Towards the Speech Features of Mild Cognitive Impairment: Universal Evidence from Structured and Unstructured Connected Speech of Chinese

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□ *Mild cognitive impairment (MCI)*
- A preclinical stage of Alzheimer's disease
- Total number of people suffering from dementia will reach **82 million** in 2030

□ *Subtle changes in language ability* - Apparent years or even decades before cognitive deterioration

□ *Conventional test batteries* - Not effective in detecting very early stage of cognitive decline

□ *Connected speech production* - Easy to obtain, multiple dimensions to analyze, sensitive index of cognitive function

(A) Normal
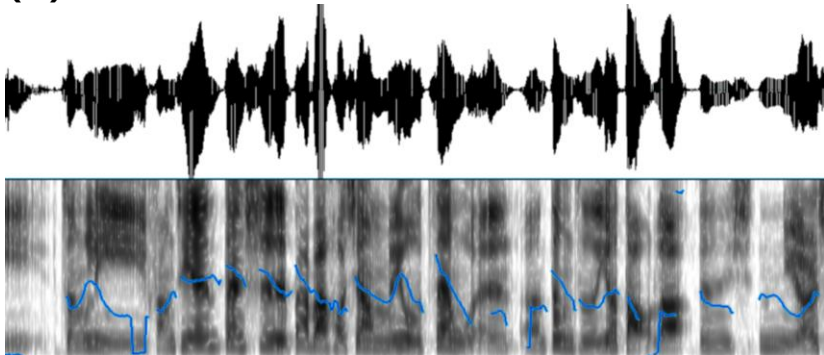
(B) MCI - empty speech
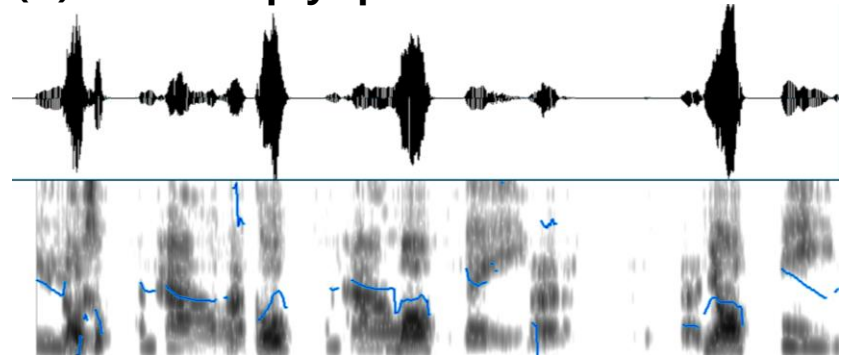
☐ *Lack of universal evidence* - Limit the generalization of salient linguistic features associated with MCI

☐ *Reports on Chinese* - Remain scarce

☐ *Speech samples from MCI* - Very limited

Comparison of DementiaBank and our database

	DementiaBank	The Present Study
Institution	University of Pittsburgh	中国科学院深圳先进技术研究院 SHENZHEN INSTITUTES OF ADVANCED TECHNOLOGY CHINESE ACADEMY OF SCIENCES
Subjects	Probable and Possible AD	Patients with MCI
Data Quality	Varied	High
Tasks	Picture description Speech fluency	Multiple tasks, including: Structured and Unstructured Task

☐ *Find universal features among different tasks*

   - **Structured:** situational picture description
   - **Unstructured:** spontaneous self-introduction

☐ *Generalize of features to different languages* - Chinese

☐ *Render salient features applicable to the preclinical stages* - MCI

Framework of the Study
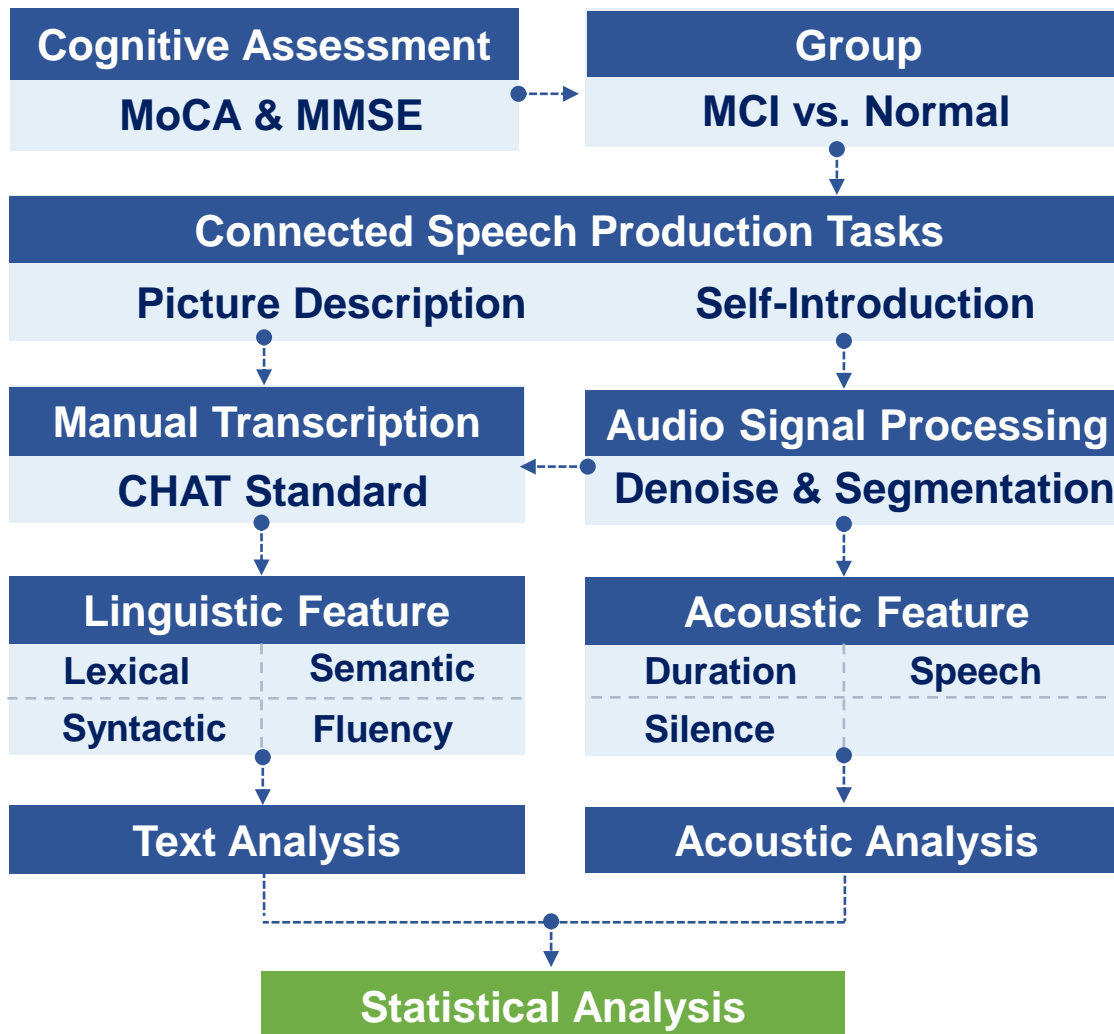
2.1 | Participants

☐ **MCI**

- History of cognitive decline
- Results of mental status examination (i.e. MoCA and MMSE)

☐ **Healthy control**

- No complaint of cognitive decline
- No history of psychiatric issues or neurological disorders

Demographic information (mean and SD)

	MCI N = 19	Normal N = 56	Statistics
Age (years)	65.6 (5.7)	67.9 (5.9)	t = -1.47
Gender (F/M)	11/8	29/27	χ^2 = 0.213
MoCA (30)	23.7 (2.4)	27.8 (1.3)	t = -7.22***
MMSE (30)	25.2 (2.7)	29.2 (1.0)	t = -6.15***
Education (years)	10.4 (2.7)	13.3 (2.5)	t = -4.17***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

2.1 | Participants

☐ The two groups were not matched for education level, which is one limitation of the study.

Correlation between Word/Vocabulary Frequency and Education Level

word frequency

$\rho = .116$, $p = .156$, ns

vocabulary frequency

$\rho = -.219$, $p = .007$ **
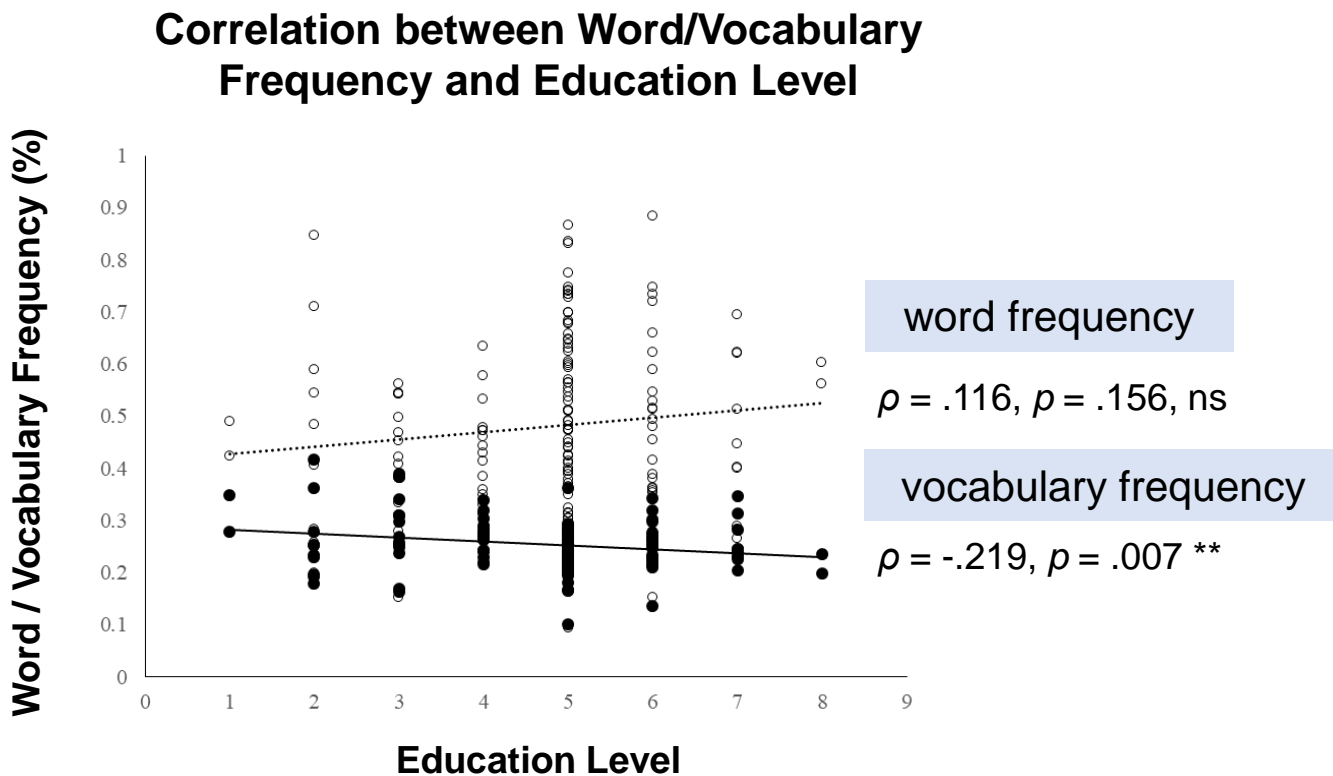
2.2 | Tasks

☐ **Structured connected speech**
- "Cookie Theft" picture description task - Describe everything they see in the picture
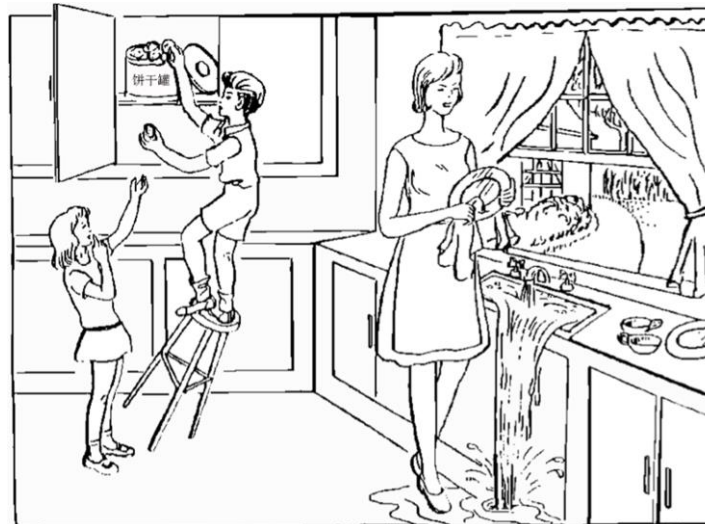
☐ **Unstructured connected speech**
- Predefined open-ended questions: family, career, hobbies, etc.

☐ Both tasks were constrained to **one minute** for comparison

2.3 | Hypothesis

- ☐ *Lexico-semantic* - anterior temporal lobes

- ☐ *Fluency reductions and simplified syntax* - left temporoparietal junction

- ☐ *Deficits in informative content* - semantic memory impairment

- ☐ *Acoustic abnormalities* - frontal premotor circuits involved in speech

Frontal premotor circuits

Left temporoparietal junction

Left anterior temporal lobe

Kathleen C. Fraser, Jed A. Melter, Frank Rudzicz. Linguistic features identify Alzheimer's disease in narrative speech. Journal of Alzheimer's disease. 2016, pp407-422.

2.4 | Features

Feature	Description
Lexical features	
Total words/characters	Total number of words/characters
POS rate	
Open-class words	Open-class words are noun, verb, adjective, adverb
Closed-class words	The rest are closed-class words
Content density	Open-class words / closed-class words
Lexical richness	
Type-token ratio	Number of vocabulary / number of words
Brunét's index	Number of words * number of vocabulary$^{-0.165}$
Honoré's statistic	100 * log [number of words / (1 - once / vocabulary)]
Word/vocabulary frequency	Frequency of words/vocabulary

2.4 | Features

Feature	Description
Semantics features	
Semantic units	Number of human-supplied information content unit
Idea density	Number of content unit / number of words
Idea efficiency	Number of content unit / speech segment duration
Syntactic features	
Utterance length	Average number of words for utterance
Dependent elements linked to the noun	Number of dependent elements linked to the head (e.g., adjectives, relative clauses)
Syntactic complexity	Grammatical subordinates and embeddedness

2.4 | Features

Feature	Description
Speech fluency features	
Filled pause count	Number of filled pause
Filled pause rate	Number of filled pause / total number of words
Disfluency count	Number of disfluency
Disfluency rate	Number of disfluency / total number of words
Acoustic features	
Silence duration	Duration without speech
Speech duration	Duration with speech
Voice-silence ratio	Speech duration / silence duration
Verbal rate	Number of words / total locution time (incl. pause)
Std. phonation rate	Number of words / total phonation time (excl. pause)

Methods

2.4 | Speech Analysis

☐ **Feature extraction**

- Language Technology Platform (LTP)
- Double checked by two raters

2.5 | Statistical Analysis

☐ **Linear mix-effect regression model**

feature ~ group + age + (1|participant) + (1|task) + ε   **full model**

vs.

feature ~ age + (1|participant) + (1|task) + ε   **reduced model**

Wanxiang Che, Zhenghua Li, Ting Liu. LTP: A Chinese Language Technology Platform. In Proceedings of the Coling 2010:Demonstrations. 2010.08, pp13-16, Beijing, China.

3.1 │ Comparison of Speech Features

	Picture Description		Self-Introduction		Group		Likelihood Ratio Test	
	MCI	Normal	MCI	Normal	β	SE	χ^2	*p*-value
(A) Lexical								
Total words	93.89 (24.3)	118.07 (30.5)	96.42 (26.4)	106.93 (25.6)	-17.63	6.066	8.003	0.005**
Total characters	129.79 (34.7)	167.05 (42.0)	146.37 (38.6)	163.36 (38.7)	-27.93	8.755	9.545	0.002**
POS rate								
Open-class words	0.55 (0.05)	0.57 (0.05)	0.60 (0.09)	0.59 (0.06)	-0.014	0.012	1.229	0.268
Closed-class words	0.45 (0.05)	0.42 (0.05)	0.40 (0.09)	0.41 (0.06)	0.014	0.012	1.229	0.268
Content density	1.39 (0.27)	1.55 (0.35)	1.70 (0.65)	1.56 (0.50)	-0.052	0.092	0.319	0.572
Lexical richness								
Type-token ratio	0.63 (0.1)	0.63 (0.1)	0.67 (0.1)	0.67 (0.1)	-0.007	0.017	0.154	0.695
Brunét's index	47.95 (11.1)	57.92 (13.4)	48.57 (12.2)	52.79 (11.3)	-7.168	2.705	6.713	0.010**
Honoré's index	567.84 (28.7)	589.44 (26.1)	588.51 (21.6)	604.13 (23.4)	-21.33	4.735	17.930	0.000***
Word frequency	0.45 (0.14)	0.50 (0.16)	0.45 (0.13)	0.48 (0.18)	-0.043	0.035	1.492	0.222
Vocabulary frequency	0.29 (0.07)	0.26 (0.04)	0.27 (0.03)	0.23 (0.04)	0.036	0.008	16.424	0.000***
(B) Semantic								
Semantic units	11.00 (4.16)	15.57 (3.95)	11.95 (2.84)	13.63 (2.60)	-3.455	0.651	23.906	0.000***
Idea density	0.12 (0.05)	0.14 (0.04)	0.13 (0.05)	0.13 (0.02)	-0.009	0.008	1.354	0.245
Idea efficiency	0.18 (0.07)	0.26 (0.07)	0.20 (0.05)	0.22 (0.04)	-0.055	0.011	20.818	0.000***

*p < 0.05, **p < 0.01, ***p < 0.001

Results

3.1 | Comparison of Speech Features

(Continued)

	Picture Description		Self-Introduction		Group		Likelihood Ratio Test	
	MCI	Normal	MCI	Normal	β	SE	χ^2	*p*-value
(C) Syntactic								
Utterance length	7.99 (2.03)	8.65 (2.03)	6.27 (1.18)	7.51 (1.52)	-1.072	0.356	8.567	0.003**
Dependent element linked to the noun	1.50 (0.54)	1.62 (0.61)	1.26 (0.60)	1.59 (0.54)	-0.244	0.113	4.484	0.034*
Syntactic complexity	0.74 (0.09)	0.71 (0.10)	0.75 (0.09)	0.75 (0.08)	0.017	0.017	1.000	0.317
(D) Speech fluency								
Filled pause count	2.21 (1.65)	2.85 (3.00)	5.16 (3.82)	4.89 (2.93)	-0.308	0.613	0.252	0.616
Filled pause rate	0.03 (0.02)	0.02 (0.02)	0.05 (0.03)	0.05 (0.03)	0.002	0.006	0.118	0.731
Disfluency	3.37 (2.67)	2.05 (1.61)	1.68 (1.92)	1.34 (1.42)	0.917	0.35	6.581	0.010*
Disfluency rate	0.03 (0.02)	0.02 (0.01)	0.02 (0.02)	0.01 (0.01)	0.011	0.003	12.418	0.000***
(E) Acoustic								
Silence duration	13.55 (5.53)	7.71 (5.03)	12.26 (8.92)	8.24 (4.69)	4.811	1.24	13.724	0.000***
Speech duration	46.64 (5.79)	53.63 (7.82)	48.50 (9.00)	52.68 (5.27)	-5.6	1.494	12.866	0.000***
Voice-silence ratio	4.43 (2.78)	10.11 (6.05)	8.32 (8.47)	9.01 (5.60)	-2.956	1.198	5.857	0.016*
Verbal rate	1.56 (0.40)	1.91 (0.43)	1.59 (0.44)	1.75 (0.40)	-0.259	0.093	7.373	0.007**
Std. phonation rate	2.00 (0.40)	2.18 (0.43)	1.98 (0.37)	2.02 (0.42)	-0.118	0.091	1.677	0.195

*p < 0.05, **p < 0.01, ***p < 0.001

3.2 | Summary of Results

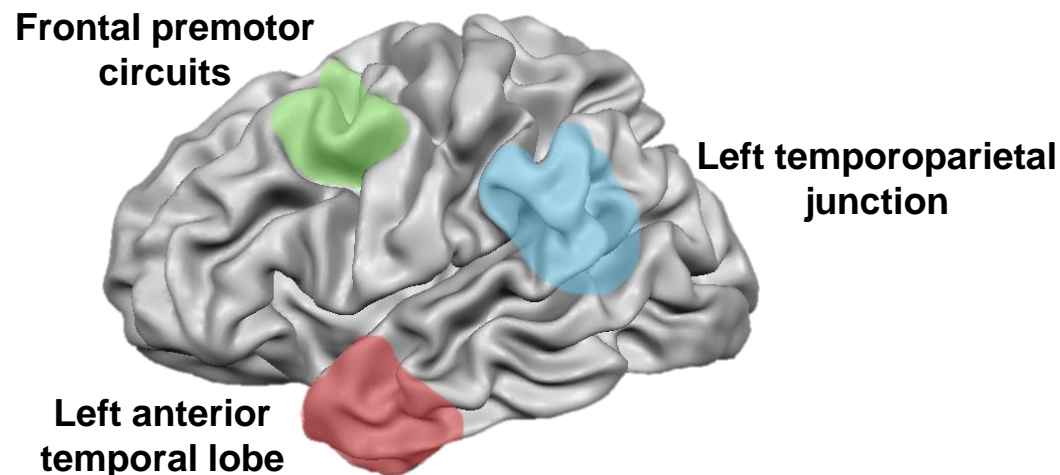|		
Semantic	• Semantic units ($\downarrow$ $p < 0.001$) • Idea efficiency ($\downarrow$ $p < 0.001$)	• Semantic memory impairment • Reduced ability to retrieve semantic information
Syntactic	• Utterance length ($\downarrow$ $p < 0.01$) • Dependent elements linked to the noun ($\downarrow$ $p < 0.05$)	• Reduced structural complexity
Speech Fluency	• Number of repetition, false start, and repairs ($\uparrow$ $p < 0.001$)	• Significant signs of dysfluency
Acoustic	• Duration of silence ($\uparrow$ $p < 0.001$) • Duration of speech ($\downarrow$ $p < 0.001$) • Verbal rate ($\downarrow$ $p < 0.01$)	• Temporal alterations in speech signal
Lexical	• Open-class rate ($\downarrow$ ns) • Closed-class rate ($\uparrow$ ns) • Content density ($\downarrow$ ns) • Lexical richness parameters ($\downarrow$ ns)	• Lexical features poorly modified • Unreliable predictor of cognitive decline, at least for Chinese

3.3 │ Back to our hypothesis

☐ *Lexico-semantic* - anterior temporal lobes

☐ *Fluency reductions and simplified syntax* - left temporoparietal junction

☐ *Deficits in informative content* - semantic memory impairment

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☐ **Test the relationship between language alterations and brain atrophy**

- Collection of Magnetic Resonance Imaging (MRI) data
- Collection of EEG data for time-course analysis of lexical retrieval and source reconstruction
- Language samples

☐ **Realize automatic screening**

- Translate the observations into simple and specific biomarkers
- Application of automatic speech recognition system

☐ **Validate the salience of features among different tasks and languages**

- Structured and unstructured connected speech
- Chinese

☐ **Far-reaching clinical implications**

- Guide development of methods for screening and diagnosis

Our Lab and Funding

☐ **CAS Key Laboratory of Human-Machine Intelligence-Synergy System**
☐ **Speech Science Laboratory, The University of Hong Kong**
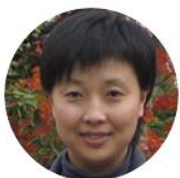
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