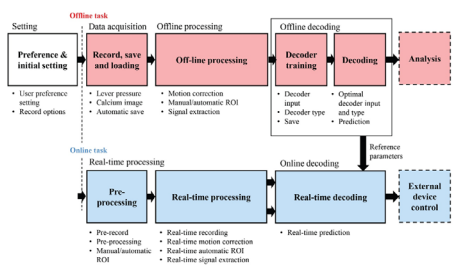
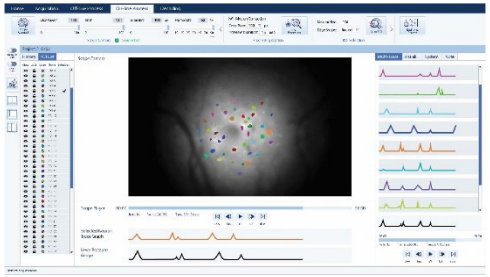
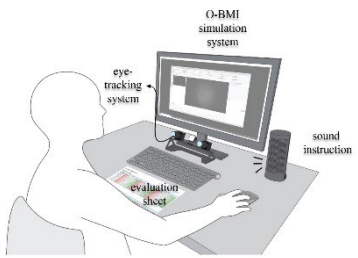
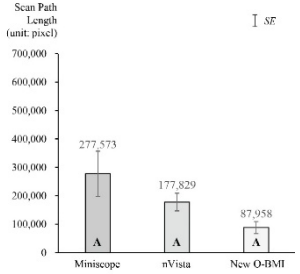
Subjective and Objective Evaluation of the Ergonomic User Interface (UI) Design of a New Optical Brain-Machine Interface (O-BMI) System

신규 광학적 뇌-기계 인터페이스 시스템의 인간공학적 UI 디자인의 주관적 및 객관적 평가









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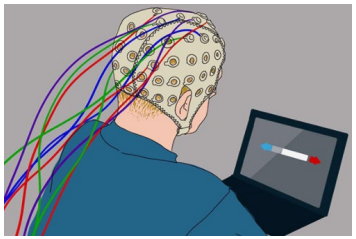
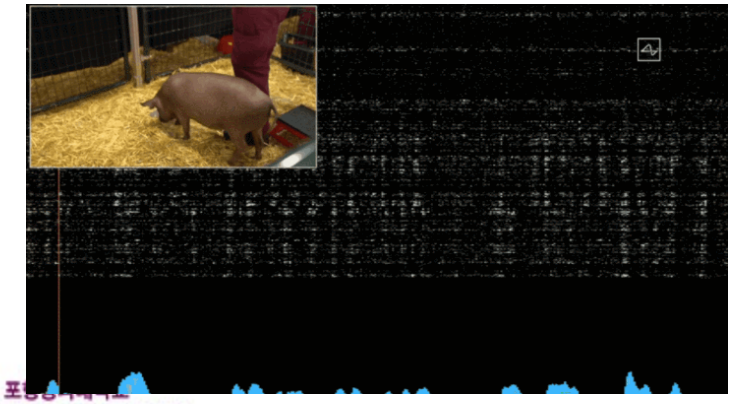
Background: O-BMI System

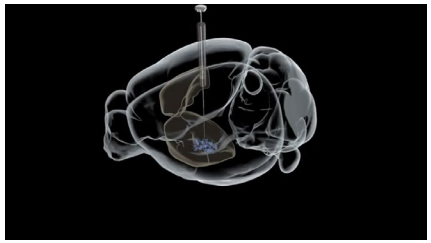
- A brain-machine interface (BMI) is a device that translates neuronal information into commands capable of controlling an external device.
- **Optical brain-machine interface (O-BMI)** research based on calcium imaging technology has shown great advantages in brain science

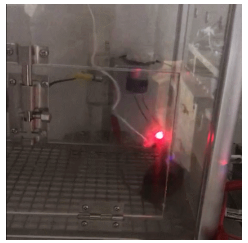
Electrophysiology-based BMI systems

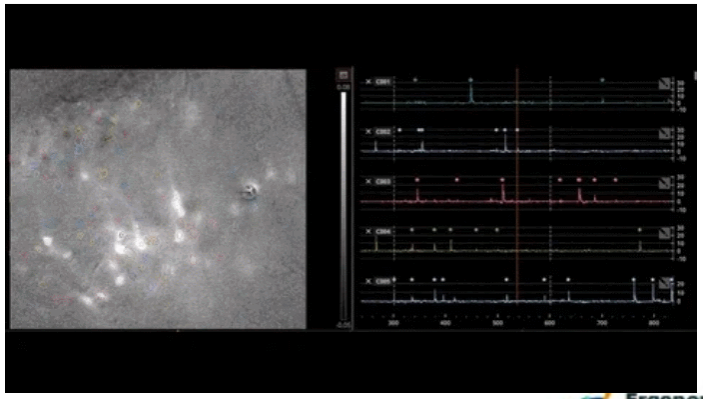




Calcium imaging-based BMI systems



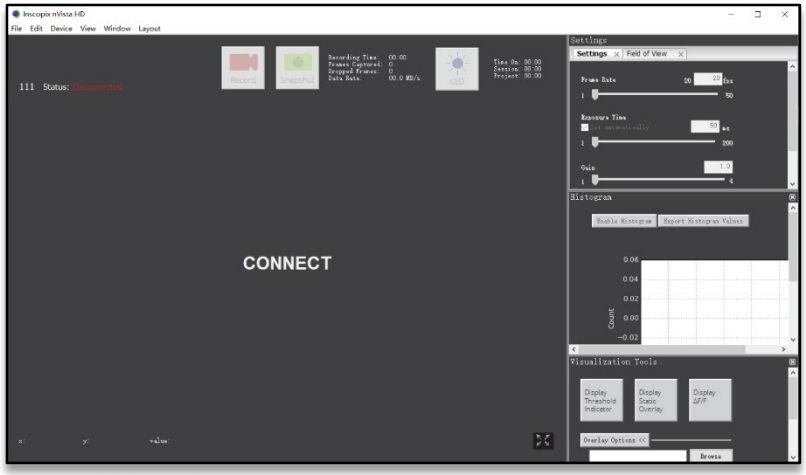




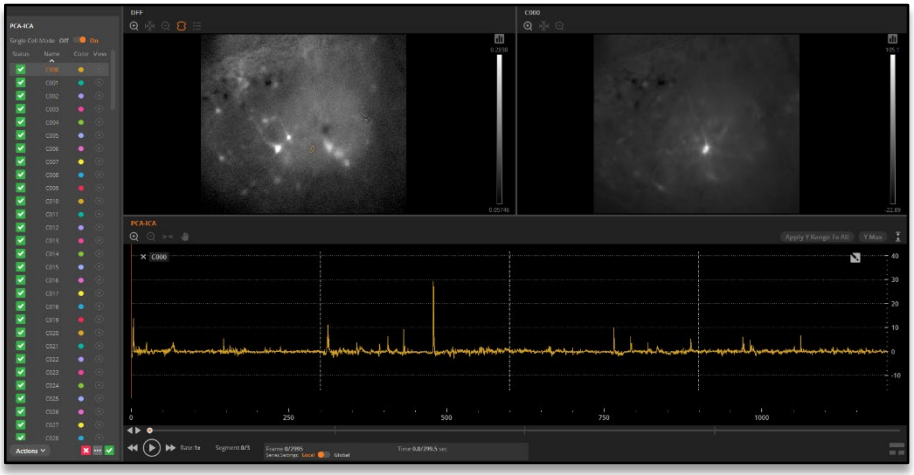
Limitations of Existing O-BMI System

- **Few O-BMI system** is developed for video acquisition, image processing, neuron extraction, and signal visualization.
- Limitations of existing OBMI S/W need to be improved.
  - ✓ Requirement of real-time processing of neuron signals to control external devices
  - ✓ Many usage problems (e.g., inconvenience of using independent modules) were complained by neuron scientists.

Examples of existing O-BMI system



S/W for Signal acquisition (Inscopix nVisata HD)

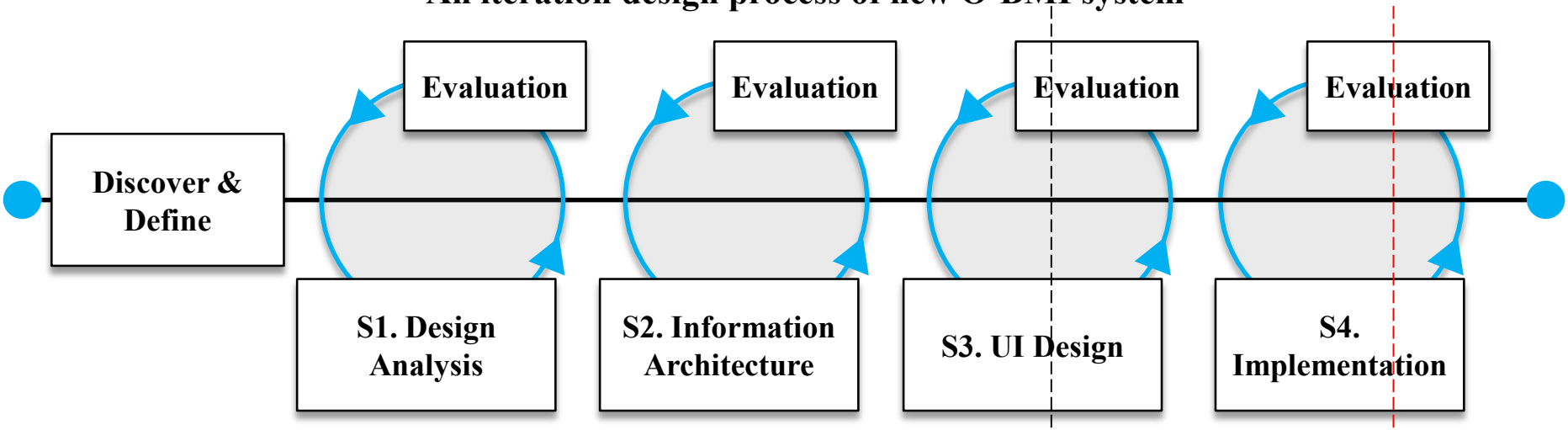


S/W for signal processing and visualization (Inscopix)

Development of an Ergonomic UI Design of a O-BMI System (1/2)

- An new O-BMI system is developed through a iteration design process by user researches

An iteration design process of new O-BMI system



- **Preferred design features**
- Important and frequently used **functions** and **parameters**
- **Natural workflow** by literature review

- Wireframe
- Graphic design

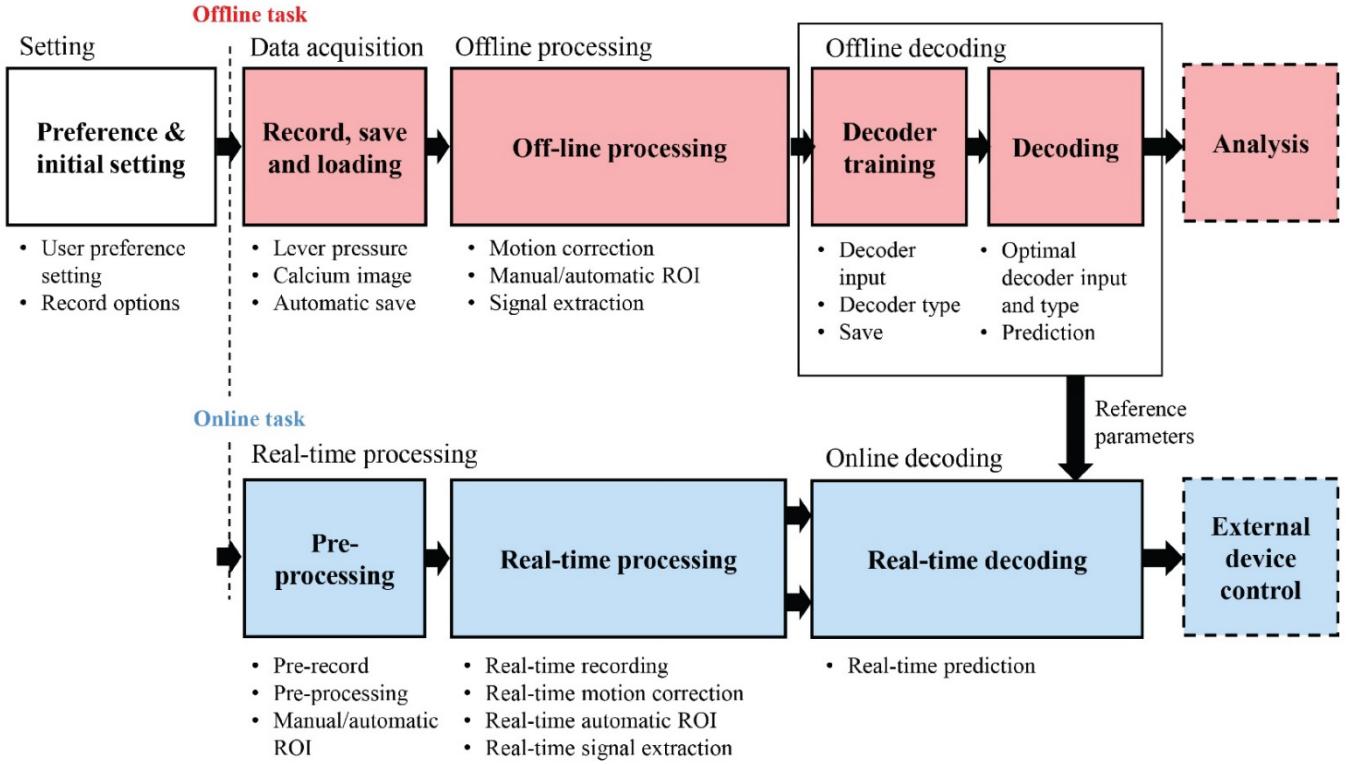
Previous presentation

Current study

Modules of a O-BMI System

- **Four modules** were included: **(1) data acquisition**, **(2) off-line processing**, **(3) on-line processing**, **(4) decoding**.

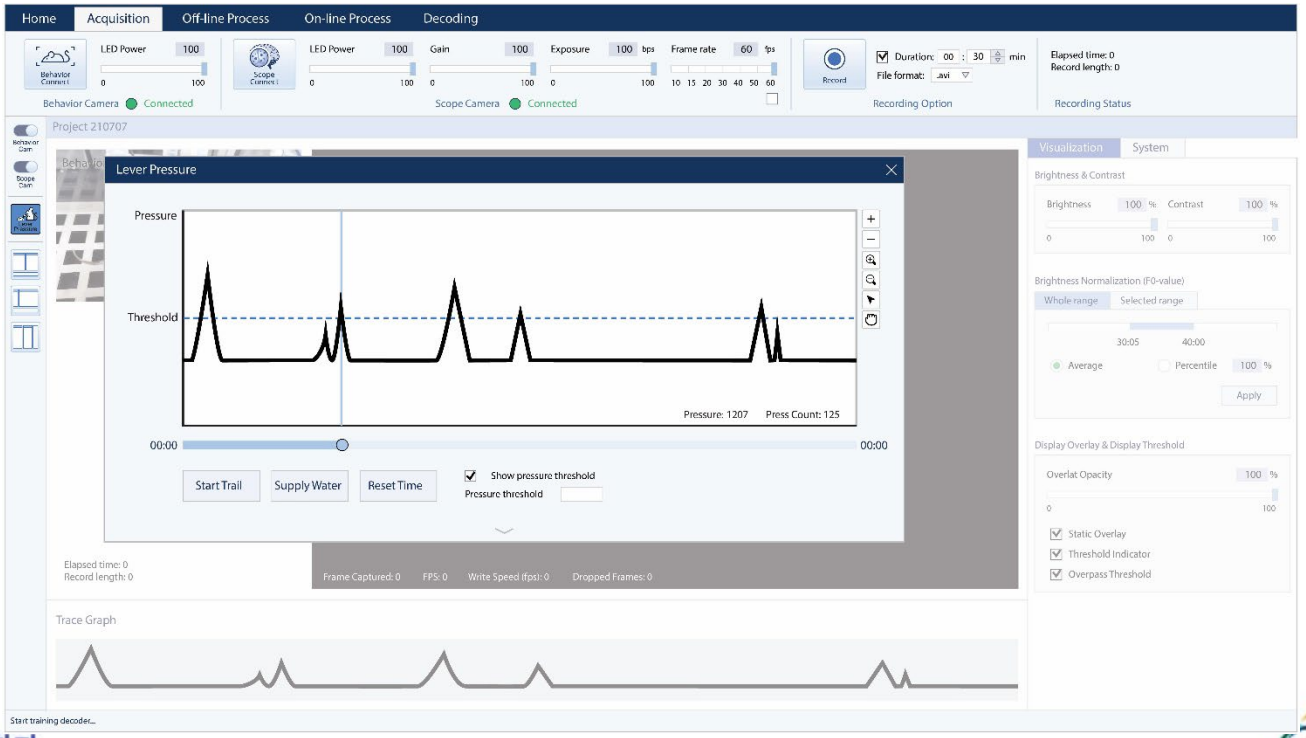
Task flow of a new O-BMI system based on the benchmarking of existing systems



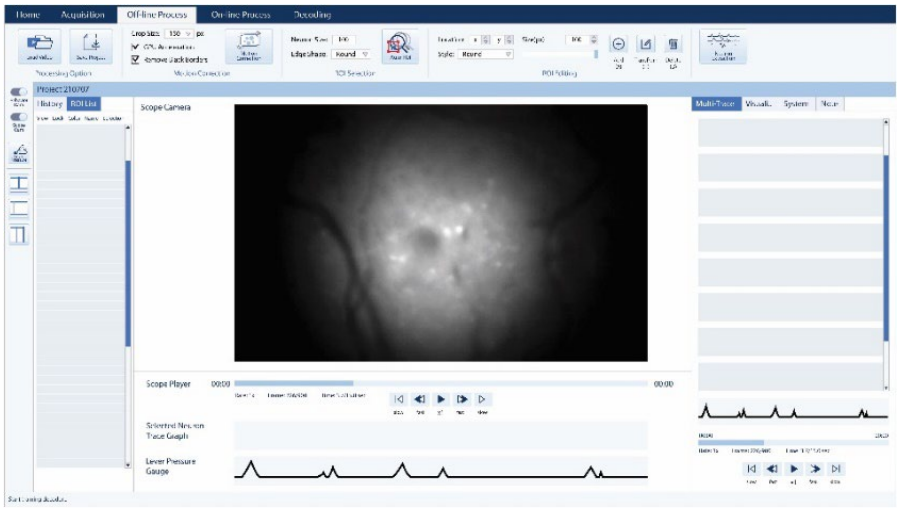
UI Design Features of O-BMI System

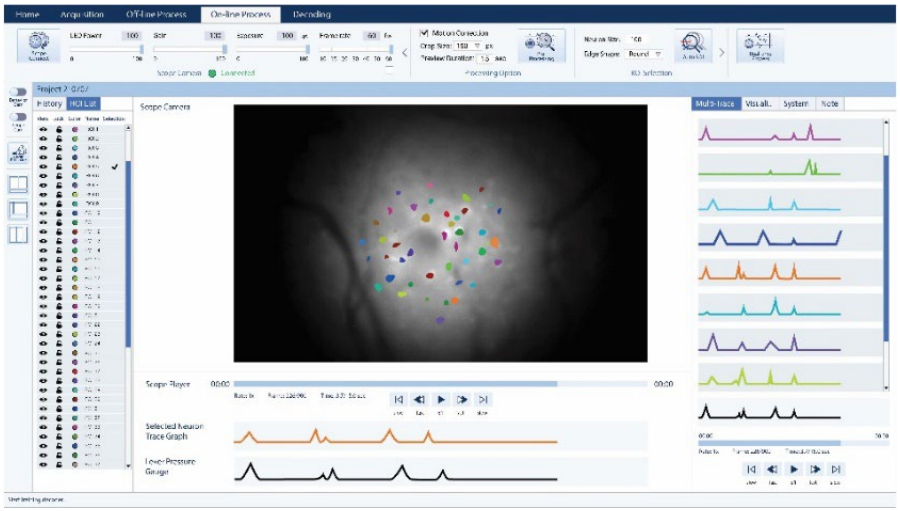
- **Advanced design features** were provides in terms of **task-oriented navigation**, **a modularized structure**, **a changeable and adjustable layout**, and **integrated functions**.

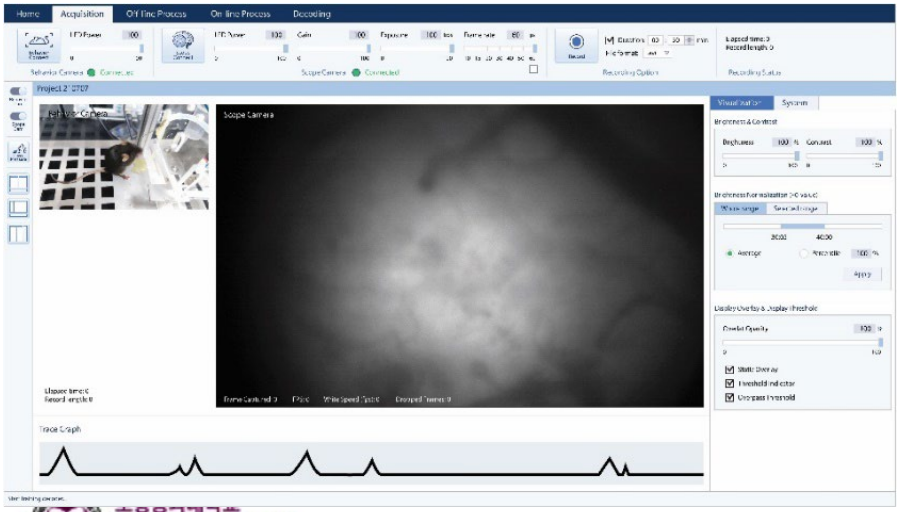
Integration of display- and control-related functions of lever pressure gauge in a new O-BMI system (illustrated)

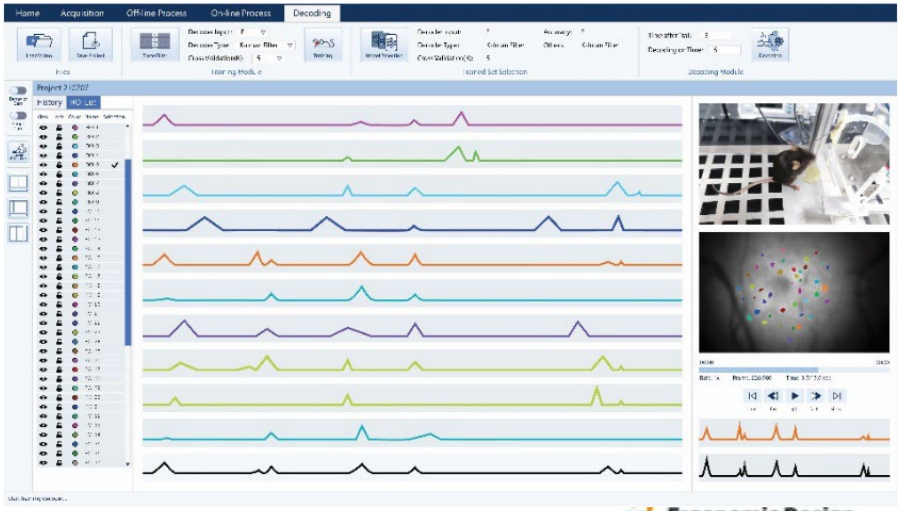


GUI Design of the New O-BMI System









Objective of the Study

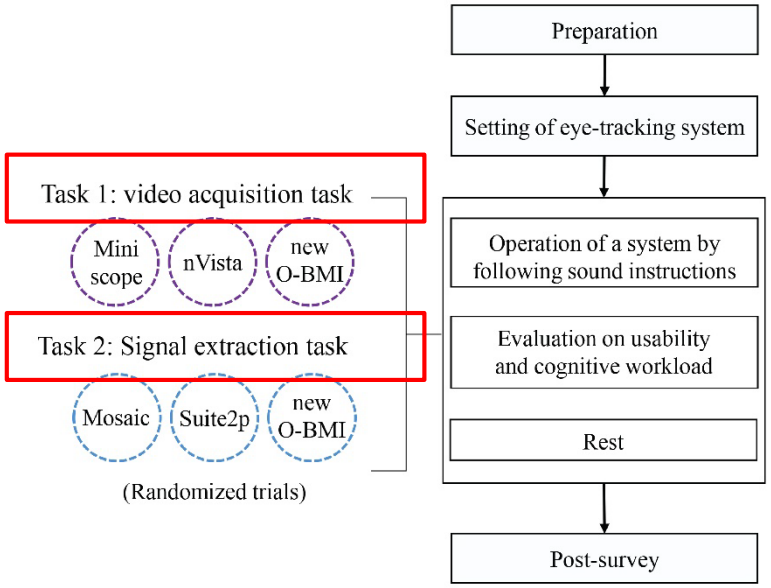
Subjective and Objective Evaluation of the UI Design of the New O-BMI System

1. **Development of subjective and objective evaluation protocols** for the UI design of the new O-BMI system
2. **Evaluation on the new UI design of O-BMI system by comparing with the existing systems**

Experimental Protocol

- The usability test was developed to evaluate **the task completion time, scan path length, perceived cognitive workload, satisfaction** of the UI design **using subjective and objective methods**
- Three steps (1) preparation of the experiment, (2) simulation of system operations, and (3) evaluation of perceived cognitive workload and satisfaction

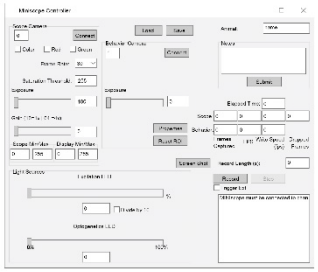
Experiment procedure of O-BMI usability testing



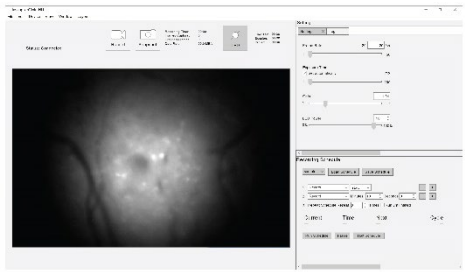
Participant & Test Object

- **10 participants** (age = 27.1 ± 3.9 years)
  - ✓ 5 neuroscience researchers (work experience =3.4 ± 1.1 years)
  - ✓ 5 ergonomic experts (work experience =3.6 ± 2.7 years)
- The O-BMI UI prototypes were compared with 4 existing systems (Miniscope, nVista, Mosaic, and Suite2p; grayscale color scheme digital prototyped)

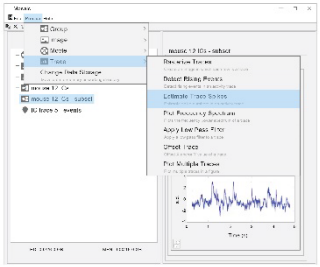
Miniscope



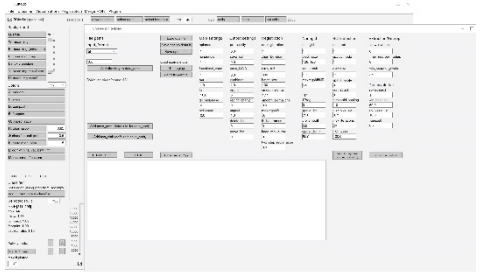
nVista



Mosaic



Suite2p

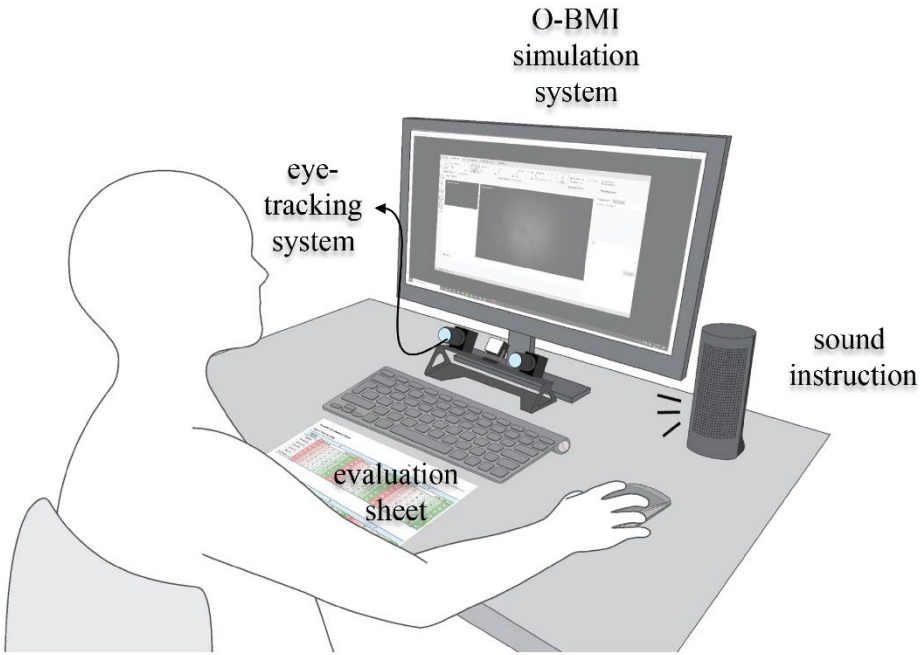


The present study was approved by the Institutional Review Board of the Pohang University of Science and Technology (PIRB-2020-E033) and each participant was given informed consent.

Apparatus & Environment

- A **screen recorder** and a **eye-tracking system** were used to measure the **task completion time** and **scan-path length**.
- A **usability questionnaire** was used to evaluate the **perceived cognitive workload** and **satisfaction**.

Experiment setup for usability testing of O-BMI systems.



Eye-tracking system (faceLAB™, Seeing Machine); RecMaster (Suzhou Aunbox Software Co., Ltd., Suzhou, China)

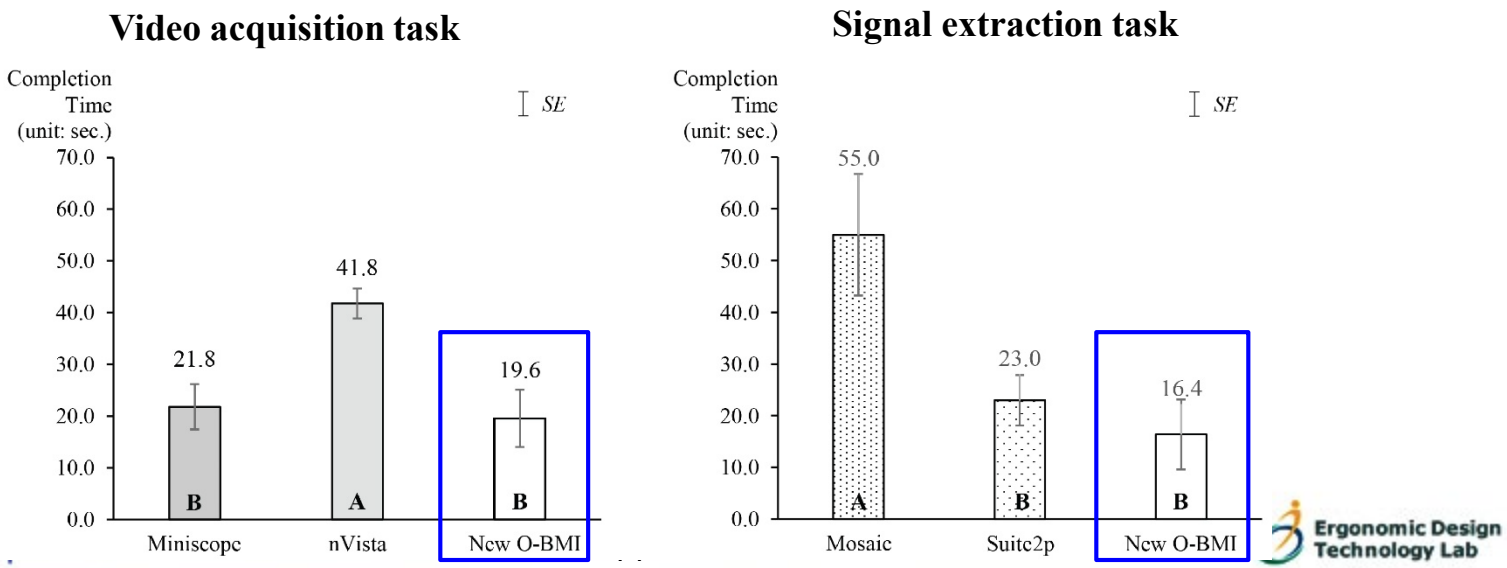
Statistic Analysis

- Statistical differences were analyzed by ANOVA followed by a post hoc analysis with the Tukey's HSD test at $\alpha = 0.05$. Minitab v.19.
  - ✓ Task completion time
  - ✓ Scan-path length
  - ✓ Perceived cognitive workload
  - ✓ Satisfaction

Results: Task Completion Time

- The new O-BMI UI design showed **improved performance** than the existing O-BMI UI designs in terms of task completion time.
  - ✓ Video acquisition task: ↓ 10.1% and ↓ 53.1% compared to Miniscope and nVista UI designs, respectively ($F[2, 12] = 7.70$, $p = 0.007$)
  - ✓ Signal extraction task: ↓ 70.2% and ↓ 28.7% compared to Mosaic and Suite2p UI designs, respectively ($F[2, 12] = 6.16$, $p = 0.014$)

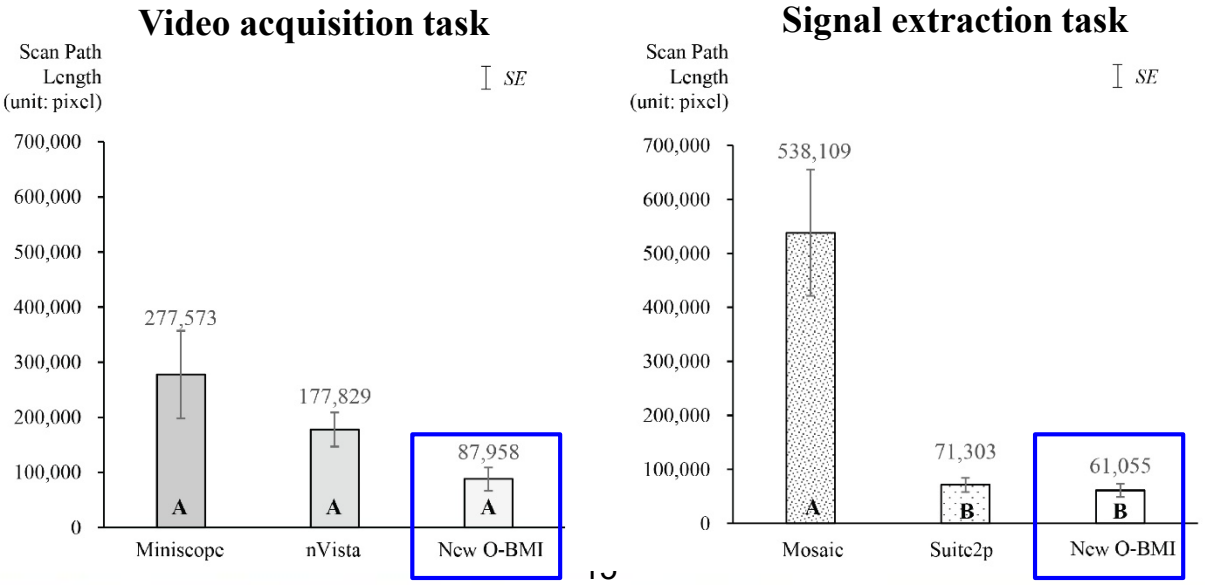
Comparison of O-BMI user interface designs in terms of task completion time



Results: Scan-Path Length

- The new O-BMI UI design showed **better performance** than the existing O-BMI UI designs in terms of scan-path length (significant difference in signal extraction task).
  - ✓ Video acquisition task: ↓ 68.4% and ↓ 50.7% compared to Miniscope and nVista UI designs, respectively ($F[2, 12] = 3.49$, $p = 0.064$)
  - ✓ Signal extraction task: ↓ 88.7% and ↓ 14.4% compared to Mosaic and Suite2p UI designs, respectively ($F[2, 12] = 15.91$, $p = 0.001$)

Comparison of O-BMI user interface designs in terms of scan-path length



Results: Perceived Cognitive Workload

- The new O-BMI UI design showed **a lower perceived cognitive workload** than the existing O-BMI UI designs in terms of **mental demand, temporal demand, and effort.**
  - ✓ Video acquisition task: **O-BMI ☺ < Miniscope (12.2% ~ 28.9%)**; **O-BMI ☺ < nVista (14.3% ~ 27.3%)**
  - ✓ Signal extraction task: **O-BMI ☺ < Mosaic (30.2% ~ 37.9%); O-BMI ☺ < Suite2p (24.0% ~ 30.2%)**

Comparison of UI designs of O-BMI systems in terms of perceived cognitive workload

Video acquisition task

	Measure	Miniscope	nVista	New O-BMI	Test Statistic
Perceived cognitive workload	Mental demand	4.1 ± 0.4	4.2 ± 0.5	3.6 ± 0.7	$F(2, 27) = 0.38$
	Temporal demand	4.5 ± 0.4	4.4 ± 0.5	3.2 ± 0.5	$F(2, 27) = 2.34$
	Effort	4.2 ± 0.4	4.2 ± 0.5	3.4 ± 0.6	$F(2, 27) = 0.83$

Signal extraction task

	Measure	Mosaic		Suite2p		New O-BMI		Test Statistic	
Perceived cognitive workload	Mental demand	5.3 ± 0.3	A	5.3 ± 0.4	A	3.7 ± 0.5	B	$F(2, 27) = 4.77$	*
	Temporal demand	5.8 ± 0.3	A	5.0 ± 0.5	AB	3.8 ± 0.6	B	$F(2, 27) = 4.47$	*
	Effort	5.8 ± 0.3		5.1 ± 0.4	AB	3.6 ± 0.6	B	$F(2, 27) = 5.79$	**

Results: Satisfaction

- The new O-BMI UI design displayed **higher satisfaction** than the existing O-BMI UI designs in terms of **simplicity, distinctiveness, systematicity, accessibility, learnability, ease of use, and overall satisfaction.**
  - ✓ Video acquisition task: **O-BMI ☺ > Miniscope (20.8% ~ 47.5%); O-BMI ☺ < nVista (11.3% ~ 27.7%)**

Comparison of UI designs of O-BMI systems in terms of satisfaction

Video acquisition task

	Measure	Miniscope		nVista		New O-BMI		Test Statistic	
Satisfaction	Simplicity	4.4 ± 0.5		4.5 ± 0.4		5.6 ± 0.3		$F(2, 27) = 2.43$	
	Distinctiveness	4.0 ± 0.4	A	5.0 ± 0.4	AB	6.0 ± 0.2	B	$F(2, 27) = 7.50$	**
	Systematicity	4.0 ± 0.4	A	5.3 ± 0.4	AB	5.9 ± 0.3	B	$F(2, 27) = 6.21$	**
	Accessibility	4.8 ± 0.4		5.0 ± 0.3		5.8 ± 0.2		$F(2, 27) = 2.59$	
	Learnability	5.0 ± 0.5		5.2 ± 0.3		6.0 ± 0.3		$F(2, 27) = 2.01$	
	Ease of use	4.3 ± 0.6	A	4.7 ± 0.5	AB	6.0 ± 0.2	B	$F(2, 27) = 3.80$	*
	Overall satisfaction	4.3 ± 0.4	A	4.9 ± 0.3	AB	5.8 ± 0.3	B	$F(2, 27) = 4.72$	*

Results: Satisfaction

- The new O-BMI UI design displayed **higher satisfaction** than the existing O-BMI UI designs in terms of **simplicity, distinctiveness, systematicity, accessibility, learnability, ease of use, and overall satisfaction.**
  - ✓ Signal extraction task: **O-BMI ☺ >Mosaic (42.5% ~ 74.3%); O-BMI ☺ < Suite2p (39.0% ~ 67.6%)**

Comparison of UI designs of O-BMI systems in terms of satisfaction

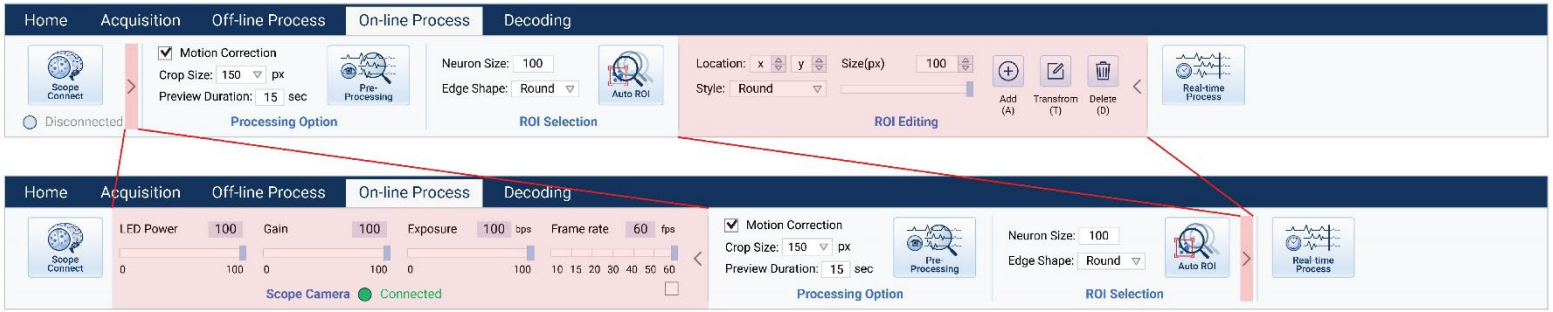
Signal extraction task

	Measure	Mosaic		Suite2p		New O-BMI		Test Statistic	
Satisfaction	Simplicity	4.0 ± 0.4	A	3.7 ± 0.6	A	5.7 ± 0.3	B	$F(2, 27) = 5.59$	**
	Distinctiveness	3.9 ± 0.5	A	3.7 ± 0.7	A	6.2 ± 0.2	B	$F(2, 27) = 7.38$	**
	Systematicity	3.7 ± 0.4	A	4.1 ± 0.5	A	5.7 ± 0.2	B	$F(2, 27) = 7.02$	**
	Accessibility	3.3 ± 0.5	A	3.9 ± 0.5	A	5.6 ± 0.2	B	$F(2, 27) = 7.48$	**
	Learnability	3.4 ± 0.5	A	3.8 ± 0.6	A	5.9 ± 0.2	B	$F(2, 27) = 7.28$	**
	Ease of use	3.5 ± 0.5	A	4.2 ± 0.7	A	6.1 ± 0.2	B	$F(2, 27) = 7.52$	**
	Overall satisfaction	3.5 ± 0.5	A	4.0 ± 0.6	A	5.9 ± 0.1	B	$F(2, 27) = 8.76$	**

Discussion (1/2)

- The usability testing results of the present study showed that the new proposed designs of (1) modularized structure UI, (2) task sequence-based UI, (3) adaptive and collapsible UI, and (4) integrated UI were **effective for better usability for an O-BMI system**.

A collapsible and expandable user interface for online processing (illustrated)



Discussion (2/2)

- The usability testing was conducted in the present study using both subjective and objective methods.
  - ✓ The O-BMI UI designs in the present study were compared by analyzing task completion times measured by a screen recording program and scan-path length data measured by an eye-tracking system as well as subjective evaluation scores obtained by a usability questionnaire.
  - ✓ The usability testing protocol of the present study can be used to design, evaluate, and improve UI designs of various systems in neuroscience research in the future.

Limitation & Future Work

- Limitation
  - ✓ Using the working digital prototypes, not real system (real system in developing)
  - ✓ Testing with a small group of participants (n = 10)
- Future work
  - ✓ The usability results of the O-BMI UI designs using working digital prototypes need to be validated in the future with working O-BMI systems with a larger group of researchers in neuroscience.

Q & A

경청해 주셔서 감사합니다.

본 연구는 양산부산대학교병원 (Pusan National University Yangsan Hospital) 의생명융합연구소의 인큐베이팅 연구과제의 지원을 받아 수행된 결과임

Appendix