賽馬會 Jockey Club 智家樂計劃 SMART Family-Link Project

Empowering Families with Dementia: Early Diagnosis and Prognosis through the 'VEEM Digital Biomarker'

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SEOULTECH SEOUL NATIONAL UNIVERSITY OF SCIENCE & TECHNOLOGY

HAI LAB

#1 National University in Seoul with More than 115 years of History

Introduction

HAI Lab designs **AI systems** that **sense**, **interpret**, and **augment** human behavior and cognition using complex multimodal data—across health, education, and industry

01 Healthcare

Early Screening for Dementia

Dementia Prognosis Prediction

Digital Biomarkers

한양대학교구리병원 HANYANG UNIVERSITY GURI HOSPITAL

KNA 100세시대 뇌지킴이 신경과 대한신경과학회

대한치매학회 Korean Dementia Association

02 Education

Copilot for Personalized Education

Assessing Student Competencies

Career-Counseling Chatbot

Microsoft

SEOUL METROPOLITAN OFFICE OF EDUCATION

THE UNIVERSITY OF BRITISH COLUMBIA

03 Industry

Manufacturing Factory Digital Twin

Real-Time Synthetic Data

Improving Training Experiences

HYUNDAI

KITECH 한국생산기술연구원

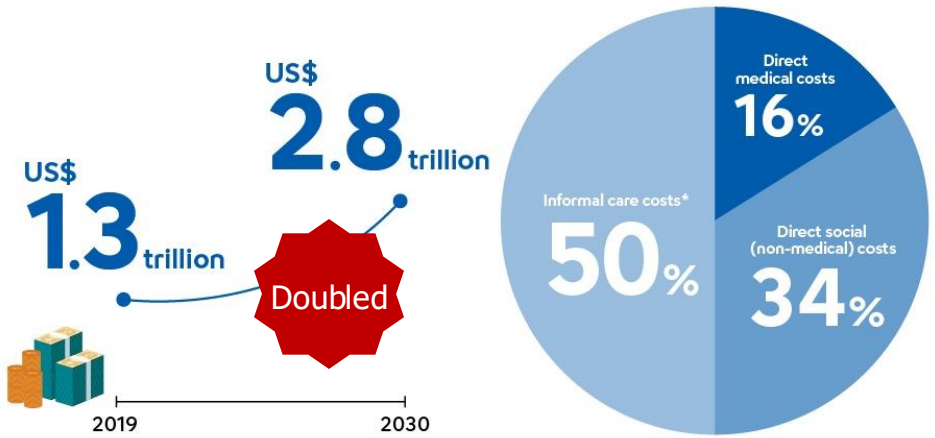
Ministry of Science and ICT

Contents

1. Problem Space

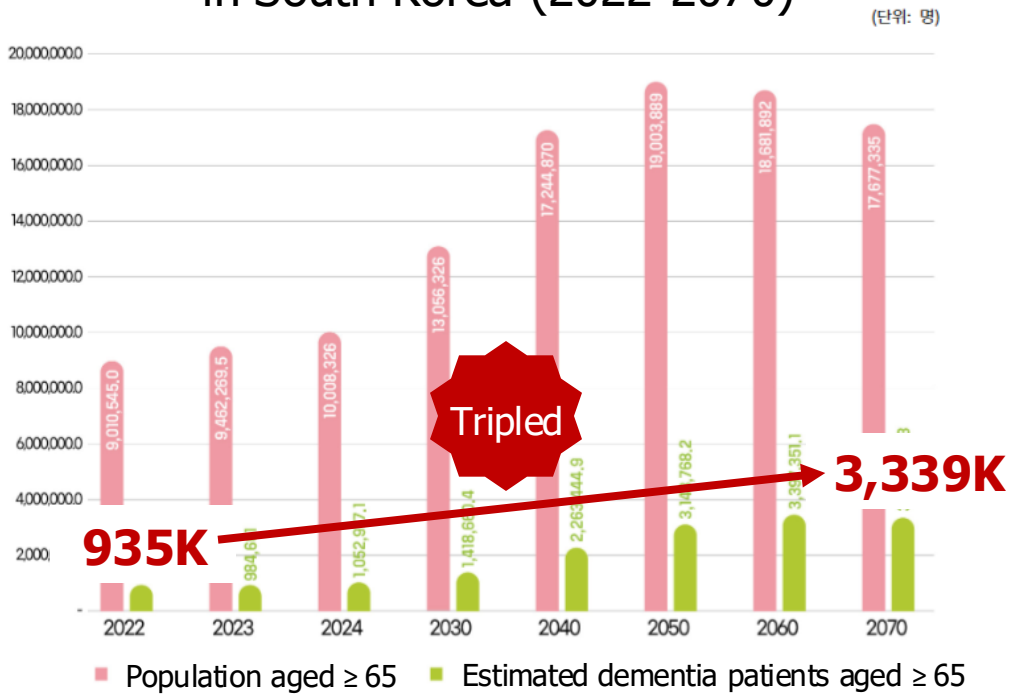
Families in South Korea are facing a dementia crisis—cases are projected to triple by 2070, prompting the launch of the 'National Responsibility for Dementia' policy

The Growing Dementia Crisis



Source: World Health Organization, 2021 & Sysmex, 2021

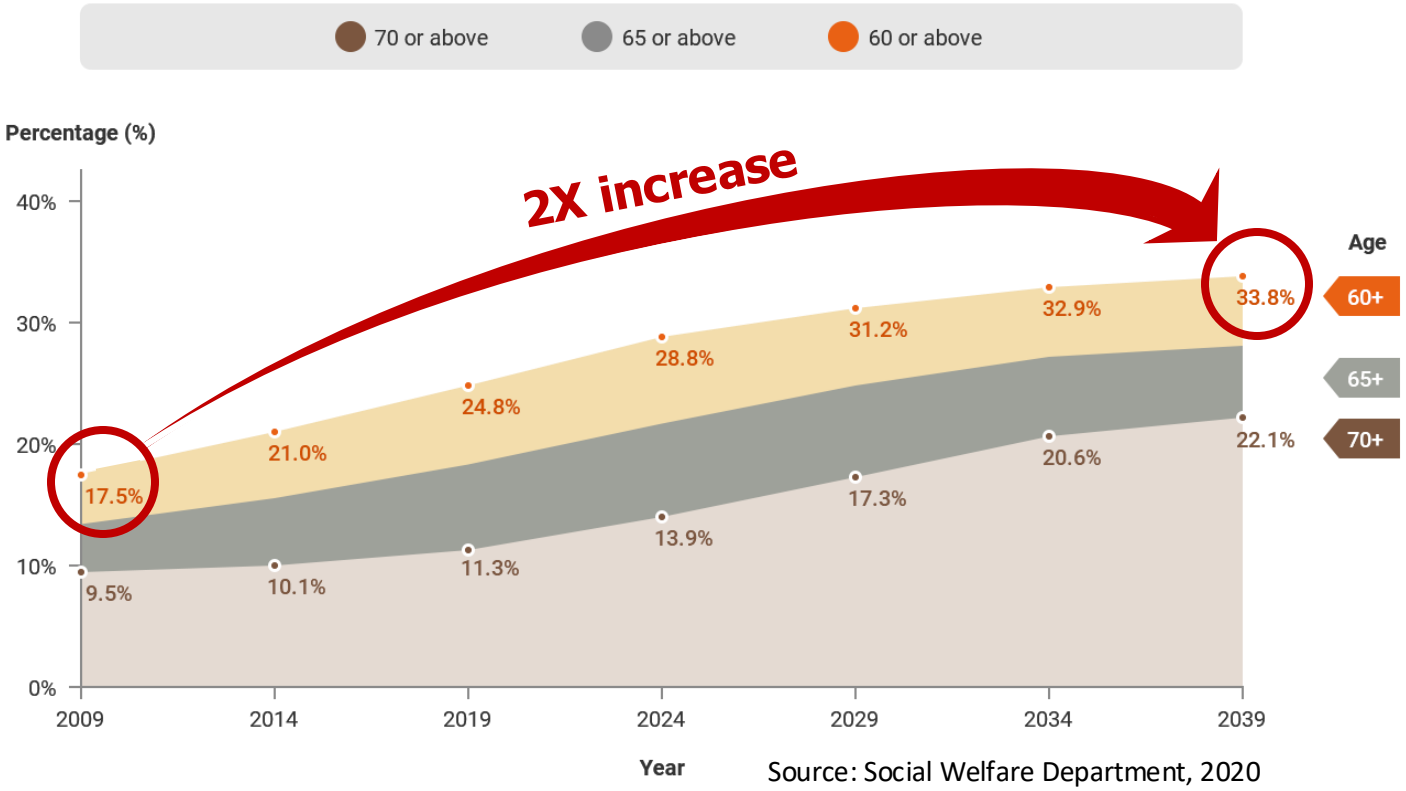
Estimated Growth in Dementia Patients in South Korea (2022-2070)



Source: Ministry of Health and Welfare, 2024

Hong Kong shows a similarly concerning outlook,
suggesting that related research will be increasingly important

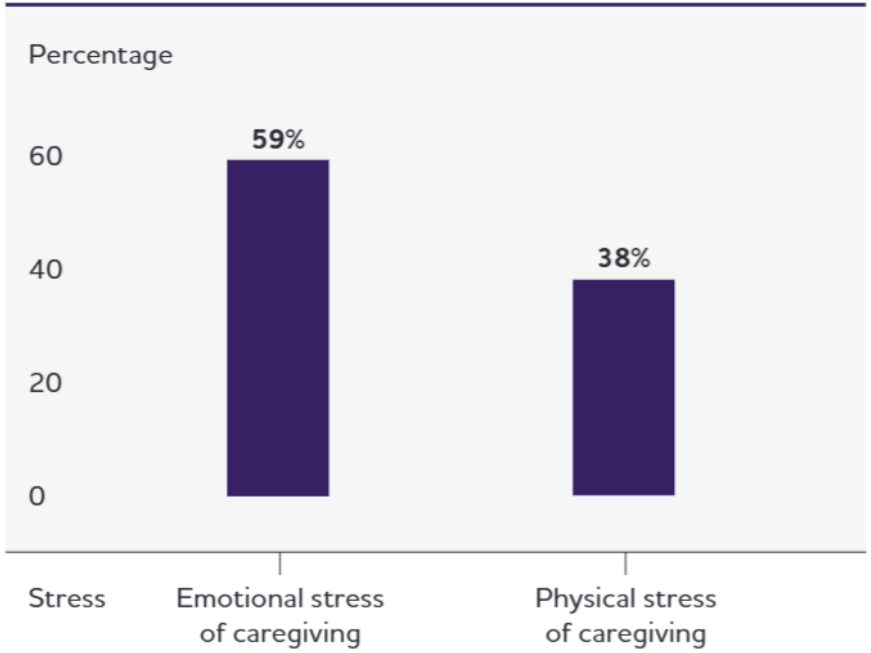
33.8% of Hong Kong's population will be over 60 by 2039



Source: Social Welfare Department, 2020

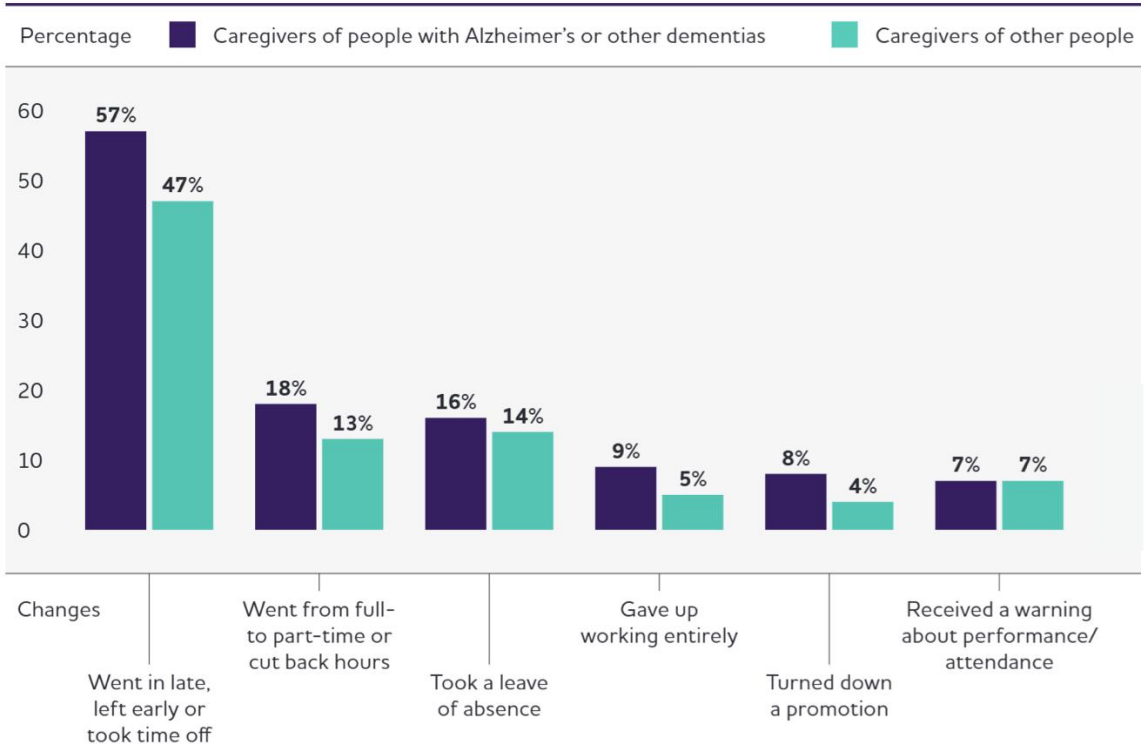
Families with dementia face **emotional, physical, and financial burdens**
as they witness the relentless loss of memory and independence

Percentage of Dementia Caregivers Who Report High to Very High Stress Due to Caregiving



Source: Alzheimer's Association, 2024

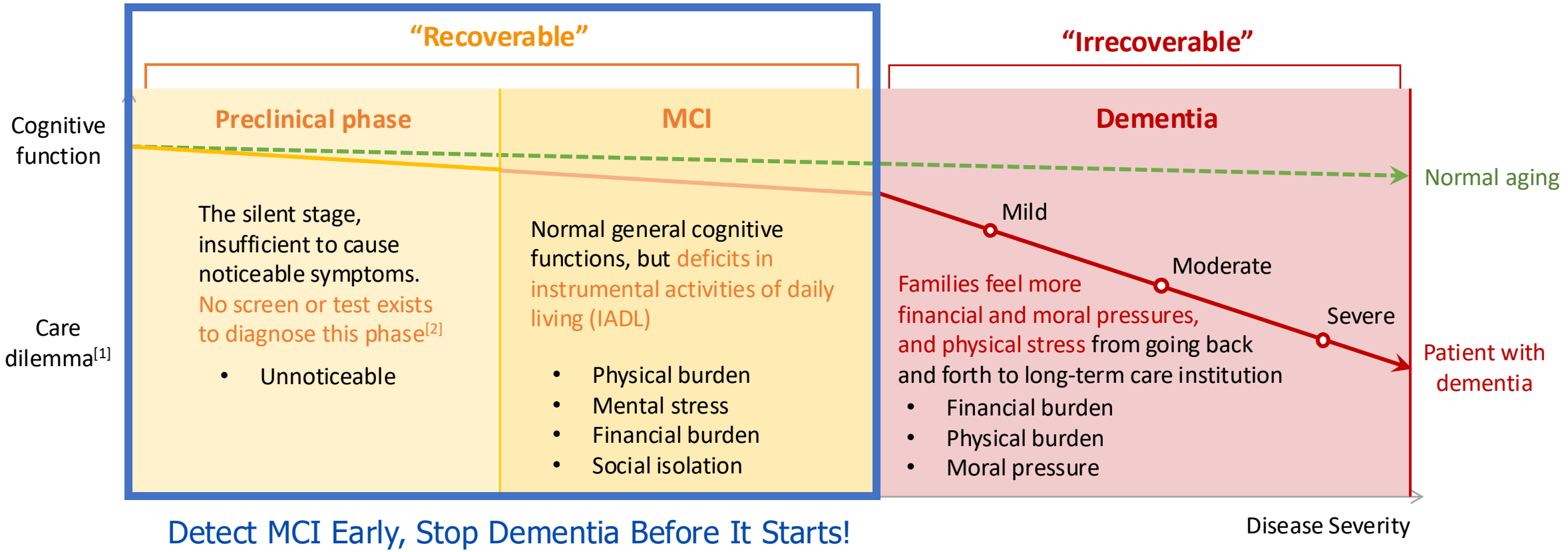
Work-Related Changes Among Caregivers of People with Alzheimer's or Other Dementias Who Had Been Employed at Any Time Since They Began Caregiving



Source: Alzheimer's Association, 2024

1. Problem Space

Early diagnosis and prognosis of dementia is the last chance to slow or prevent dementia progression



Detect MCI Early, Stop Dementia Before It Starts!

1. Problem Space

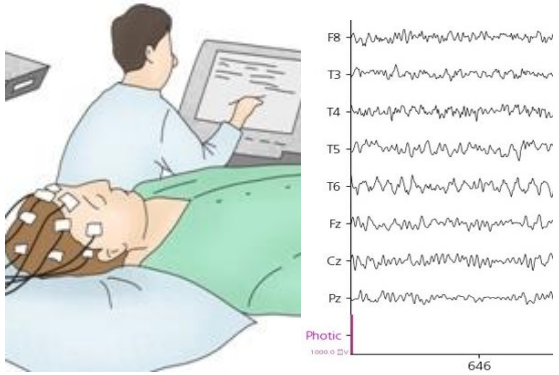
Today's diagnostic tools center on dementia detection,
but fall short in diagnosing MCI early—leaving families with little real support

Questionnaires (e.g., MMSE, SNSB-C)

Quantifying the comprehensive cognitive functions[3]

Requires over 2 hours; scores are affected by demographic factors (e.g., age, education level)[4]

Evoked potential (EP), Electroencephalography (EEG)



Assessment of neurological alterations[5]

Limited sensitivity compared to conventional biomarkers[6]

Magnetic resonance imaging (MRI)

Quantifying atrophies of brain structures[7]

Low accessibility due to high cost and extensive examination time

1. Problem Space

To empower families with dementia, our research focuses on **three critical questions**:

1. How can we achieve **rapid** and **accurate** early diagnosis of dementia using technology?

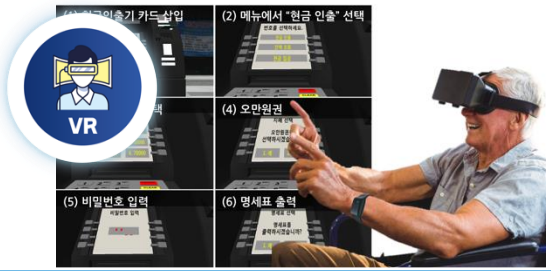
2. How can **multimodal** methods ensure **reliable** early detection?

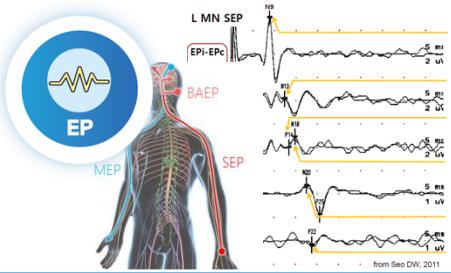
3. How can we deliver **accessible diagnostic tools** that truly support families?

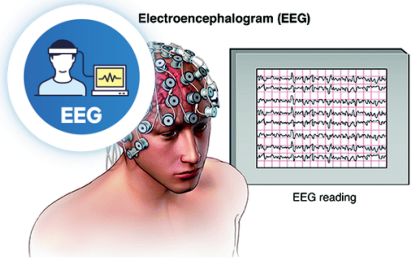
Contents

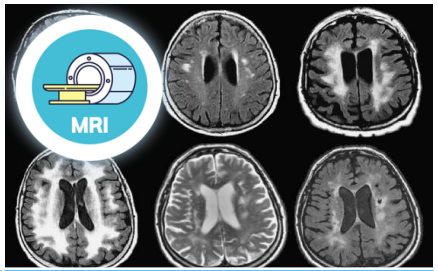
2. VEEM Digital Biomarkers

Our goal is to develop the VEEM Digital Biomarker that enables
Rapid, **Reliable**, and **Accessible** early diagnosis and prognosis of dementia







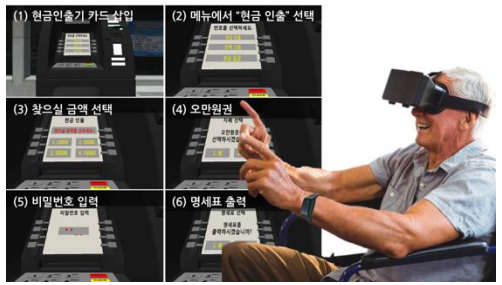


Behavioral alterations	Neurological alterations		Structural alterations
Assessing **behavioral performance** in VR	Assessing impairment of the **optic nerve**	Assessing abnormal **brain signals**	Assessing **brain atrophy**
Insufficient practical evidence →**Limited prognostic capability**	Sensitive to neurological and structural changes, but **limited in early diagnosis**		
High accessibility	**High interpretability**		

2. VEEM Digital Biomarkers

VR-based instrumental activities of daily living (IADL) tasks have potential for early diagnosis **quantifying behavioral changes**

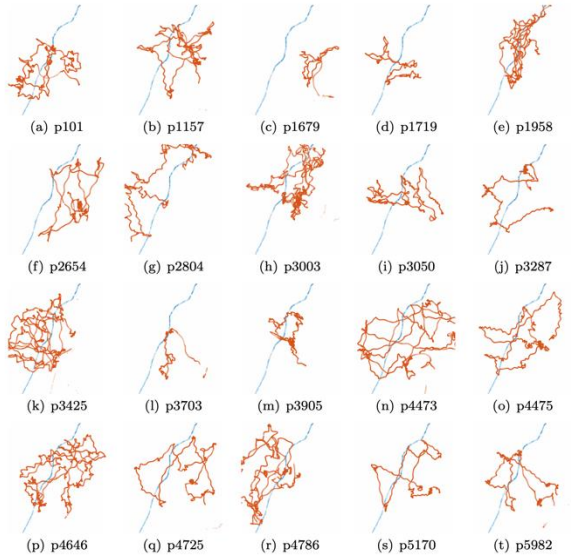
VR



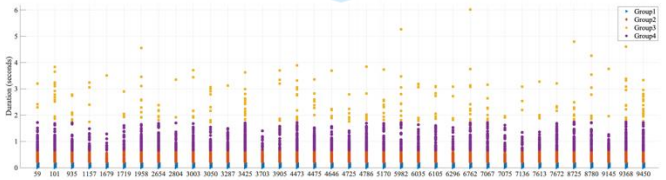
Behavioral Changes

- **Evaluates behavioral performance** during VR-based IADL tasks
- Limited understanding of neuropathological mechanisms → makes **prognosis challenging**

Analysis of Behavioral Patterns in IADL Tasks



Analysis Algorithm

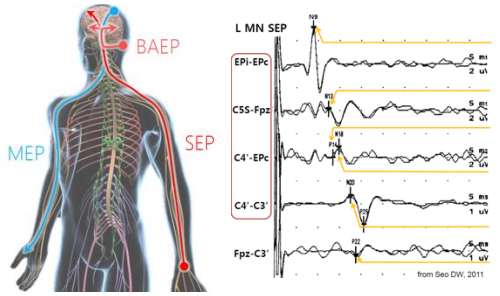


Early Diagnosis of Dementia via VR Performance

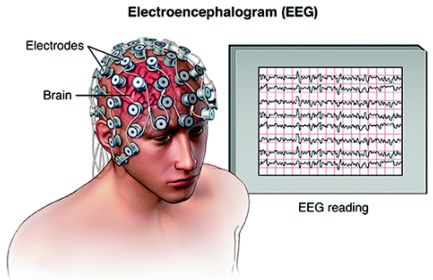
2. VEEM Digital Biomarkers

EP and EEG enable the **assessment of neural alterations** in brain electrical activity

EP



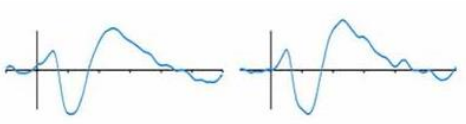
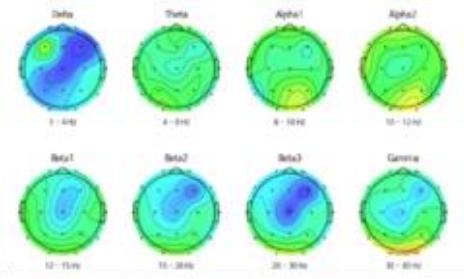
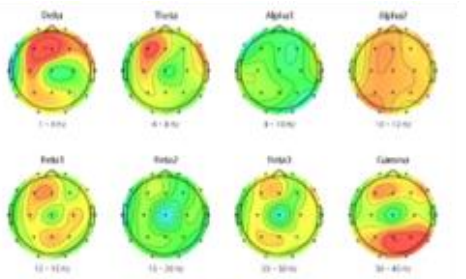
EEG



Neurological Alterations

- Assesses severity of **sensory nerve damage**
- Evaluates changes in **brain electrical activity**
- While EP/EEG provide information on neurological alterations, they are **difficult to use independently** as **early diagnostic or prognostic biomarkers**

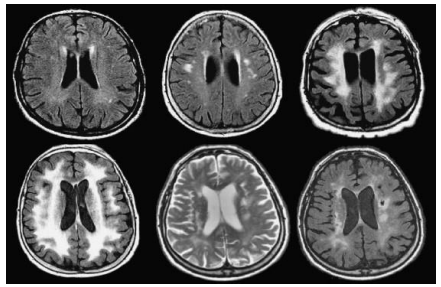
Pathological Changes in EP & EEG (Example)

	HC (Healthy control)	MCI (Mild cognitive impairment)
EP data		
EEG data		

2. VEEM Digital Biomarkers

As MRI identifies underlying brain lesions, it is suitable for prognosis and evaluation of dementia
→ its **high cost makes it difficult to perform easily, quickly, and repeatedly**

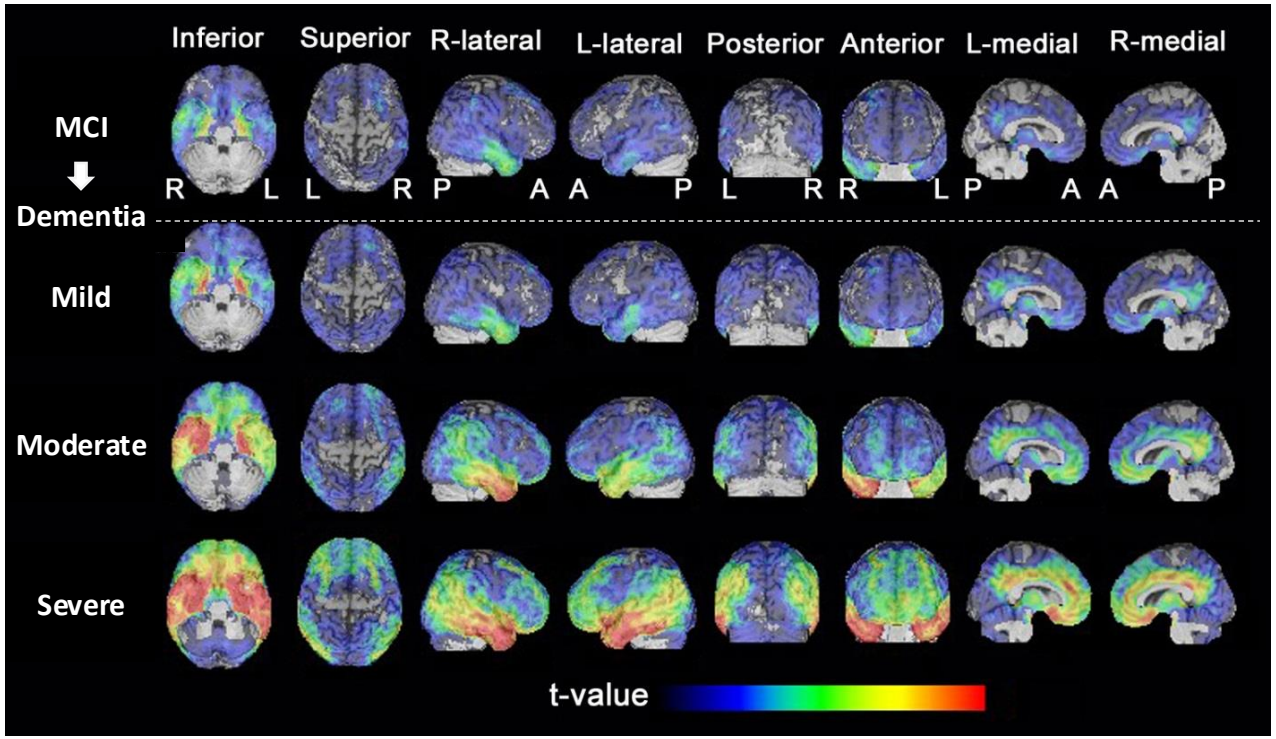
MRI



Structural Alterations

- **Evaluates structural abnormalities** in the brain (e.g., hippocampal atrophy)
- Limited by high cost and time constraints, making **early diagnosis challenging**

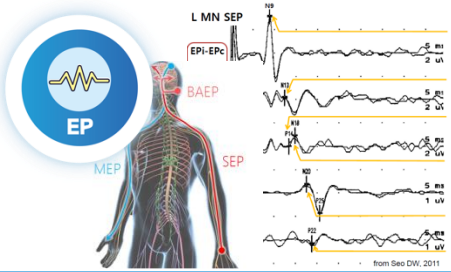
Detection of structural abnormalities in MRI → prognosis of dementia (Example)

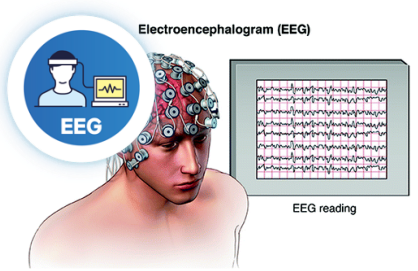


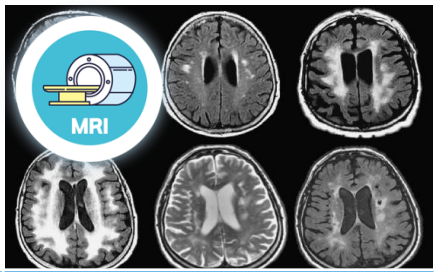
2. VEEM Digital Biomarkers

Our goal is to develop the VEEM Digital Biomarker that enables
Rapid, **Reliable**, and **Accessible** early diagnosis and prognosis of dementia for families

(1) Rapid Digital Biomarker
→ VR-based assessment







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High accessibility	**High interpretability**		

2. VEEM Digital Biomarkers

Our goal is to develop the VEEM Digital Biomarker that enables
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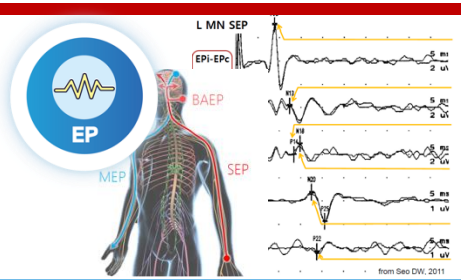
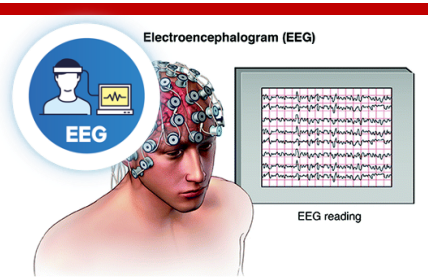
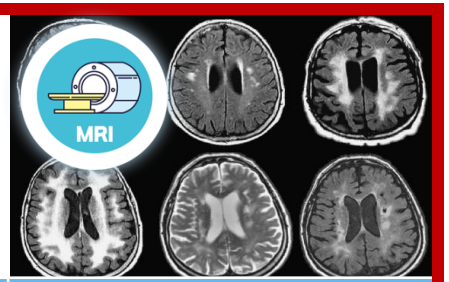
(2) Reliable Digital Biomarker
→ Multimodal learning (VR-EP-EEG-MRI)







Behavioral alterations	Neurological alterations		Structural alterations
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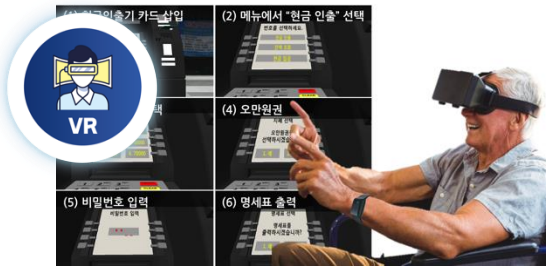
High accessibility — **High interpretability**

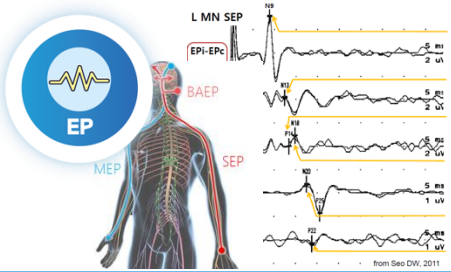
VEEM Digital Biomarkers

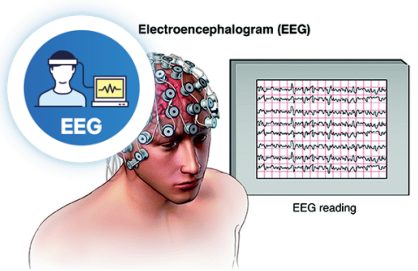
2. VEEM Digital Biomarkers

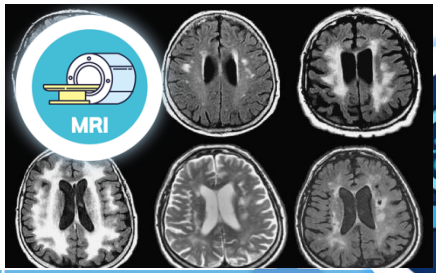
Our goal is to develop the VEEM Digital Biomarker that enables
Rapid, **Reliable**, and **Accessible** early diagnosis and prognosis of dementia for families

(3) Accessible Digital Biomarker
→ LLM-based clinical reasoning









LLM

Behavioral alterations	Neurological alterations		Structural alterations
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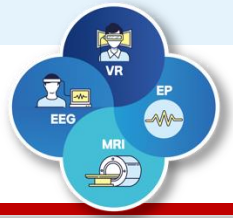
ChatGPT

Claude

High accessibility — **High interpretability**



VEEM Digital Biomarkers

Contents

3.1 Research Findings – Rapid Digital Biomarker

Research on **kinematic movement analysis for VR behavioral data—specifically evaluating hand and head movements** during tasks such as withdrawing money or taking a bus.

PLOS ONE

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

Virtual daily living test to screen for mild cognitive impairment using kinematic movement analysis

Kyoungwon Seo, Jae-kwan Kim, Dong Hoon Oh, Hokyoung Ryu, Hojin Choi

Published: July 24, 2017 • https://doi.org/10.1371/journal.pone.0181883

3.1 Research Findings – Rapid Digital Biomarker

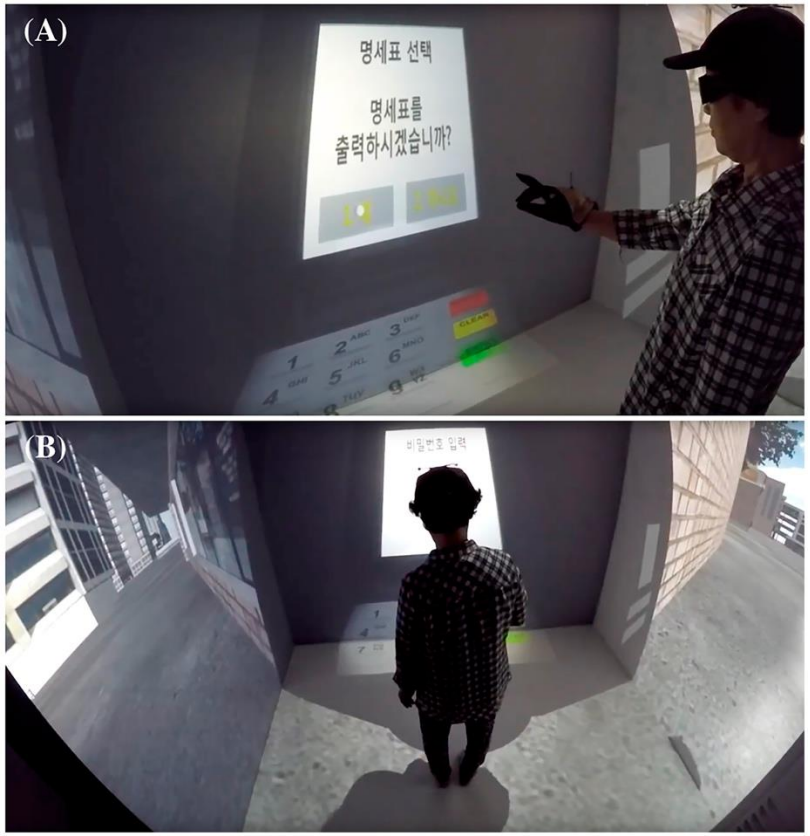
Cognitively demanding IADL tasks, such as withdrawing money and taking a bus, were simulated in VR

Participants

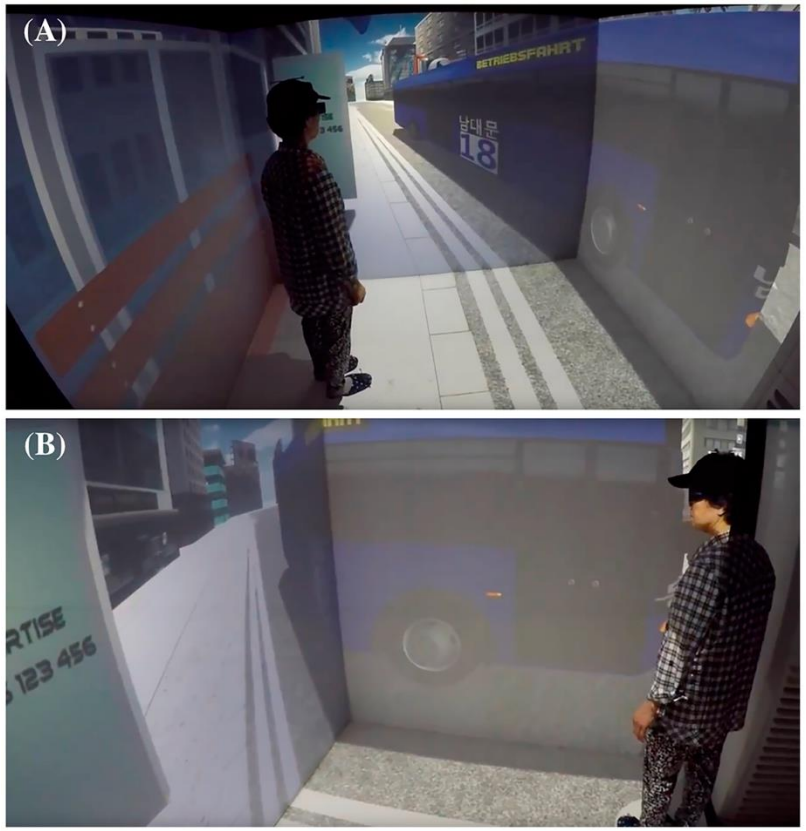
22 HC
(Healthy controls)

20 MCI patients

Task 1: Withdraw money



Task 2: Take a bus



3.1 Research Findings – Rapid Digital Biomarker

MCI patients exhibited **significantly reduced hand and head movement speed** during VR-based IADL tasks compared to healthy controls

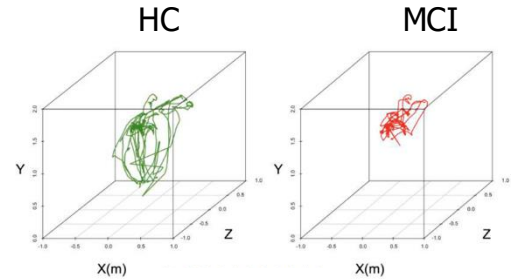
Performance in VR IADL Tasks

	Healthy controls	MCI patients	$F(1, 40)$	p
Task 1: Withdraw money				
Hand trajectory (meters)	49.5±40.5	32.2±20.3	2.970	0.093
Time to completion (seconds)	81.1±26.5	106.5±38.0	6.417	0.015
Hand speed (m/s)	0.6±0.4	0.3±0.1	12.694	0.001
Number of errors	0.2±0.5	0.7±0.8	5.154	0.029
Task 2: Take a bus				
Head trajectory (meters)	125.4±35.8	100.7±24.5	6.678	0.014
Time to completion (minutes)	13.5±0.7	13.5±0.7	0.003	0.953
Head speed (m/s)	0.4±0.1	0.3±0.1	11.029	0.002
Number of errors	0.8±0.9	2.3±1.4	16.444	<0.001

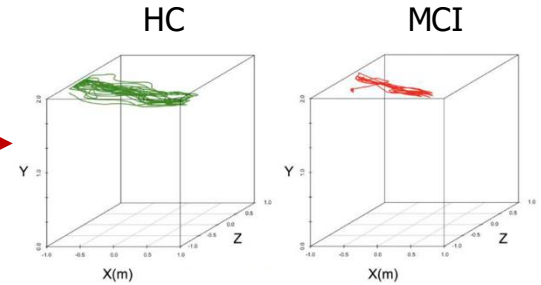
Values are means±SD.

https://doi.org/10.1371/journal.pone.0181883.t002

Hand movement in Task 1: Withdraw money



Head movement in Task 2: Take a bus



3.1 Research Findings – Rapid Digital Biomarker

We developed **a more cognitively demanding** VR daily living assessment, the Virtual Kiosk Test, and used **hand** and **eye movement data** to train an early screening model for MCI

Top 3% SCIE journal in *Health Care Sciences & Services* (2022)

JOURNAL OF MEDICAL INTERNET RESEARCH Kim et al

Original Paper

Digital Marker for Early Screening of Mild Cognitive Impairment Through Hand and Eye Movement Analysis in Virtual Reality Using Machine Learning: First Validation Study

Se Young Kim[1*], BSc; Jinseok Park[2*], MD, PhD; Hojin Choi[2], MD, PhD; Martin Loeser[3], PhD; Hokyoung Ryu[4], PhD; Kyoungwon Seo[1], PhD

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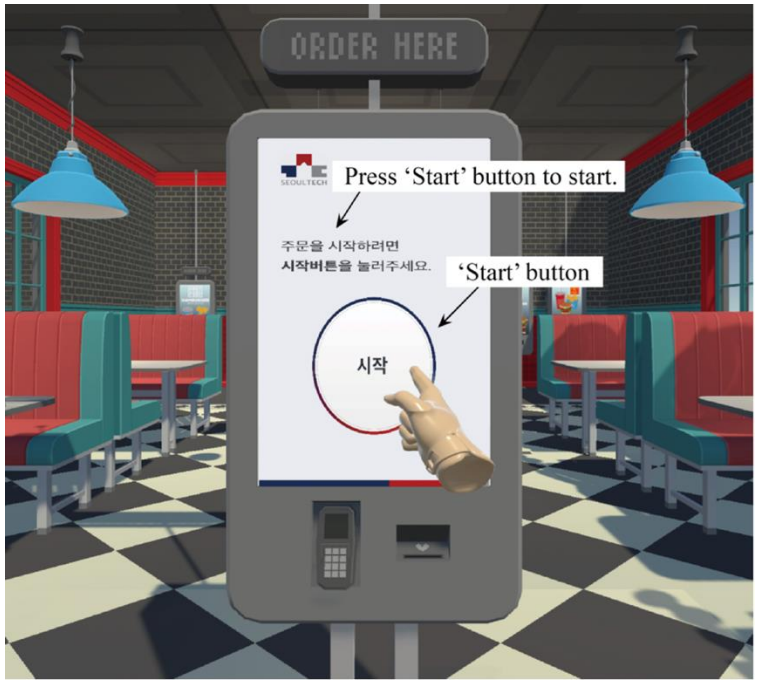
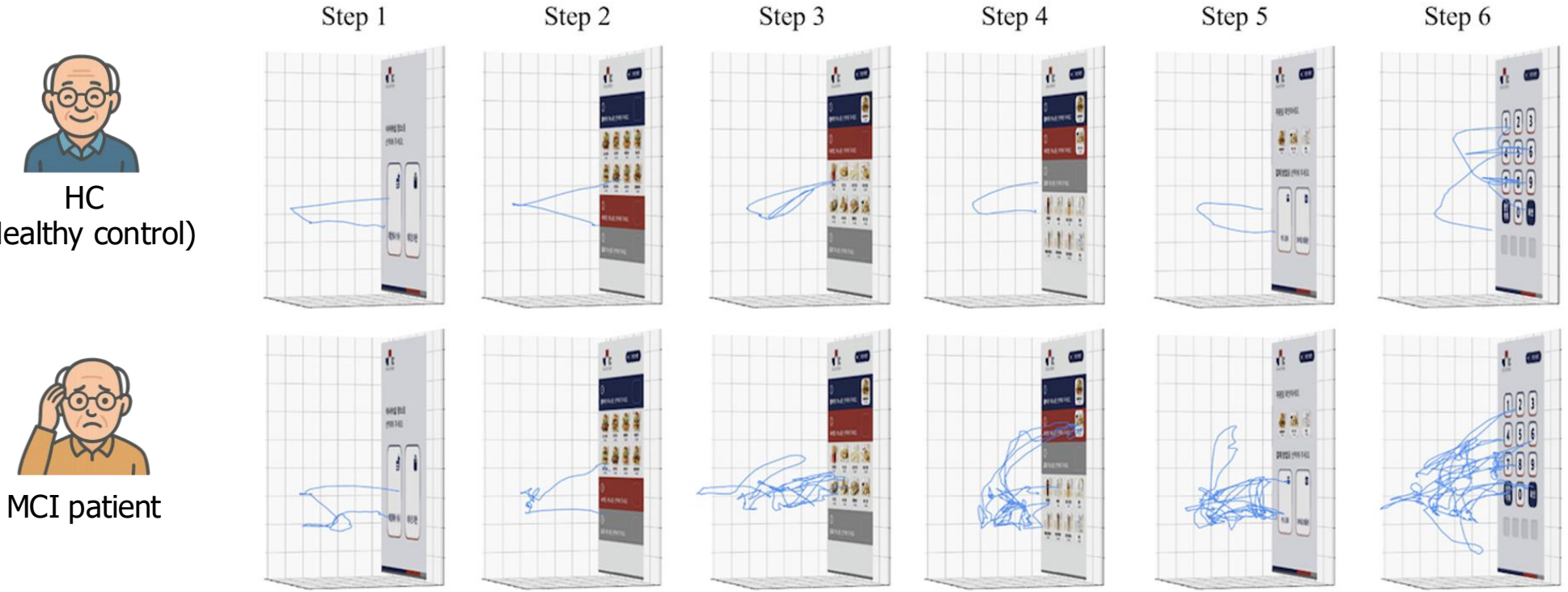


3.1 Research Findings – Rapid Digital Biomarker

MCI patient exhibited **increasingly complex and inefficient hand-movement patterns**, reflecting impaired motor planning and cognitive control compared to healthy controls

Figure 4. Comparison of hand movements between a healthy control (participant No. 9) and a patient with MCI (participant No. 25) for different virtual kiosk screens. MCI: mild cognitive impairment.



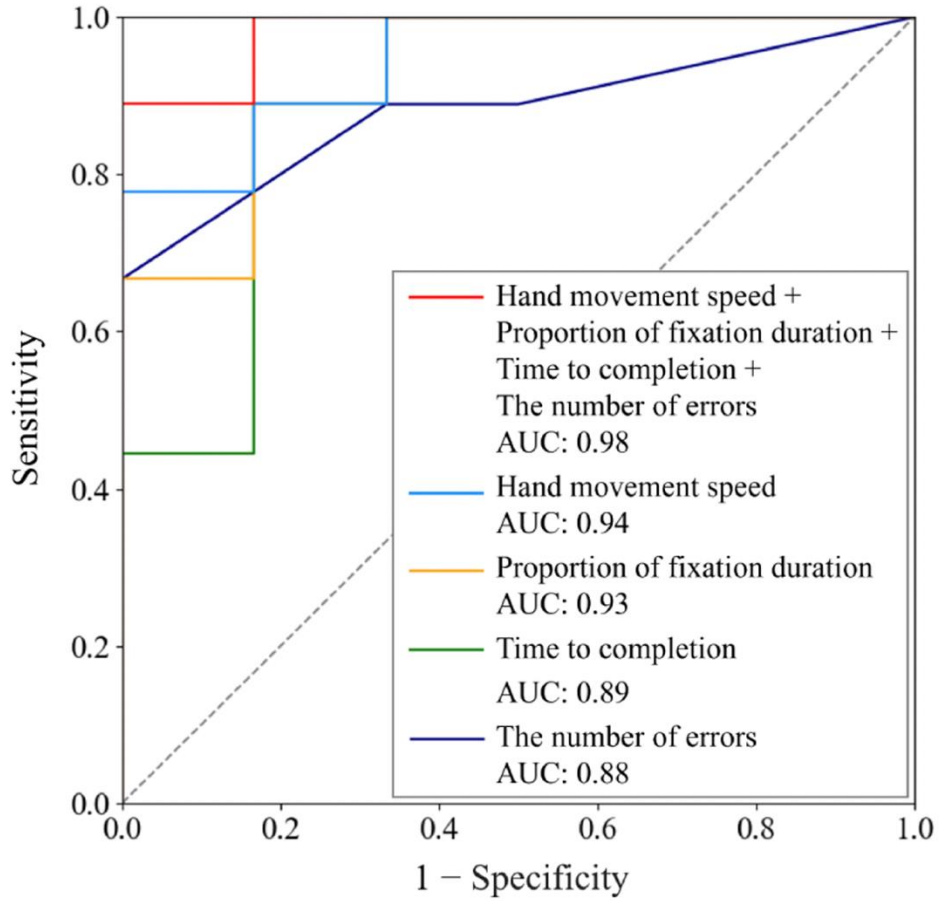
3.1 Research Findings – Rapid Digital Biomarker

MCI patient exhibited **increasingly distracted and scattered eye-movement patterns**, indicating deficits in attention and visual information processing

Figure 5. Comparison of eye movements between a healthy control (participant No. 9) and a patient with MCI (participant No. 25). Participants' areas with more eye fixation are shown in red, and areas with less eye fixation are shown in blue. Target menu items for each step feature a white frame. MCI: mild cognitive impairment.

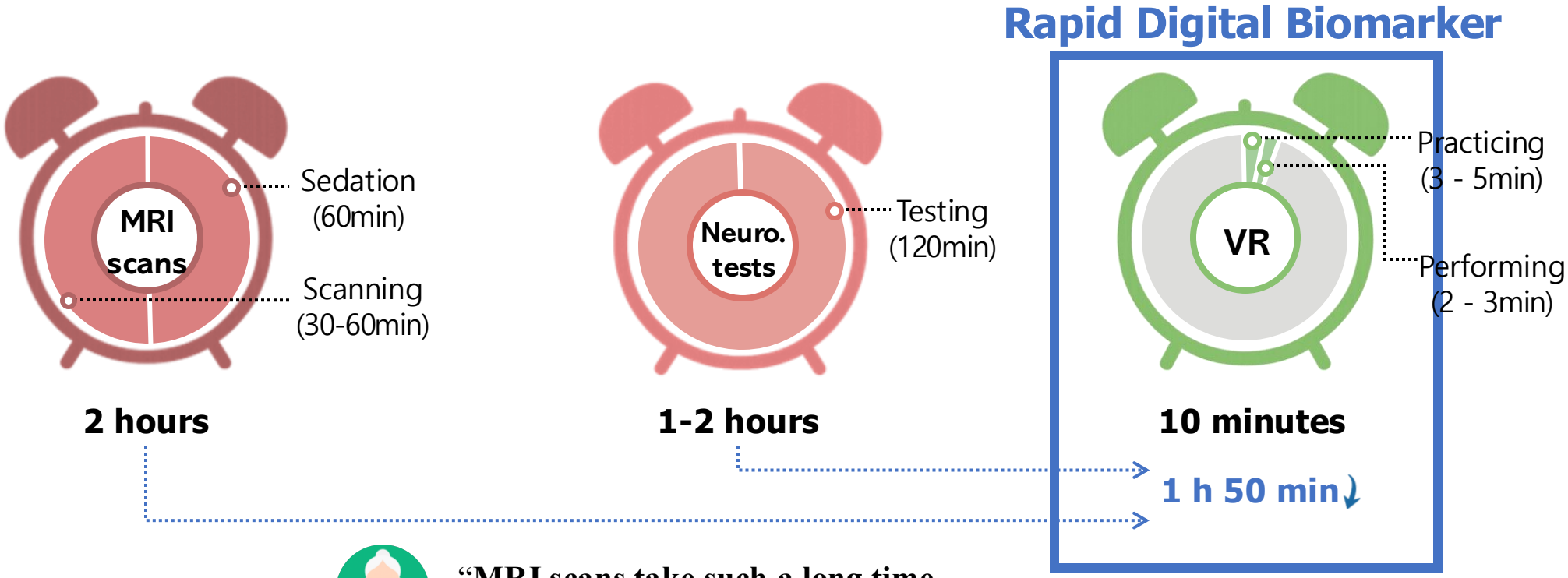
3.1 Research Findings – Rapid Digital Biomarker

By analyzing hand and eye movements, **the Virtual Kiosk Test detected MCI with 93.3% accuracy**, reflecting impaired IADL performance



3.1 Research Findings – Rapid Digital Biomarker

Rapid MCI detection is possible: VR digital biomarkers outperform traditional assessments (MRI scans, neuropsychological tests) in speed and accessibility



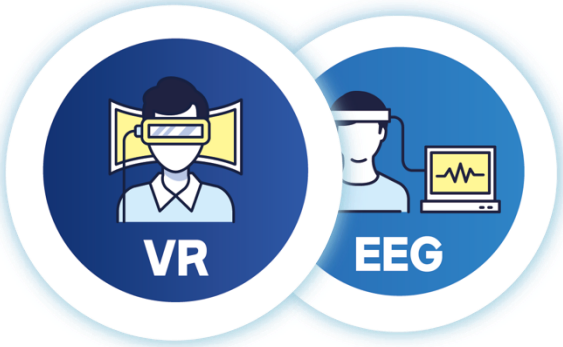
P39

"**MRI scans take such a long time,** and it was really uncomfortable trying to stay completely still."

Contents

3.2 Research Findings – Reliable Digital Biomarker

Exploring the integration of VR-based performance metrics with EEG biomarkers
to establish more **reliable digital biomarkers** for dementia detection



Open Access Article

Exploring the Relationship between Behavioral and Neurological Impairments Due to Mild Cognitive Impairment: Correlation Study between Virtual Kiosk Test and EEG-SSVEP

by Dohyun Kim [1], Yuwon Kim [1], Jinseok Park [2], Hojin Choi [2], Hokyoung Ryu [3], Martin Loeser [4] and Kyoungwon Seo [*]

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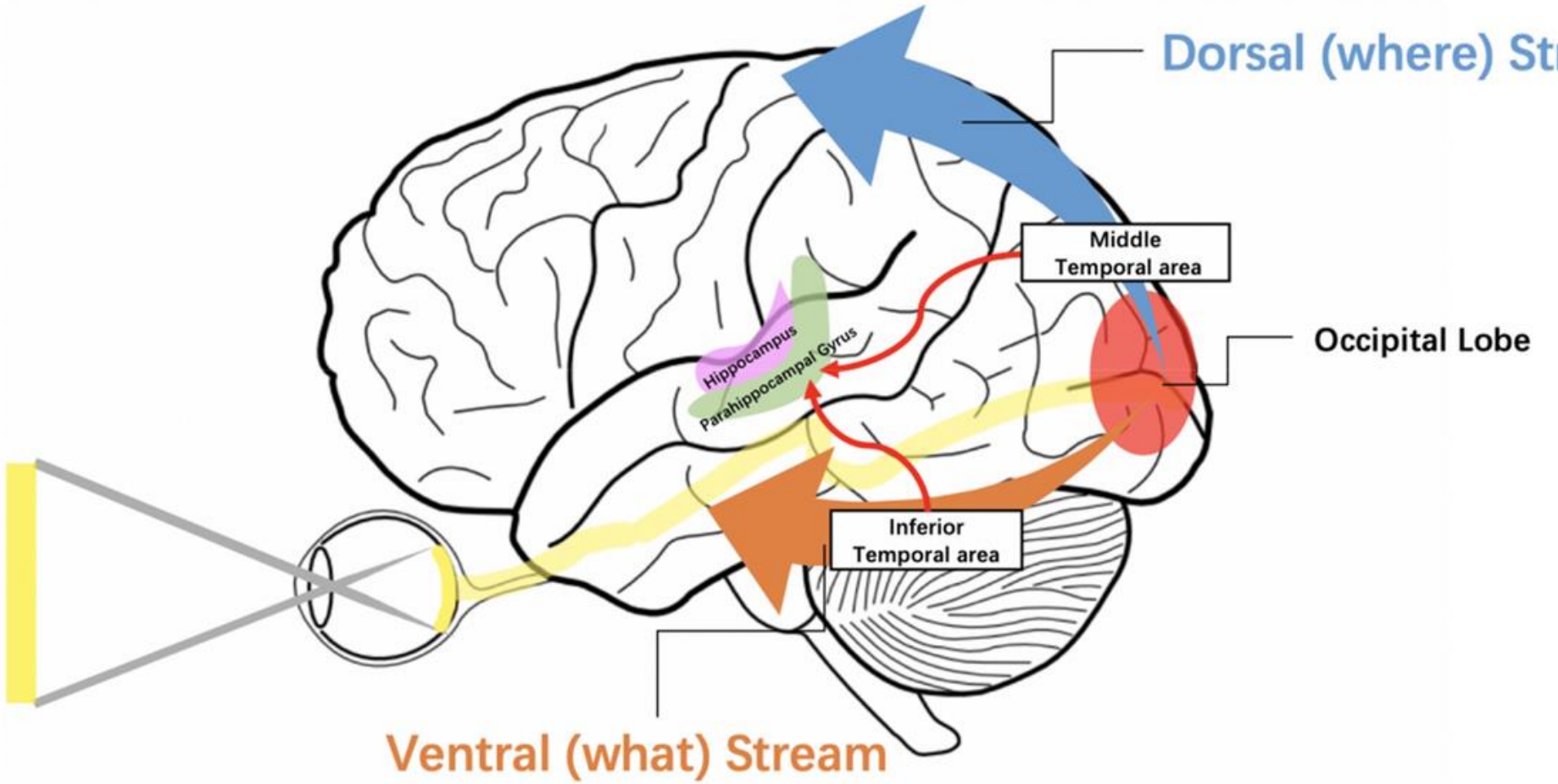
Sensors **2024**, *24*(11), 3543; **https://doi.org/10.3390/s24113543**

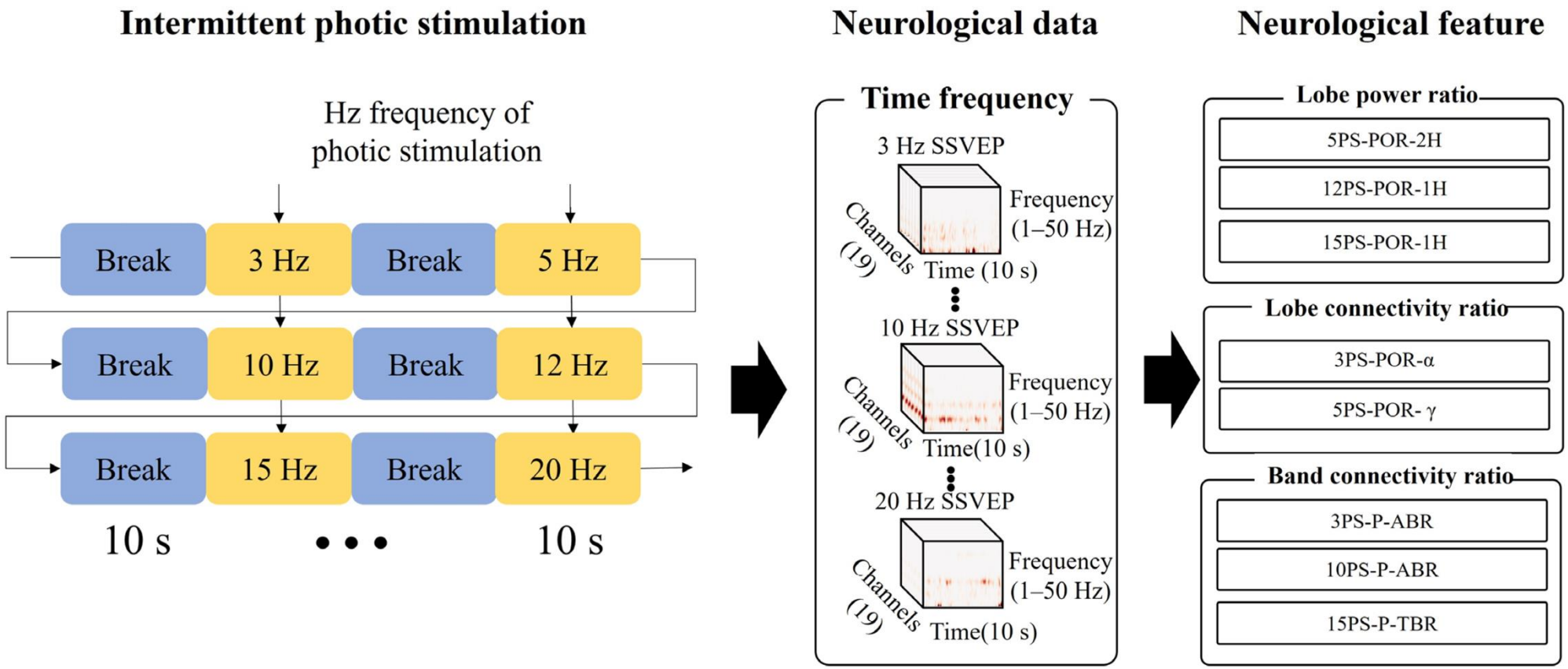
3.2 Research Findings – Reliable Digital Biomarker

VR IADL ability (hand and eye movement) + **EEG brain activity** (Ventral and Dorsal Streams)



3.2 Research Findings – Reliable Digital Biomarker

Using a deep learning model, **EEG-based neurological features** were derived (Ventral and Dorsal Streams)



3.2 Research Findings – Reliable Digital Biomarker

VR (hand + eye movements) and **EEG** (ventral + dorsal streams) are **strongly linked**
—integrating them improves MCI detection performance

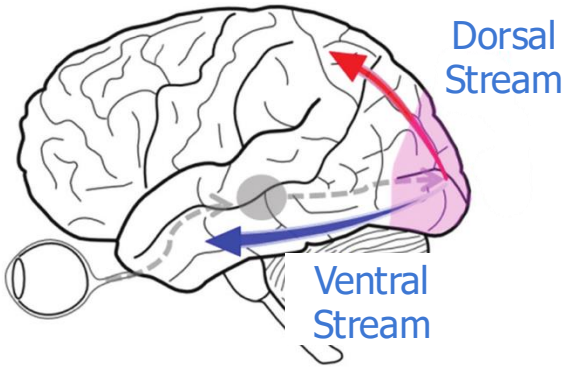
	5PS-POR-2H	12PS-POR-1H	15PS-POR-1H	3PS-POR-α	5PS-POR-γ	3PS-P-ABR	10PS-P-ABR	15PS-P-TBR
Scanpath length (m)	0.25	0.20	0.18	0.16	0.16	−0.12	−0.08	−0.00
Proportion of fixation duration (%)	−0.24	**−0.35***	**−0.33***	**−0.29***	−0.17	−0.25	0.02	−0.24
Hand movement distance (m)	0.22	0.15	0.05	0.22	0.06	−0.10	−0.12	−0.03
Hand movement speed (m/s)	−0.23	**−0.40***	**−0.32***	−0.24	−0.24	−0.03	−0.11	**−0.30***
Time to completion (s)	**0.29***	**0.32***	0.24	0.22	0.20	−0.09	−0.05	0.06
The number of errors	**0.40***	**0.34***	0.23	0.28	−0.02	0.03	−0.04	0.20

*BH corrected Pearson correlation $p < 0.05$

3.2 Research Findings – Reliable Digital Biomarker

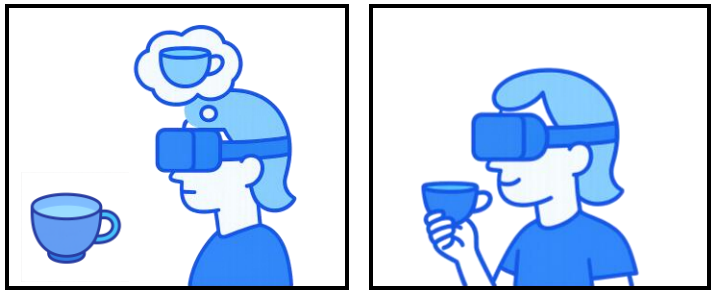
VR eye (ventral stream) and **hand (dorsal stream)** movements mirror EEG biomarkers, showing that VR performance reliably reflects neural impairments and enhances MCI detection

01 The Visual Pathway



- Information from the retina is transmitted to the brain via the **Magnocellular** and **Parvocellular** pathways.
- Visual information is processed through the **Dorsal Stream** and **Ventral Stream**.

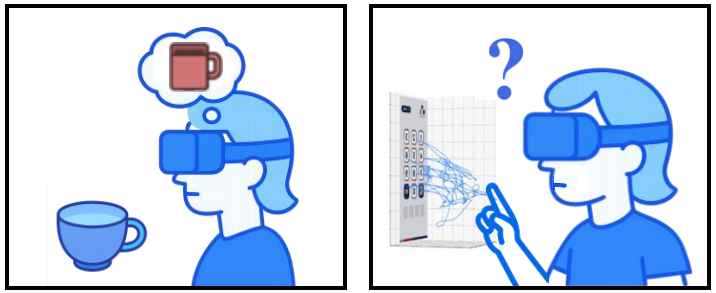
02 Visual Processing



Perception (Ventral Stream) | Action (Dorsal Stream)

- The **Ventral Stream** (left) is responsible for **object recognition and perception**.
- The **Dorsal Stream** (right) is responsible for **visually guided actions**.

03 Reliable Digital Biomarker

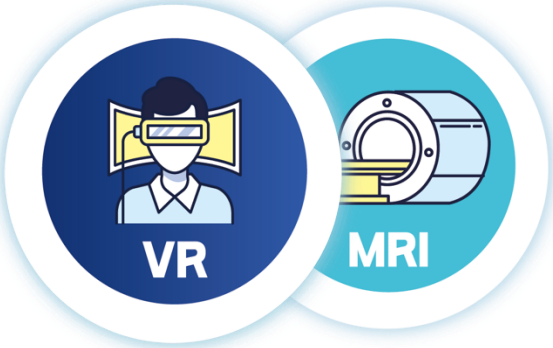


Impaired perception (Ventral Stream) | Impaired Action (Dorsal Stream)

- Damage to the **Ventral Stream** (left) results in **impaired object recognition (VR eye)**.
- Damage to the **Dorsal Stream** (right) results in **impaired ability to perform visually guided actions (VR hand)**.

3.2 Research Findings – Reliable Digital Biomarker

Exploring the integration of **VR-based performance metrics** with **MRI biomarkers** to uncover the mechanisms linking behavior and brain structures



JOURNAL OF MEDICAL INTERNET RESEARCH Park et al

Original Paper

Integrating Biomarkers From Virtual Reality and Magnetic Resonance Imaging for the Early Detection of Mild Cognitive Impairment Using a Multimodal Learning Approach: Validation Study

Bogyeom Park[1*], BSc; Yuwon Kim[1*], BSc; Jinseok Park[2], MD, PhD; Hojin Choi[2], MD, PhD; Seong-Eun Kim[1], PhD; Hokyoung Ryu[3], PhD; Kyoungwon Seo[1], PhD

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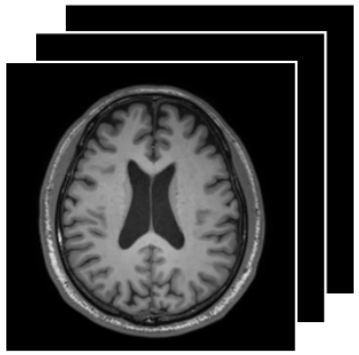
Top 3% SCIE journal in *Health Care Sciences & Services* (2022)

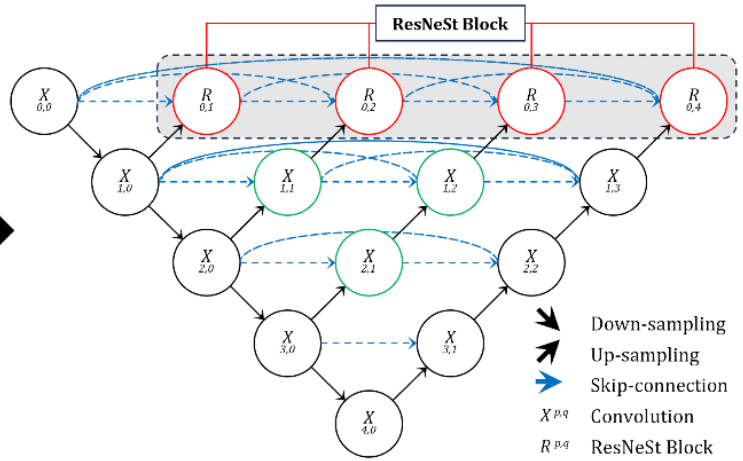
3.2 Research Findings – Reliable Digital Biomarker

Deep learning derived **22 MRI biomarkers** from scan segmentations,
which were integrated with VR digital biomarkers for analysis

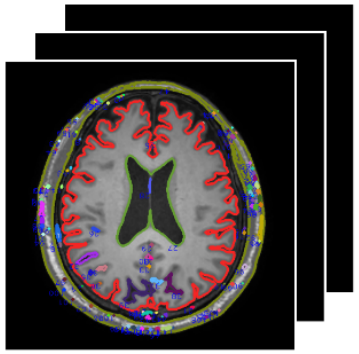
T1-weighted MRI



Split-attention U-Net Architecture



Multi-label Segmentation

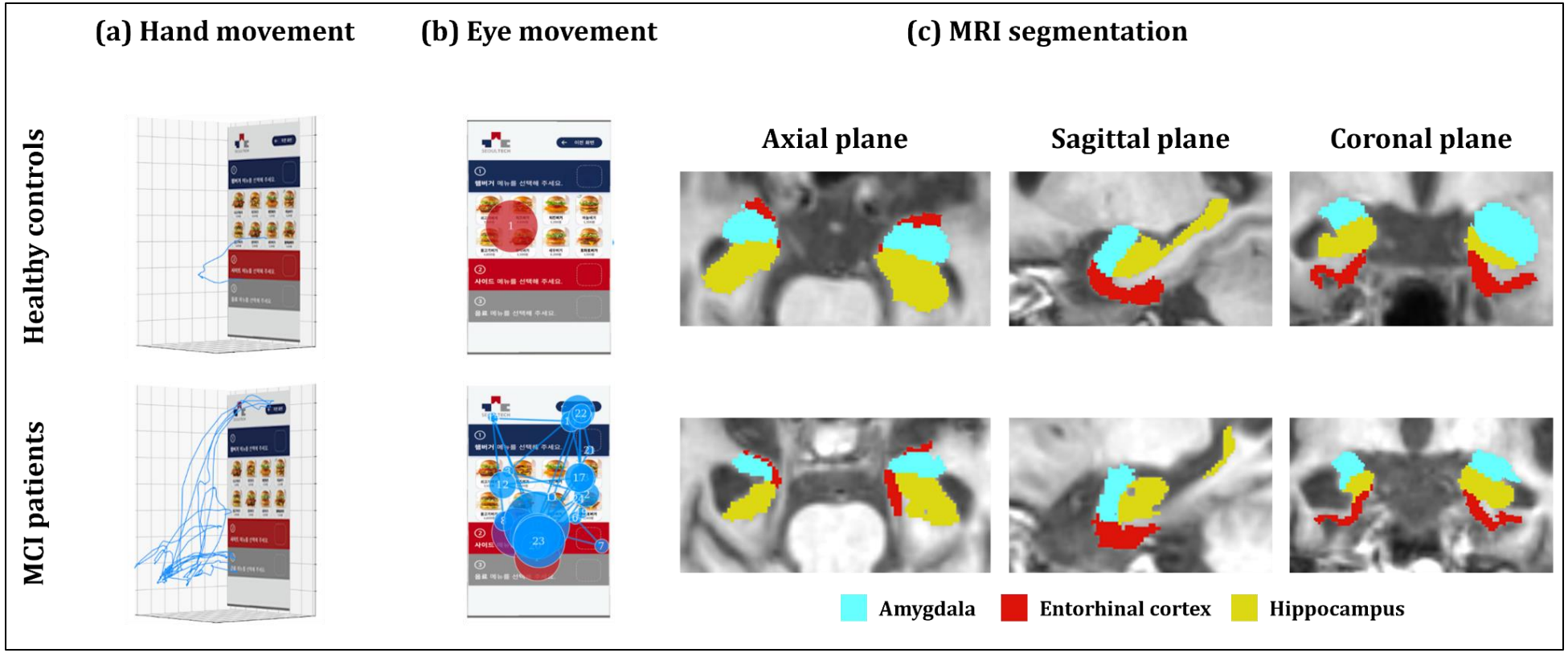


MRI biomarkers

- Left/Right Cerebral white matter
- Left/Right Cerebral gray matter
- Left/Right Ventricles
- Left/Right Amygdala
- Left/Right Hippocampus
- Left/Right Entorhinal cortex
- Left/Right Parahippocampal gyrus
- Left/Right Fusiform gyrus
- Left/Right Superior temporal gyrus
- Left/Right Middle temporal gyrus
- Left/Right Inferior temporal gyrus

3.2 Research Findings – Reliable Digital Biomarker

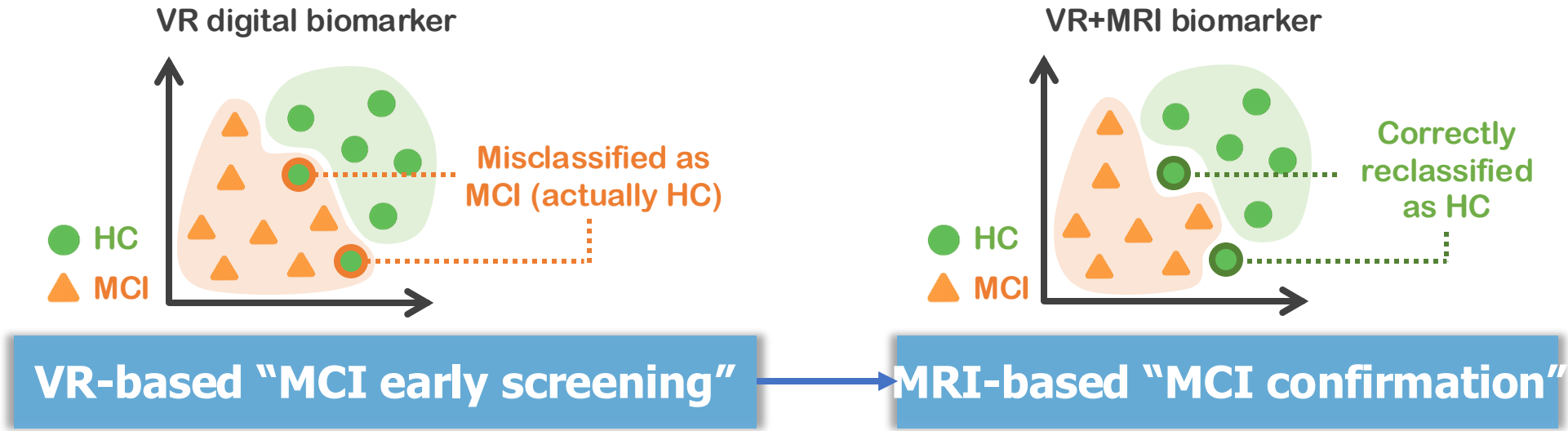
Abnormal VR hand and eye movements mirror hippocampal and medial temporal atrophy on MRI
—demonstrating **VR as a reliable digital biomarker**



3.2 Research Findings – Reliable Digital Biomarker

VR digital biomarker → **Higher specificity** (accurate in identifying HC, healthy controls)
MRI biomarker → **Higher sensitivity** (effective in detecting MCI)

Biomarker data	Accuracy (%)	Sensitivity (%)	Specificity (%)	Precision (%)	F1 score (%)
VR+MRI	94.4	100.0	90.9	87.5	93.3
VR	88.9	87.5	**90.0**	87.5	87.5
MRI	83.3	**90.9**	71.4	83.3	87.0



3.2 Research Findings – Reliable Digital Biomarker

VR, EEG, and MRI biomarkers emerge as complementary modalities that together provide reliable digital biomarkers for MCI detection

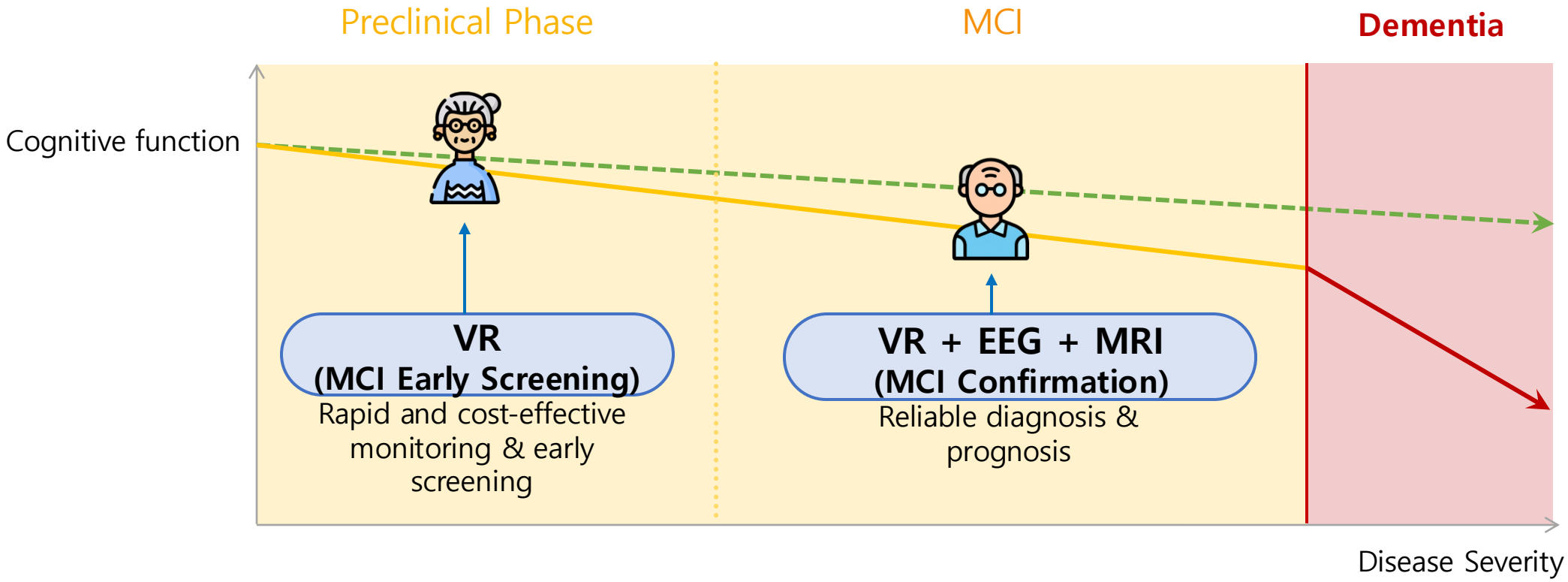
erations	ological alt	Stru ions
Assessing **behavioral performance** in VR	Assessing impairment of the **optic nerve**	Assessing abnormal **brain signals**	Assessing **brain atrophy**
Insufficient practical evidence →**Limited prognostic capability**	Sensitive to neurological and structural changes, but **limited in early diagnosis**	

High accessibility — **High interpretability**

VR-EEG-MRI
VEEM Digital Biomarkers

3.2 Research Findings – Reliable Digital Biomarker

VEEM Digital Biomarker enables a pathway: frequent **VR for early screening**, complemented by **EEG & MRI for reliable MCI prognosis and confirmation**



Contents

3.3 Research Findings – Accessible Digital Biomarker

Exploring how **LLMs can generate MCI diagnosis reports** as **accessible digital biomarkers**, supporting physicians and providing meaningful help to families with dementia

> Conferences > CHI > Proceedings > CHI EA '25 > CLONE: Synthetic Guideline-based
> al Reasoning with Large Language Models for Early Diagnosis of Mild Cognitive Impairment

ORK IN PROGRESS

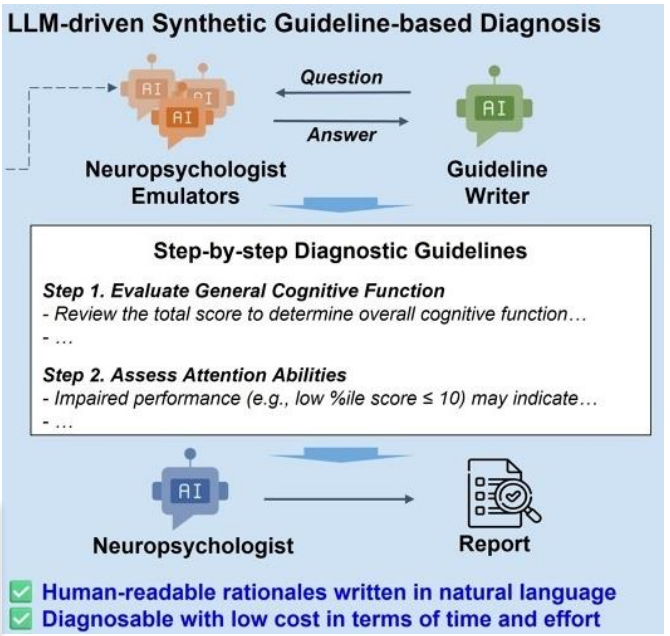
CLONE: Synthetic Guideline-based Clinical Reasoning with Large Language Models for Early Diagnosis of Mild Cognitive Impairment

Authors: Seungeon Cha, Jinseok Park, Hojin Choi, Hokyoung Ryu, Kyoungwon Seo | Authors Info & Claims

CHI EA '25: Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems
Article No.: 122, Pages 1 - 14 • https

Published: 25 April 2025 Publication

The **Top-tier** international *Computer Science* conference (CHI 2025)



3.3 Research Findings – Accessible Digital Biomarker

LLMs turn complex cognitive assessments into accessible digital biomarkers
→ Clear reports that **save time**, **lower cost**, and **support MCI diagnosis**

Test results
- Attention score
- Language score

...

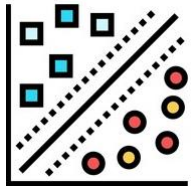
Neuropsychologist manual report

"This patient has experienced subjective cognitive deficits since..."

Requires Human Effort

Time-consuming

Machine learning approach



Using the Scores as input

HC

MCI

Lacks Rationales

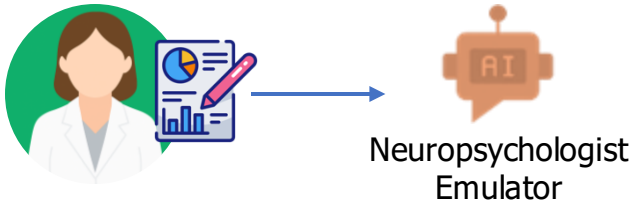
Large Language Model

- Automatically generates reports
- Provides natural language explanations

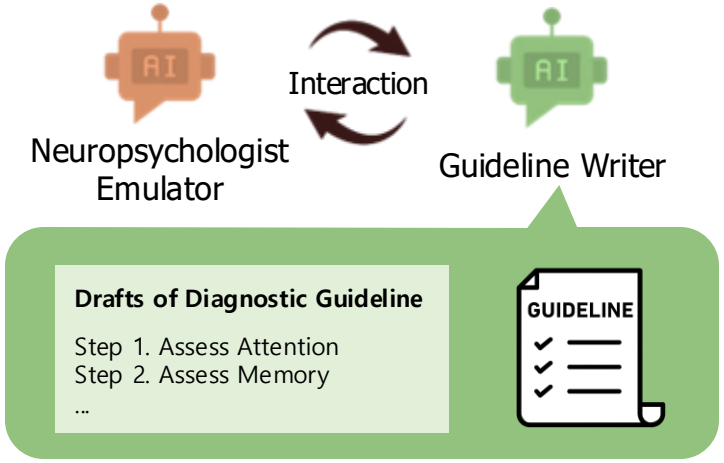
3.3 Research Findings – Accessible Digital Biomarker

LLMs can **transform clinical data** into **accessible digital biomarkers**,
generating guideline-based reports that deliver interpretable medical insights for MCI diagnosis

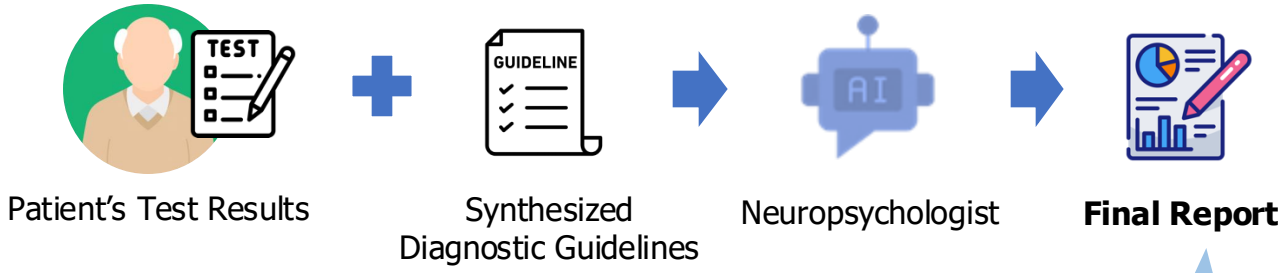
1) Emulating Experts



2) Synthesizing Step-by-step Diagnostic Guidelines



3) Generating Reports



Drafts of Diagnostic Guideline

...Considering these results, the subject shows **significant impairment in visuospatial functions** and some difficulties with working memory, attention, and language repetition. However, the subject's performance in **other cognitive domains is relatively preserved**. The subject also exhibits independence in daily living activities.

Final Diagnosis

(Group B) **Mild Cognitive Impairment, Early stage of dementia, or Alzheimer's disease**.

3.3 Research Findings – Accessible Digital Biomarker

Our developed LLM (CLONE) outperformed standard LLMs in both **diagnostic accuracy** and **rationale quality**, demonstrating the potential of building more accessible and reliable medical LLMs

Diagnostic accuracy

		Accuracy	Sensitivity	Specificity	Precision	F1-score
Llama 3.3 (70B)	0-shot + CoT	80.00	**100.00**	53.57	74.00	85.06
	1-shot + CoT	83.08	91.89	71.43	80.95	86.08
	2-shot + CoT	81.54	91.89	67.86	79.07	85.00
	CLONE	**89.23**	94.59	**82.14**	**87.50**	**90.91**

		Accuracy	Sensitivity	Specificity	Precision	F1-score
Phi 4 (14B)	0-shot + CoT	75.38	91.89	53.57	72.34	80.95
	1-shot + CoT	72.31	83.78	57.14	72.09	77.50
	2-shot + CoT	70.77	86.49	50.00	69.57	77.11
	CLONE	**81.54**	**91.89**	**67.86**	**79.07**	**85.00**

Rationale quality

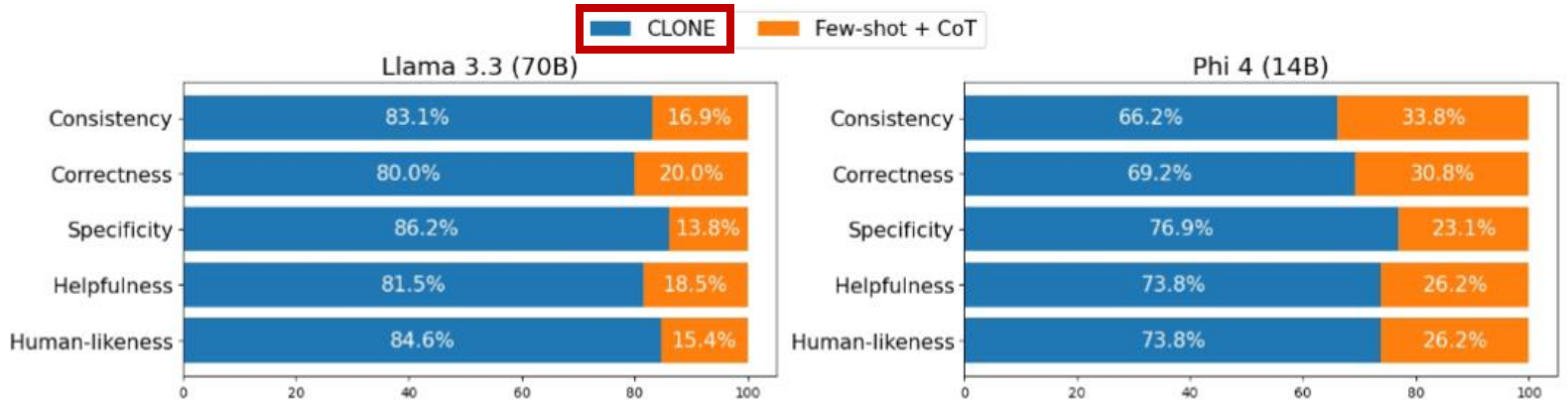
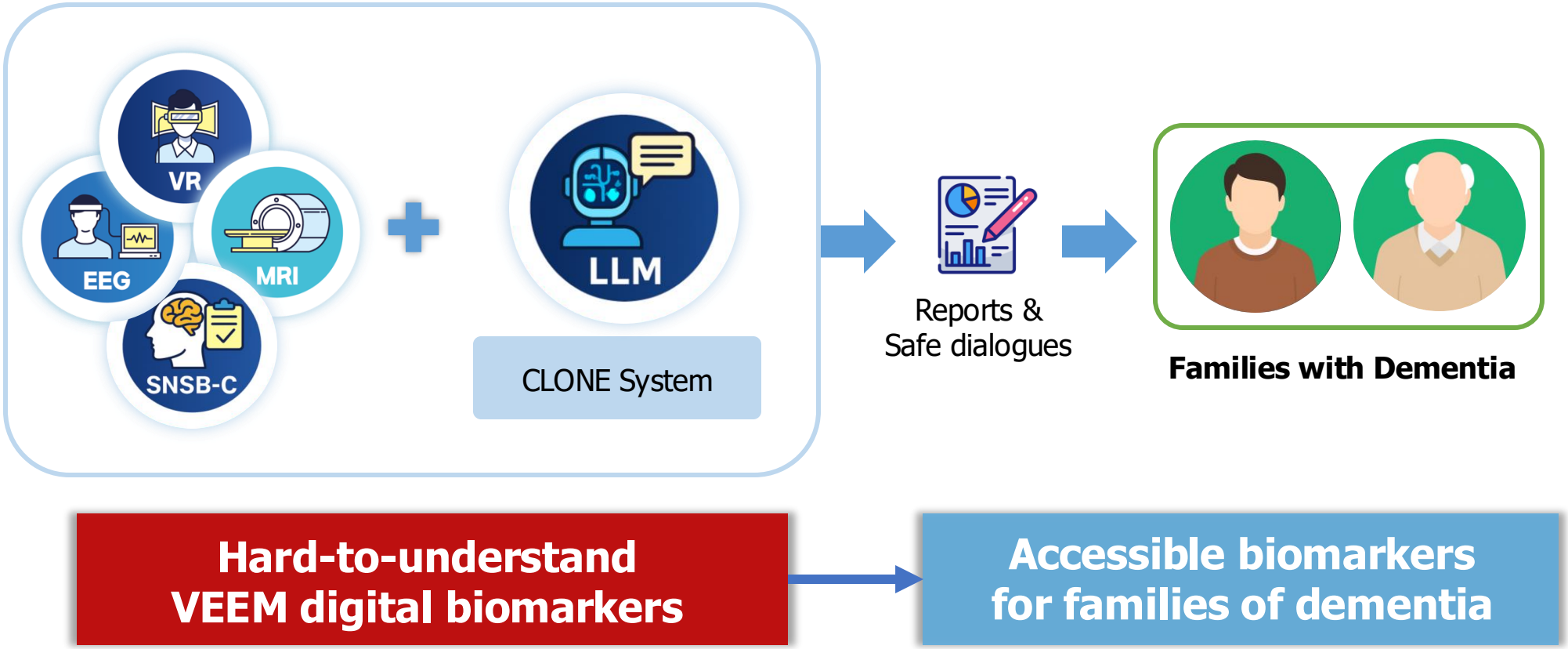


Figure 3: Winning rate of generated rationale quality between the proposed CLONE framework and the most accurate few-shot CoT baseline. The orange bars represent 1-shot CoT for Llama 3.3 (70B) and 0-shot CoT for Phi 4 (14B).

3.3 Research Findings – Accessible Digital Biomarker

(Ongoing project) LLMs for VEEM Digital Biomarkers (VR, EEG, MRI): creating easy-to-read reports and safe dialogues that help patients and families with dementia



Hard-to-understand VEEM digital biomarkers → **Accessible biomarkers for families of dementia**

Contents

4. Empowering Families with Dementia

Empowering Families with Dementia through **Rapid**, **Reliable**, and **Accessible Digital Biomarkers**

Phase of Care

Noticing changes → Making adjustment → Shifting responsibilities → Increasing demands → Full-time care

Caregiver Families' Major Concerns[6]

Preclinical phase

- Detecting **early signs of dementia** through ***Rapid Digital Biomarkers***

MCI

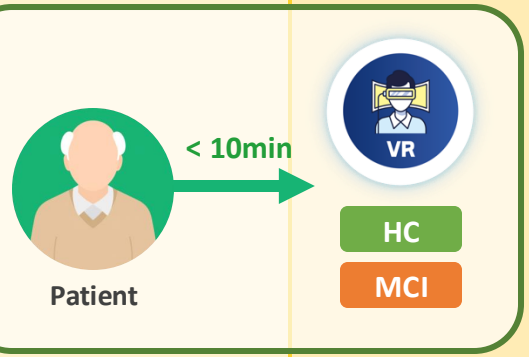
- ***Reliable Digital Biomarkers*** **(+ EEG, MRI)** enable a quicker and clearer path to diagnosis
- **Keeping families reliably informed** throughout the diagnostic journey

Dementia

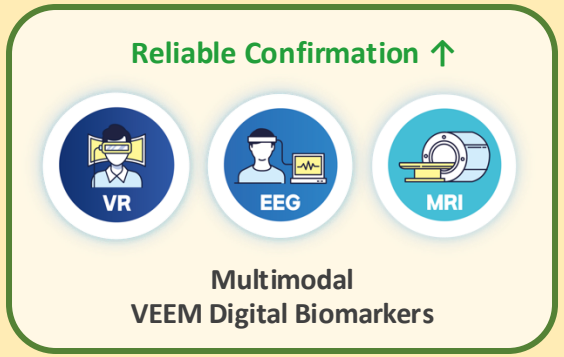
- ***Accessible Digital Biomarkers*** guide home adjustments for patient safety
- They provide families with *timely self-care guidance*

Empowering Families with Dementia

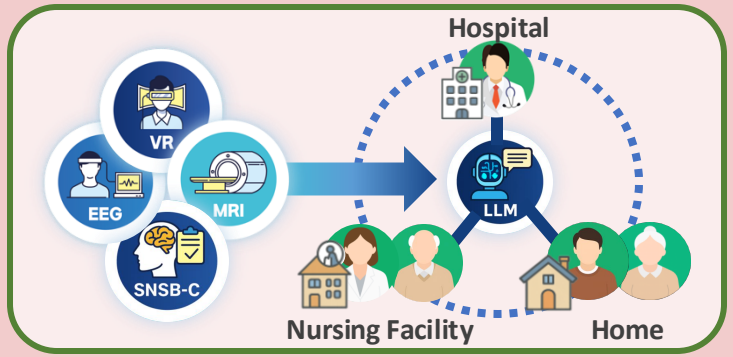
Rapid **Digital Biomarker**



Reliable **Digital Biomarker**



Accessible **Digital Biomarker**



Disease Severity

賽馬會 Jockey Club 智家樂計劃 SMART Family-Link Project

Thank you for your attention.

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