Postprint: Handwriting Characteristics of Older Adults with Mild Cognitive Impairment and Their Application Value

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Abstract

Background: Handwriting kinematic feature analysis technology has been extensively studied in the detection of related cognitive disorders such as dementia and Parkinson's disease. Research on handwriting features in elderly individuals with mild cognitive impairment (MCI) remains to be expanded.

Objective: To reveal the differences in handwriting features between elderly individuals with MCI and cognitively normal elderly individuals, and to explore the application value of handwriting features in MCI screening.

Methods: From January 2022 to April 2022, 33 community-dwelling elderly individuals with MCI in Huzhou City were selected as the MCI group, while 43 community-dwelling cognitively normal elderly individuals matched for age, gender, and education level were enrolled as the control group during the same period. Six handwriting tasks were completed using a digital dot-matrix pen to collect kinematic parameters of participants' handwriting features. Discriminant analysis and receiver operating characteristic (ROC) curve analysis were employed to analyze the accuracy, sensitivity, and specificity of handwriting features for MCI identification.

Results: Compared with the control group, in the graph task, the MCI group exhibited lower writing accuracy, higher writing pressure, and longer writing thinking time, pen-down time, and total task completion time, with statistically significant differences between groups (Z=-3.593, -2.122, -4.302, -3.663, t=-5.565, all $P<0.05$). In the Chinese character task, the MCI group had longer writing thinking time and total task completion time (Z=-3.464, -2.94, both $P<0.05$). Compared with the Chinese character task, the total completion time of the graph task demonstrated the highest specificity (93.02%) in discriminating MCI, with an area under the ROC curve of 0.828. The graph handwriting feature set

could correctly classify 80.26% of individuals with MCI, with a sensitivity of 87.88% and a specificity of 79.07%, and its efficacy in identifying MCI was superior to that of the MMSE scale.

Conclusion: Graph handwriting features may have potential application value for screening individuals suspected of MCI before community medical institutions conduct comprehensive neuropsychological test batteries.

Full Text

Study on Handwriting Characteristics and Its Application Value in Elderly Patients with Mild Cognitive Impairment

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Abstract

Background: Handwriting characterization techniques have been extensively studied in cognitive impairment detection related to dementia and Parkinson' s disease, yet research on handwriting characteristics among older adults with mild cognitive impairment (MCI) remains to be expanded. **Objective:** To reveal differences in handwriting characteristics between elderly MCI patients and cognitively normal older adults, and to explore the application value of handwriting features in MCI screening. **Methods:** From January 2022 to April 2022, 33 community-dwelling older adults with MCI in Huzhou were selected as the observation group, and 43 age-, gender-, and education-matched community older adults with normal cognitive function were included as the control group. Six handwriting tasks were completed using a digital pen to collect kinematic parameters of handwriting characteristics. Discriminant analysis and receiver

operating characteristic (ROC) curve analysis were used to evaluate the accuracy, sensitivity, and specificity of handwriting features for MCI identification. **Results:** Compared with the control group, the MCI group exhibited lower writing accuracy, higher writing pressure, and longer reflection time, pen-down time, and total task completion time in graphical tasks, with statistically significant differences (Z = -3.593, -2.122, -4.302, -3.663, t = -5.565, all $P < 0.05$). In Chinese character tasks, the MCI group showed longer reflection time and total task completion time (Z = -3.464, -2.94, both $P < 0.05$). Compared with Chinese character tasks, total task completion time in graphical tasks demonstrated the highest specificity (93.02%) for MCI discrimination, with an area under the ROC curve (AUC) of 0.828. The graphical handwriting feature set correctly classified 80.26% of MCI individuals, with 87.88% sensitivity and 79.07% specificity, showing higher diagnostic efficacy than the MMSE scale. **Conclusion:** Graphical handwriting characteristics may have potential application value in screening suspected MCI populations before administering comprehensive neuropsychological tests in community healthcare settings.

Keywords: Older adults; Mild cognitive impairment; Handwriting characteristics; Kinematic parameters; Screening tool

Introduction

Mild cognitive impairment (MCI) represents a transitional state between normal aging and dementia, characterized by declines in episodic memory, attention, executive function, language, and visuospatial abilities. A recent meta-analysis reported that the prevalence of MCI among Chinese adults over 60 years old reaches as high as 19%. However, current routine screening guidelines for MCI have not reached consensus, leaving most MCI cases in communities undiagnosed and consequently missing the optimal window for effective cognitive maintenance and reversal. Presently, both basic research and clinical practice predominantly rely on comprehensive neuropsychological test batteries for MCI screening, whose professional complexity, subjective reporting biases, and cross-sectional assessment characteristics often limit their applicability and accuracy. Therefore, developing a convenient and feasible screening method for MCI in community settings is urgently needed.

Early cognitive impairment can manifest as writing function deficits. Foreign scholars have attempted to analyze individual handwriting characteristics (based on handwriting kinematic parameters) to identify cognitive and/or motor impairments in patients with dementia, Parkinson' s disease, and Huntington' s disease. Compared with healthy individuals, MCI patients demonstrate lower flexibility, slower speed, and poorer fluency when performing fine motor tasks. Consequently, applying quantitative handwriting analysis technology for MCI identification possesses both theoretical feasibility and practical necessity. Regarding task design for MCI patients, foreign studies

have primarily employed dictation, copying tasks, and 临摹 two-dimensional or three-dimensional graphics. However, task heterogeneity significantly influences quantitative handwriting analysis, and English letter writing differs fundamentally from Chinese character writing. Thus, whether handwriting characteristics in Chinese character and graphical tasks differ between MCI and normal elderly populations, and whether such differences hold potential screening value for MCI identification, warrants further investigation.

This study explores handwriting characteristics of MCI individuals under dual-task conditions (Chinese characters and graphics), analyzing the discriminative efficacy of different handwriting features to provide novel screening clues for rapid identification of suspected MCI populations.

Methods

1.1 Study Subjects

Using convenience sampling, we recruited community-dwelling individuals aged $ $60 years, right-handed, with primary school education or higher, without self-reported visual or hearing impairments, and with clear consciousness from January 2022 to April 2022. For the MCI group, participants had to meet Petersen's diagnostic criteria: (1) subjective cognitive complaints (from informants or physicians); (2) Montreal Cognitive Assessment-Basic (MoCA-B) scores <19 (education $ $6 years), <22 (6 < education $ $12 years), or <24 (education >12 years); (3) Mini-Mental State Examination (MMSE) scores >20 (primary school) or >24 (middle school and above); (4) Activity of Daily Living Scale (ADL) scores $ $16; and (5) no dementia diagnosed by community physicians. Normal control subjects had to report no memory decline, MMSE scores >24, and essentially normal daily living abilities.

Exclusion criteria included: (1) history of alcohol intoxication, drug addiction, or severe head trauma affecting central nervous system function; (2) history of stroke or severe physical illness (e.g., cancer, depression); (3) neurological or psychiatric disorders such as Parkinson's disease, essential tremor, severe schizophrenia, or depression, or use of medications affecting cognitive function (including antipsychotics, antidepressants, and sedative-hypnotics); and (4) hand motor impairments due to dystonia, masses, infection, deformity, disability, sensory deficits, or injuries preventing task execution.

After strict screening, 33 MCI patients and 43 healthy older adults matched for age, gender, and education were selected. This study was approved by the Ethics Committee of Huzhou Third People' s Hospital (Approval No.: 2022-049). All participants were informed about the study purpose, content, and procedures, and provided written informed consent.

1.2.1 General Information Collection

General data were collected using a self-designed questionnaire including age, gender, education, chronic disease status, marital status, and occupation. Neuropsychological assessments were conducted by professional neuropsychologists and included: (1) MMSE for dementia screening across six domains (orientation, memory, attention, etc.); (2) MoCA-B for MCI screening across ten items (visuoperception, executive function, naming, language fluency, etc.); (3) ADL assessing physical self-maintenance (6 items) and instrumental activities (8 items); and (4) Geriatric Depression Scale (GDS-15) to assess depressive symptoms in the past week, with positive cases (GDS-15 >5) excluded.

1.2.2 Handwriting Characteristics Collection

Handwriting Data Acquisition Tool: This study used a digital pen (similar to ordinary writing pens) and dot-matrix paper (printed with Anoto dot-matrix technology) developed by Tstudy China to extract handwriting characteristics. This tool mimics familiar pen-and-paper writing habits and experiences, synchronizing writing behavior with kinematic parameter collection. Testing duration was 5-10 minutes, with data collection concluding upon task completion.

Writing Task Design: Based on previous research and characteristics of Chinese older adults, six writing tasks were developed (four Chinese character tasks, two graphical tasks) to assess writing accuracy, fine wrist control, executive function, visuospatial ability, attention, writing stability, short-term memory, and semantic expression. Details of tasks and scoring criteria are provided in Appendix 1.

Feature Extraction: During Chinese character/graphical task execution, a high-speed camera at the pen tip sampled position codes (x, y coordinates) at 60-80 frames per second. Simultaneously, a force-sensitive tip (1024 levels) transmitted pressure data to the processor (null when pressure <100 levels), enabling real-time digital representation of original handwriting and delivery of parameters including coordinates, stroke paths, tip pressure, and movement timing. This study collected 24 handwriting features across four dimensions: writing time, pressure, speed, and morphology (Table 1).

Collection Requirements: Participants were seated in a quiet environment with appropriately sized desks and chairs, provided with A4 dot-matrix paper containing writing tasks and a digital pen. Researchers demonstrated the writing procedure and confirmed participant understanding before task execution.

1.3 Statistical Analysis

SPSS 21.0 was used for statistical analysis. Normally distributed quantitative data were described as mean ± standard deviation ($\bar{x} \pm s$) and compared between groups using independent samples t-tests. Non-normally distributed data were described as median (interquartile range) [M (IQR)] and compared using

Mann-Whitney U tests. Categorical variables were expressed as frequencies and percentages, compared using ^{2} tests. Spearman correlation analysis examined relationships between education level and handwriting features. After controlling for gender, age, and education, partial correlation analysis explored associations between handwriting features in graphical/Chinese character tasks and MoCA-B sub-domain scores. Discriminant analysis evaluated classification accuracy, and MedCalc 20.027 constructed ROC curves to examine sensitivity, specificity, and AUC values. AUC comparisons used the Delong non-parametric method, with $P < 0.05$ considered statistically significant.

Results

2.1 Comparison of General Information

The MCI group included 33 participants aged 60-94 years, and the control group included 43 participants aged 60-96 years. No statistically significant differences were found between groups in age, gender, education, monthly income, marital status, chronic diseases, or occupation (all $P > 0.05$). The MCI group had lower MoCA-B and MMSE scores than the control group ($t = 10.326$, $Z = -4.159$, both $P < 0.05$). Education level showed no significant correlation with handwriting features in either group (all $P > 0.05$) (Table 2).

2.2 Comparison of Handwriting Characteristics and Accuracy

To simplify analysis and test hypotheses, this study extracted mean values of handwriting features across total graphical and total Chinese character tasks. Table 3 shows that compared with controls, the MCI group exhibited higher average pressure ($Z = -2.122$, $P = 0.034$) and longer reflection time, pen-down time, and total task completion time (all $P < 0.01$) in graphical tasks, with slower average speed, x- and y-direction average speed, x-direction maximum speed, and x-direction average acceleration (all $P < 0.05$). In Chinese character tasks, the MCI group showed longer reflection time and total task completion time (both $P < 0.05$). Regarding task accuracy, only total graphical task accuracy showed statistically significant between-group differences ($Z = -3.593$, $P < 0.01$) (Table 3 shows only features with significant between-group differences).

2.3 Correlation Analysis Between Handwriting Features and Cognitive Function

After controlling for gender, age, and education, graphical task average pressure, reflection time, pen-down time, and total task completion time all negatively correlated with total MoCA-B score (all $P < 0.05$). Among MoCA-B sub-domains, average pressure negatively correlated with language fluency and attention (both $P < 0.05$); reflection time negatively correlated with language fluency, calculation, and delayed recall (all $P < 0.05$); pen-down time negatively correlated with orientation, attention, and delayed recall (all $P < 0.05$); and total task time negatively correlated with language fluency, calculation, orientation, and

visuoperception (all $P < 0.05$). In Chinese character tasks, no handwriting features showed significant correlations with MoCA-B total or sub-domain scores (all $P > 0.05$) (Table 4).

2.4 Efficacy of Handwriting Features in MCI Differentiation

In addition to individual features, five MCI differentiation schemes were evaluated: handwriting feature set, writing accuracy, MMSE, MMSE combined with handwriting feature set (dual scheme), and MMSE combined with handwriting feature set and writing accuracy (triple scheme). Discriminant analysis showed that total task completion time achieved the highest individual classification accuracy (81.58%) in graphical tasks, with the dual scheme improving accuracy to 84.21%. In Chinese character tasks, the triple scheme achieved the highest classification accuracy (75%). ROC analysis revealed that reflection time in graphical tasks had the highest specificity (95.35%), while y-direction average speed had the highest sensitivity (90.91%). The handwriting feature set' s AUC was higher than MMSE ($Z = 1.993$, $P = 0.046$). In Chinese character tasks, reflection time and total task completion time showed highest sensitivity, with writing accuracy specificity reaching 93.02%; however, the handwriting feature set' s AUC did not significantly differ from MMSE ($Z = 0.5$, $P = 0.617$). Dual schemes in both task types showed higher AUC values than handwriting feature sets alone, but differences were not statistically significant (all $P > 0.05$). Notably, graphical and Chinese character task handwriting feature sets showed significantly different AUC values ($Z = 2.408$, $P = 0.016$) (Table 5 , Figure 1 [Figure 1: see original paper], Figure 2 [Figure 2: see original paper]).

Discussion

MCI screening has not yet been incorporated into public health service programs, with community healthcare facilities typically using MMSE for cognitive assessment. Although some non-profit organizations and primary hospitals have implemented MCI screening using MoCA combined with other neuropsychological tests, lengthy testing time, high professional requirements, and relative complexity limit widespread practice. Therefore, identifying suspected MCI populations before comprehensive cognitive assessment is practically necessary to conserve diagnostic resources and advance community MCI management. This study compared handwriting characteristics between MCI patients and cognitively normal older adults through Chinese character and graphical tasks, preliminarily revealing the potential application value of handwriting features in rapidly distinguishing suspected MCI populations.

3.1 MCI Patients Exhibit Different Handwriting Characteristics from Cognitively Normal Individuals

This study evaluated handwriting characteristics across five dimensions, including writing accuracy and specific kinematic features. Regarding accuracy, the

MCI group showed non-significant but notable phenomena in Chinese character tasks, including stroke omissions and component errors, while graphical tasks revealed deficiencies in completeness and normativity. For specific features, the MCI group demonstrated longer reflection and total task completion times in Chinese character writing, and slower speed/acceleration with higher average pressure and longer reflection, pen-down, and total times in graphical writing. These findings confirm previous research conclusions. Kawa et al. found larger Chinese character size in MCI patients; our study used x- and y-direction length for two-dimensional size measurement, showing a trend toward larger characters in the MCI group despite non-significant differences. Additionally, y-direction average speed in graphical tasks showed 90.91% sensitivity for MCI discrimination, consistent with Ghaderyan et al.' s reported 93% sensitivity. Reduced y-direction speed may indicate basal ganglia dysfunction, potentially reducing missed diagnoses. White matter integrity ensures writing fluency; prolonged reflection, pen-down, and total times may mark frontal white matter damage in executive function regions. Thus, handwriting characteristics may serve as early behavioral markers of white matter damage for MCI identification. However, associations between high writing pressure and MCI lack consistent conclusions, possibly due to task content heterogeneity or measurement method differences. Systematic research on writing pressure in MCI populations remains limited, making any interpretations exploratory.

3.2 Graphical Task-Based Handwriting Features May Be More Sensitive for MCI Differentiation

Our results indicate that graphical task-based handwriting features showed higher sensitivity, specificity, and classification accuracy than Chinese character tasks. Hayashi et al. reported that handwriting features based on self-generated or copied Chinese characters lacked discriminative power for MCI. Previous studies also found that Chinese character writing impairments become more pronounced only when MCI progresses to Alzheimer' s disease. Visuospatial dysfunction is considered a cognitive marker for detecting prodromal dementia symptoms and helps differentiate MCI from healthy populations. Graphical tasks engage more visuospatial functions, partially explaining the efficacy advantage of graphical handwriting features. The International Association of Gerontology and Geriatrics consensus recommends annual cognitive assessment for individuals over 70, ideally within 3 minutes. Our graphical task testing time did not exceed 3 minutes, significantly shorter than MMSE. For elderly individuals with literacy or age-related Chinese writing difficulties, graphical task-based handwriting features warrant further exploration regarding discriminative efficacy and accessibility.

3.3 Handwriting Features Show Potential Clinical Applicability for Rapid MCI Screening

Our results demonstrate that graphical task-based handwriting feature sets achieved higher classification accuracy, AUC, sensitivity, and specificity than MMSE, consistent with previous findings. Since dual schemes showed no significant AUC differences from handwriting feature sets alone, community MCI practice could be accelerated by adding or independently implementing multi-person, real-time handwriting feature recording and automatic analysis using digital pen technology, in addition to routine MMSE. Digital pens are low-cost and reusable by simply replacing pen refills, offering cost-effectiveness. Compared with professional, experience-dependent scale assessments, digital pen screening is simple to operate, collects data via smartphones or tablets, requires no specialized training, is not limited by testing location, and provides more objective and accurate results in shorter time.

3.4 Summary

Integrating quantitative analysis of graphical handwriting characteristics into cognitive assessment systems shows promising application prospects for identifying suspected MCI populations and facilitating rapid diagnosis and management. Despite meaningful findings, limitations exist. The sampling scope and size were limited, with participants restricted to primary school education or higher, affecting representativeness and generalizability. Future studies should increase sample size and overcome education and writing habit limitations. Although we excluded patients with severe motor function diseases, subtle motor impairments may affect handwriting performance. We have not explored differential distribution patterns and subtype discriminative ability of handwriting features across MCI subtypes, requiring further refinement. Additionally, whether practice is needed before writing tasks remains undetermined in existing research; our study did not include practice sessions, potentially introducing bias. Finally, our handwriting feature analysis remains semi-automated; future development of automated binary or multi-class classifiers is needed for real-time feature extraction and result determination.

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Conflict of Interest: The authors declare no conflict of interest.

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