

Digital Rhythmic Tapping Biomarkers For Early MCI Screening: A Micro-behavioral Analysis

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Background

- Motor timing deficits** quantified through finger tapping tasks, have emerged as early markers of neurodegenerative diseases. [1][2]
- Digital assessment** captures hundreds of micro-behavioral features—such as reaction time, inter-tap interval (ITI) variability, and rhythm entrainment—that traditional tests cannot detect.
- These abnormalities reflect frontal-striatal and cerebellar dysfunction**, which are compromised early in Alzheimer's disease and related dementias.

Methods

- Participants:** Healthy Controls (HC) and individuals with Mild Cognitive Impairment (MCI) recruited from Chonnam National University Hospital in 2025.
*Participants were categorized into each group based on their BAPL, MMSE, CDR, and SNSB scores.
- Task Protocol:** Participants completed the D35 Rhythm Tapping Task, evaluating temporal regulation and cognitive flexibility.
- Conditions:** The task comprised two difficulty levels (Lv1: 1,000ms intervals; Lv2: 1,500ms intervals) performed under guided (with auditory/visual cues) and unguided (self-maintained) conditions.
- Data Analysis:** Timing errors were defined as inter-tap intervals deviating >10% from the target tempo. We extracted 108 micro-behavioral metrics and employed machine learning classifiers to compare performance patterns.

Results

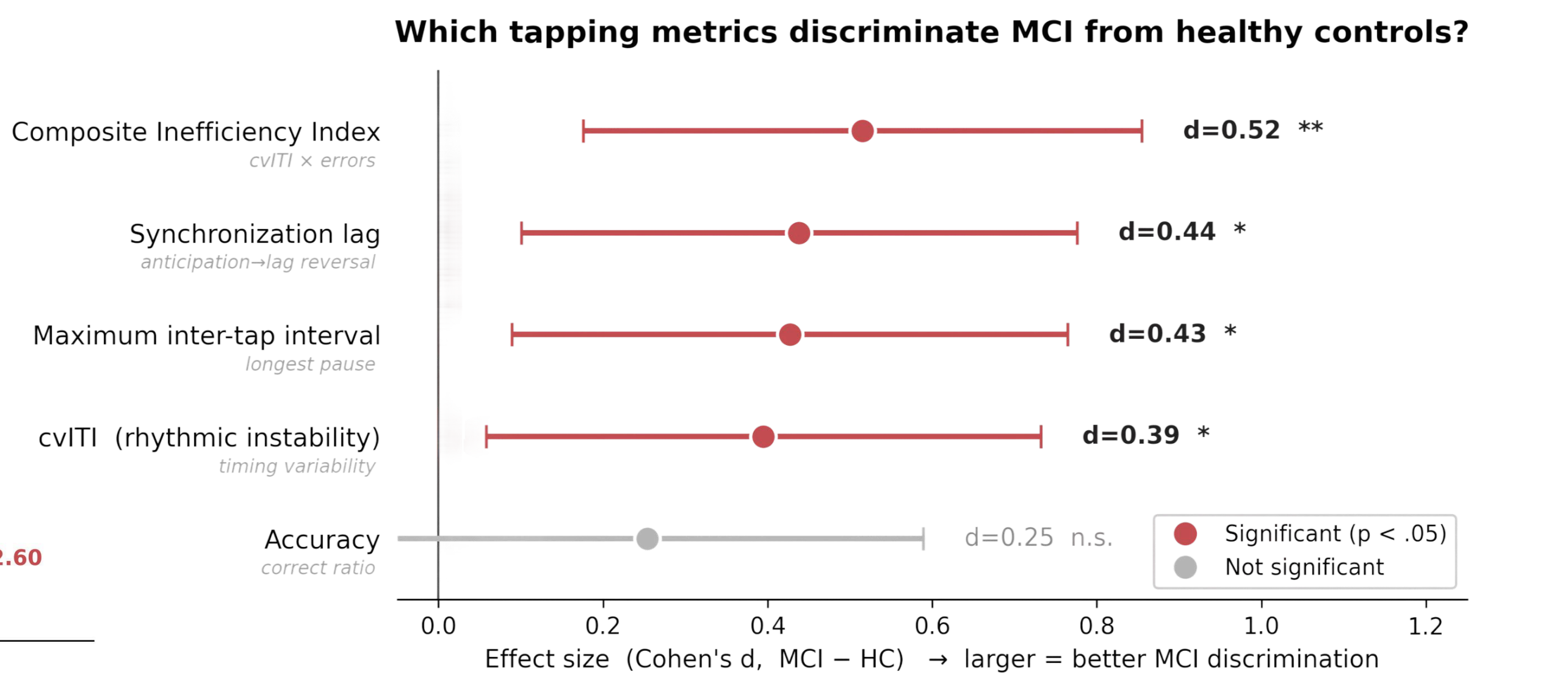
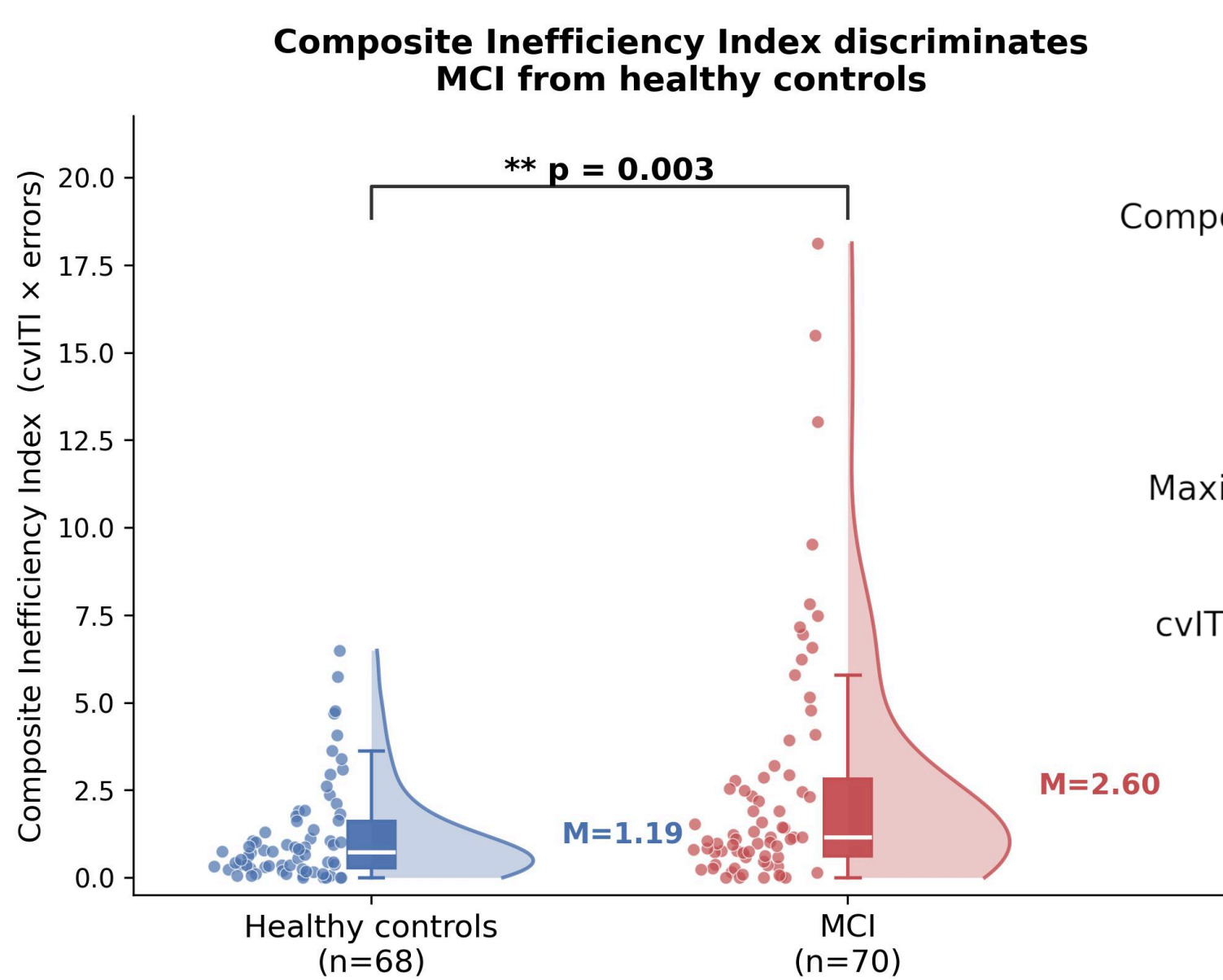
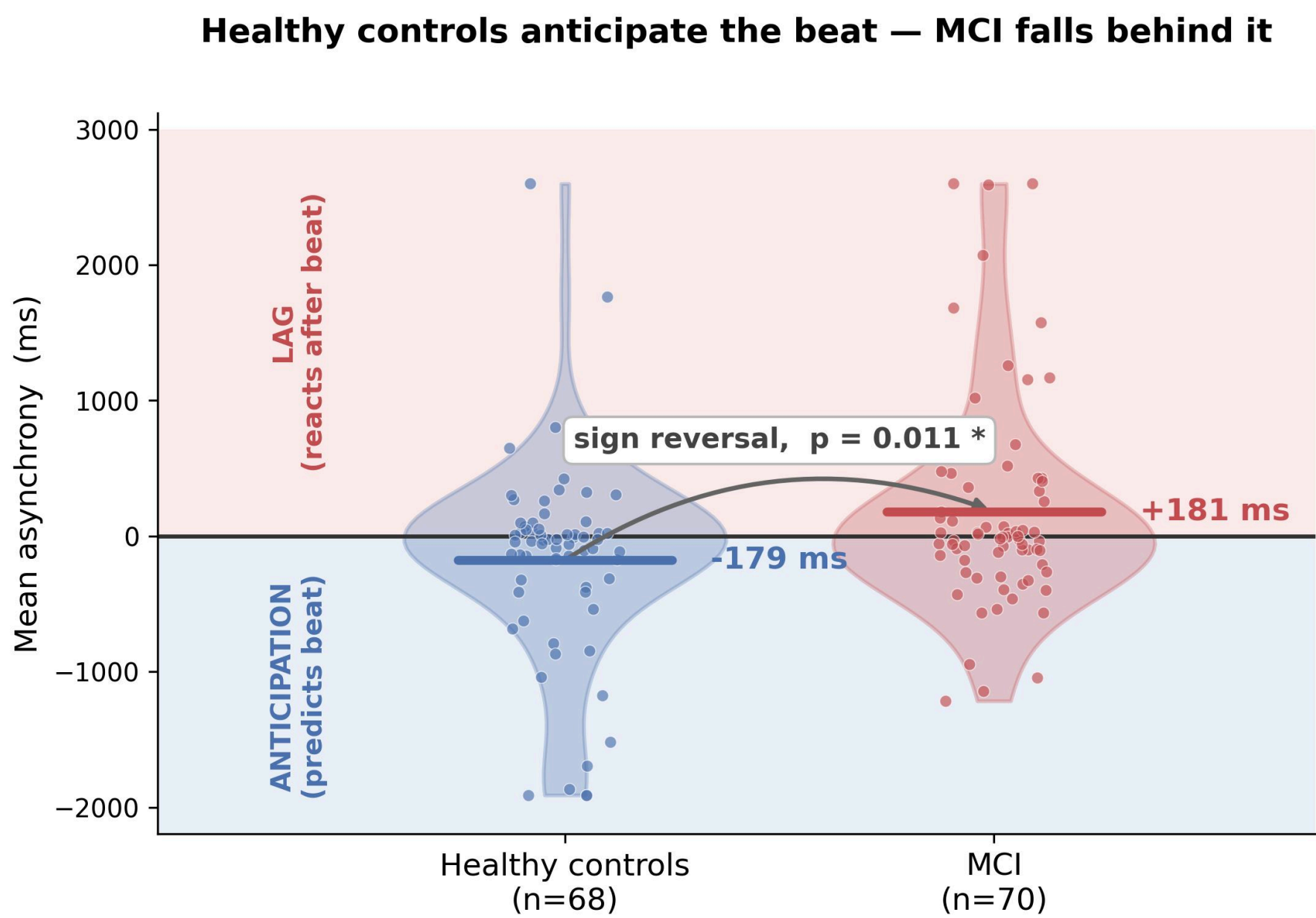
Significant differences emerged primarily in the higher-difficulty Lv2 condition.

- Comprehensive Functional Deficits:** A multi-dimensional radar plot profile reveals that the MCI group showed systemic deficits across all measured dimensions, highlighting breakdowns in motor-cognitive integration.
- Rhythmic Stability & Variability:** During unguided tasks, the MCI group exhibited significantly greater temporal variability, indicated by a higher coefficient of variation (cvITI, p=.021) and longer maximum inter-tap intervals (maxITI, p=.013) compared to healthy controls.
- Synchronization Agility:** Synchronization analysis showed distinct patterns; the MCI group exhibited a noticeable response lag, whilst healthy controls demonstrated anticipatory responses (p=.011).
- Strongest Discriminator (Composite Inefficiency Index):** Integrating timing variability (cvITI) with accuracy errors, the MCI group exhibited significantly higher impairment scores (p=.003). This composite metric demonstrated the strongest discrimination between groups, identifying it as the most sensitive marker for assessing integrated executive-motor dysfunction and breakdowns in temporal prediction.

Comparison of Tapping Performance Metrics HC and MCI Groups

Category	Metric	HC(M)	MCI(M)	t(136)	p-value
Variability	cvITI	0.15	0.24	-2.33	.021*
	maxITI(ms)	1,706	2,005	-2.50	.013*
Timing	Synchronization(ms)	-178	181	-2.57	.011*
Accuracy	Error Rate	7.91	9.37	-1.45	.146
	Accuracy	0.27	0.20	-1.49	.139
Composite	Inefficiency Index	1.19	2.60	-3.03	.003**

note. HC = Healthy Control, MCI = Mild Cognitive Impairment.
*p<.05, **p<.01



Conclusions

- Early Detection:** High-resolution digital assessment detects early MCI by capturing subtle executive failures that traditional metrics miss.
- Internal Temporal Model Breakdown:** Whilst motor speed is preserved in early MCI, deficits in the Composite Inefficiency Index, cvITI, and synchronization lag reveal breakdowns in the brain's internal temporal model.
- Beyond Motor Decline:** Asynchrony lag and rhythmic instability under high-load or unguided conditions expose impairments in temporal prediction and executive planning rather than mere motor decline.
- Clinical Value:** These micro-behavioral metrics serve as novel digital biomarkers of cognitive-motor regulation, offering significant clinical value for early MCI screening.

[1] Shimoyama I, Ninchoji T, Uemura K. The finger-tapping test: a quantitative analysis. Arch Neurol. 1990 47(6):681-684.
[2] Kluger A, Gianutsos JG, Golomb J, Ferris SH, George AE, Franssen E, et al. Motor/psychomotor dysfunction in normal aging, mild cognitive impairment, and early Alzheimer's disease: diagnostic and differential diagnostic features. Int Psychogeriatr. 1997;9 Suppl 1:307-316.
[3] Merchant H, Harrington DL, Meck WH. Neural basis of the perception and estimation of time. Annu Rev Neurosci. 2013;36:313-336.
[4] Camicioli R, Howieson D, Lehman S, Kaye J. Talking while walking the effect of a dual task in aging and Alzheimer's disease Neurology. 1997;48(4):955-958.
[5] Verghese J, Wang C, Lipton RB, Holtzer R. Motoric cognitive risk syndrome and the risk of dementia. J Gerontol A Biol Sci Med Sci. 2013 68(4):412-418.