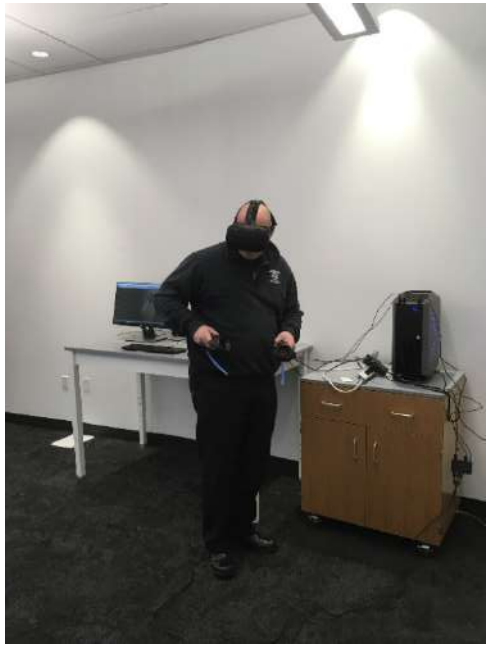
College Station Fire Department

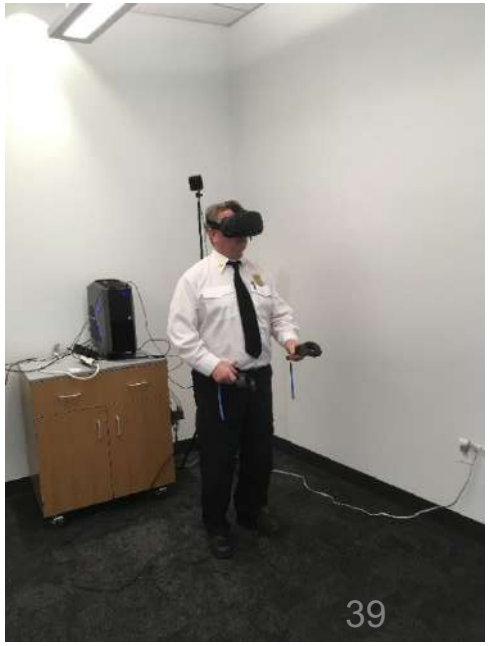
Texas Fire Training School

Texas A&M Fire and Emergency Services

Applied Research Group, National Fire Protection Association

Our Collaborators





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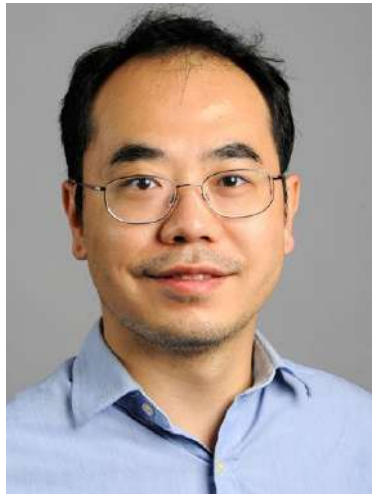

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Thank You!

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