Received: 5 March 2025 | Revised: 30 May 2025 | Accepted: 25 June 2025 | Published online: 10 July 2025

RESEARCH ARTICLE

Medinformatics
2025, Vol. 00(00) 1–12
DOI: 10.47852/bonviewMEDIN52025601

BON VIEW PUBLISHING

Formalized Assessment of Handwriting Deterioration Caused by Dementia

Yury Chernov[1,*]

[1]*Institute for Handwriting Sciences, Switzerland*

Abstract: Handwriting is a sensitive indicator of both cognitive and physical changes, making it a promising tool for the early detection of neurodegenerative conditions such as cognitive impairment (CI) and Alzheimer's disease (AD). Because dementia-related handwriting changes vary between individuals, a systematic and quantitative approach is essential. This study employs a robust analytical framework incorporating 41 handwriting and 3 linguistic features, previously shown strong discriminatory power to effectively differentiate individuals with CI/AD from healthy controls. The current work focuses on a longitudinal analysis of handwriting changes over time, using samples from 21 participants diagnosed with CI/AD. Each participant provided recent handwriting alongside samples written 10–20 years earlier. The analysis identifies the most common dementia-related handwriting changes and evaluates their statistical significance. These findings underscore handwriting analysis as a promising tool for detecting early signs of cognitive decline. This approach offers particular value in medical diagnostics, supporting timely intervention, and in forensic contexts, where handwriting changes may serve as critical evidence. Overall, the study highlights systematic handwriting analysis as a reliable, non-invasive, and accessible assessment tool.

Keywords: dementia, handwriting deterioration, biomarker, formalized assessment

1. Introduction

Dementia is a broad term that encompasses a group of symptoms affecting memory, cognition, and aspects of daily behavior. It is not a specific disease but rather a syndrome resulting from various underlying causes. The most common neurodegenerative form is Alzheimer's disease (AD), which accounts for up to 70% of cases. Other types include vascular dementia, Lewy body dementia, frontotemporal dementia, and dementia associated with Parkinson's disease. In this study, we focus on individuals diagnosed with cognitive impairment (CI) or AD. However, we acknowledge that handwriting changes are likely to reflect neurodegenerative processes characteristic of dementia, regardless of its specific type. Different types of dementia affect different parts of the cerebral cortex, resulting in impairments to various higher cortical functions. This naturally includes writing and speech. The cortical mechanism of handwriting is very complicated and not yet well enough understood to be able to model it explicitly [1]. In the current study, we base our analysis on the 'black box' principle.

AD, as a neurodegenerative disorder, is characterized by specific brain changes that lead to cognitive decline and memory loss. These changes occur at both the microscopic (cellular) and macroscopic (structural) levels. The key pathological features of AD include the accumulation of amyloid plaques (clusters of misfolded beta-amyloid protein that build up between neurons), the formation of neurofibrillary tangles (twisted fibers of tau protein inside neurons), synaptic loss (disruption of neuronal connections), and brain atrophy (shrinkage of brain tissue due to widespread neuronal degeneration), among others. However, it remains unclear whether these changes are the cause or the consequence of AD development.

These brain changes are being intensively studied using various biomarkers [2–4]. The most well-known biomarkers are brain imaging techniques, including computed tomography, magnetic resonance imaging, and positron emission tomography. Other, less established methods include cerebrospinal fluid biomarkers, as well as blood and genetic tests. In the last time, researchers introduced also digital biomarkers [5].

Research on additional biomarkers is continuously advancing. While these methods provide valuable insights into brain status, the actual cognitive decline experienced by the affected individual and their social and familial environment may be even more significant. Although brain changes naturally correlate with CI symptoms, they are not identical [6, 7].

Neurologists use a range of tools to diagnose the onset of CI. These include observing a person's behavior, administering specialized cognitive tasks, such as the well-known clock-drawing test [8], gathering information from family members, and using standardized assessment inventories [9]. Among the most widely used are the Mini-Mental State Examination (MMSE) [10] and the Montreal Cognitive Assessment (MoCA) [11]. These tests consist of diverse cognitive tasks and are relatively quick and easy to administer, with the MMSE taking 5–10 min and the MoCA 10–15 min. However, their sensitivity in detecting mild and early-stage dementia remains limited [12].

Handwriting changes in individuals affected by AD have long been observed. Numerous studies confirm a relationship between the onset of AD and handwriting deterioration. There are many comprehensive overviews of this topic. To the recent ones belong [13, 14].

*Corresponding author: Yury Chernov, Institute for Handwriting Sciences, Switzerland. Email: yc@ihs-sgg.ch

Handwriting is a unique phenomenon that extends beyond fine motor skills. It is not merely a motor activity but also a cognitive and linguistic process. Handwriting is a complex perceptual-motor skill [4], distinct from other graphomotor activities such as drawing or doodling. While the clock-drawing test – which involves drawing a circular clock face and setting a specified time with clock hands – can be loosely associated with handwriting, it remains fundamentally different. One of the main distinctions is that handwriting is closely tied to a language system, which significantly influences multiple aspects of the writing process. Handwriting integrates cognitive, kinesthetic, and perceptual-motor components, involving functions such as visual and kinesthetic awareness, motor planning, eye-hand coordination, visual-motor integration, and motor dexterity. Given these characteristics, handwriting can serve as an indicator of various health disorders. Of particular interest are those associated with dementia in general and AD in particular – especially when handwriting changes enable early screening. Often writing disorders are more severe than language difficulties [15].

Fine motor skills involve precise movements, primarily of the fingers and hands, and rely on coordinated interaction between the brain, nerves, and muscles. AD and other forms of dementia disrupt these abilities due to neurodegenerative changes in the brain. It is not just the movements themselves that are affected, but mainly their coordination. This deterioration is reflected in handwriting (see some latest studies [16–18]). Thus, formalized handwriting assessment can serve as a digital or behavioral indicator for cognitive and neurological conditions.

According to one of the most widely accepted models of handwriting [19], the writing process consists of seven levels, which can be divided into higher-level and lower-level modules (Figure 1). The higher-level modules include intention activation (ideas), semantic retrieval (concepts), syntactical construction (phrases), and spelling (words). The lower-level modules involve the selection of allographs (graphemes), size control (allographs), and muscular adjustments (strokes). The higher-level modules operate in parallel, allowing multiple tasks to be carried out simultaneously and information to flow between them. This parallel processing enables, for example, a person to begin planning the next word while still writing the current one, all while considering upcoming words. At the same time, they may also carry on a conversation or listen to music. In contrast, the lower-level modules function serially – only one command can be sent to the hand and fingers at a time, ensuring precise execution by the muscles.

AD primarily affects the higher-level modules, while the lower-level motoric functions remain relatively preserved. This explains why signatures often remain stable despite cognitive decline [20, 21]. Behrendt [22] highlights this distinction: “The fact that illness and age can affect a person’s writing has been recognized since the principles of handwriting identification were first promulgated. Most of the attention given to this subject, however, has focused on infirmities that cause physical impairment. In contrast, AD is a disorder that primarily manifests itself as a mental dysfunction.” Individuals affected by AD typically exhibit slow, hesitant, and awkward handwriting. This can be attributed to an inherent lack of self-confidence and a general sense of insecurity.

Existing studies on the impact of dementia on handwriting follow two main approaches: analyzing dynamic and static characteristics. Dynamic characteristics are recorded during the writing process itself. To capture these, researchers typically use various digital tools such as tablets, digitizers, and smart pens [23]. These devices enable highly precise measurements of writing features, offering strong discriminatory power. A comprehensive overview of studies based on the dynamic approach can be found in [24]. However, writing on digital devices – even high-quality ones – differs from writing on paper, introducing certain distortions. While digital tools effectively capture aspects such as writing speed, pressure, and even movements in the air, relying solely on these parameters is insufficient for comprehensive dementia screening. Moreover, assessments using such methods are typically conducted in controlled environments like labs or hospitals, which limits participant diversity and demands significant time and effort. Early detection is particularly important, yet individuals are often evaluated only after noticeable symptoms have already emerged. This delay reduces the potential for early intervention and underscores the need for more natural and accessible screening methods.

Static analysis is based on evaluating already written text, allowing for the examination of a wide range of handwriting features – practically all known characteristics. This is why we consider this approach to be systematic. It includes aspects related

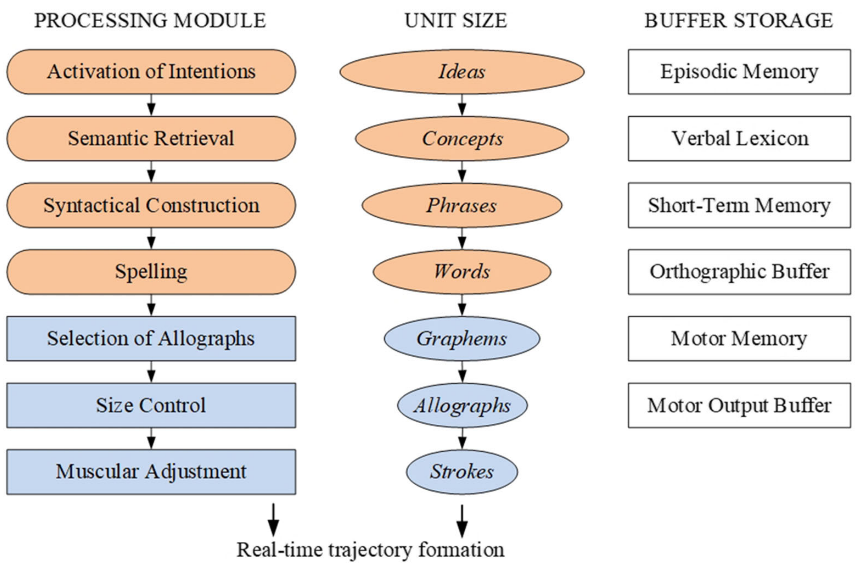


Figure 1. Van Gallen’s model of handwriting processing

to the organization of written text (such as margins, paragraphs, lines, word spacing, and indents), the geometry of letters and their elements (including vertical and horizontal size and surface area), specific letter forms, stroke characteristics, and more. Although dynamic features are typically captured in real-time during writing, they can also be inferred from static text with high reliability. This enables a comprehensive handwriting assessment without requiring specialized digital tools, making it a practical approach for broader applications.

As mentioned, several comprehensive reviews summarize existing studies on handwriting changes associated with AD. Most of these studies, however, focus on only a limited set of handwriting features. Broadly, these studies can be categorized into two groups. The first group primarily examines the linguistic aspects of handwriting, for instance [25], including spelling, punctuation, and sentence structure. The second group focuses solely on motoric activity, analyzing features related to handwriting execution, such as movement patterns and kinematics [24].

The present study aims to investigate handwriting features that are most susceptible to changes as CI and AD progress. By examining these specific characteristics, we seek to enhance early detection and improve understanding of handwriting deterioration in neurodegenerative conditions.

2. Research Methodology

2.1. Research design

Multiple studies on the impact of CI/AD on handwriting have identified certain linguistic and handwriting features that may indicate disease onset. While these findings are valuable for research, their practical application requires a tool that enables quantitative evaluation. Such a tool must comprehensively assess all relevant handwriting features, ensuring both objectivity and validated reliability for effective screening. An approach and tool proposed by a group of researchers [26, 27] partially meets these criteria and represents a step in the right direction. It enables a semi-quantitative evaluation based on two scales, with the first one assessing verbal and lexical skills using a five-point scoring system and the second one representing some handwriting characteristics. While the effort to create a quantified index is commendable, the test relies on overly broad and loosely defined features, making objective and reliable evaluation difficult. Additionally, it focuses primarily on one narrow aspect of handwriting – the spatial organization of lines – without considering other crucial handwriting characteristics.

The AD-HS instrument [28, 29] was previously presented and validated in earlier studies. Based on new data, we introduce minor refinements to enhance its accuracy. Currently, the instrument comprises 44 characteristics (denoted as N), including 41 handwriting features and 3 linguistic variables (Table 1). To ensure objectivity, each feature is precisely defined, along with clear evaluation criteria, as outlined in the table. The ADI index, introduced in earlier publications as an indicator of potential dementia onset, may serve multiple clinical roles. It can be used for diagnosis, signaling the presence of dementia; as a prognostic instrument, predicting the likely course of the disease; and for monitoring, tracking disease progression and the effects of treatment over time.

It is important to note that the handwriting features in AD-HS are language-independent for European languages. However, the

Table 1. AD-HS variables

No	Handwriting feature	Feature definition
1	Big letter size	The vertical extension of the middle zone letters (a, e, m, n, o, u, v, w, x) is over 3.5 mm.
2	Irregular letter size	Less than 80% of letters belong to the same size category (little, average, big).
3	Irregular letter width	Letter width is the relation of the interval between the basic vertical strokes of a letter to its vertical extension. Normal width is from 0.8 to 1.2. Irregular width: less than 80% of letters belong to the same width category (narrow, average, wide).
4	Reduced upper zone	The average vertical extension of the upper zone (letters b, f, h, l) is smaller than the average letter vertical extension by more than 1.5 mm.
5	Lower zone is bigger than upper zone	The average vertical extension of the lower zone (letters f, g, j, p, q, y, z) is smaller than the average vertical extension of the upper zone by more than 1.5 mm.
6	Narrow letter spacing	Letters are narrowly placed or touch each other without being connected
7	Irregular letter spacing	Letter spacing changes from narrow to wide: less than 80% belong to the same category
8	Disproportional word spaces	Inter-word spaces in the specimen are either too small or too large
9	Irregular spaces between words	Different categories of spaces (small, averages, large) are present in the same specimen.
10	Overlapping lines	Upper zone and or lower zone overlapping with the previous or/and next lines.
11	Irregular line spaces	Different line space categories (small, normal, and large) are present in the specimen.
12	Left or vertical slant	Left or vertical slant is dominating.
13	Irregular slant	Less than 80% of letters have the same slant (left, vertical, right).
14	Line direction is not horizontal	Lines are going up or down or have a wavy direction.
15	Line form is not straight	Line form uneven, hast not the form of a straight line
16	Left margin is wide	The average value of the left margin is more than 25 mm.
17	Left margin is uneven	Lines have different distances to the left edge of the page (the difference is more than an average letter width).
18	Right margin is narrow	The average right margin is less than 15 mm. Additional space due to transferring the next word completely on the following line is not considered.
19	Printed or school-like letter form	More than 60% of letters have either printed or school forms.
20	Distorted letter form (broken, untended, or distorted letters)	Letter form is so simplified or distorted that it looks confusing and illegible. It shows up in at least 20% of letters.
21	Unstable letter form	There are several (more than three) knotted formations in the specimen.

(*Continued*)

Table 1. **(*Continued*)**

No	Handwriting feature	Feature definition
22	Oversimplified letter form	
23	Mixed letter form	Different letter forms are present in the specimen: cursive, printed, or capital letters in the middle of words or small letter form by capitals.
24	Disconnected handwriting	Connected handwriting involves connections of at least three letters. Otherwise, handwriting is disconnected.
25	Fullness	Ovals in the middle zone have a relation of width to height more than 0.8; loops in the upper and lower zones have this relation more than 0.6.
26	Weak pressure	Indirectly is defined by the stroke width and the traces on the back side of the paper.
27	Irregular and unrhythmic pressure	Pressure changes in different elements of letters or different places of the specimen.
28	Slow speed	Speed can be evaluated indirectly. The major features of the slow speed: not connected writing, school letter form, angle connections, exactly put diacritic and punctuation marks, exactly made letter details, narrow letters and inter-letter intervals, additional letter elements at the word beginnings and endings,
29	Stroke tenderness, rigidness	
30	Poor stroke quality	The indication of poor stroke quality: distortions, tremors, line duplication, line breakage, deformations, retractions, breakpoints, etc.,
31	Thin stroke building	The stroke width is less than 0.3 mm. The width of strokes may depend on the writing instrument and the quality of the paper.
32	Special form elements (knots and covering strokes)	
33	High-placed diacritic marks	Diacritic marks are highly placed when they are over the letter body.
34	Weak diacritic pressure	Diacritic marks have weaker pressure than the basic part of the letter.
35	Wide punctuation	Punctuation marks are placed far from the preceding word
36	Vertical offset of punctuation marks	The vertical position of punctuation marks deviates more than 1 mm from the line base.
37	Weak punctuation pressure	Punctuation marks have weaker pressure than letters.
38	Elongated comma form	Comma has a form of stroke that is longer than the middle zone letters.
39	Lack of orderliness	There are several (at least three) crossings and/or corrections
40	General irregularity of handwriting	General irregularity is determined by irregularities of several characteristics.
41	Form dominates over dynamics	Letter form is clear by slow handwriting mostly without beginning and end strokes.
42	Low writing drive	Slowness with weak pressure and without beginning and end strokes; not finished strokes.
43	Spelling errors	Misspelled words, omission, and switching of letters
44	Punctuation errors	Misplaced or missed punctuation marks
45	Capitalization errors	Missing or an inappropriate usage of capital letters

linguistic features are inherently language-dependent and may require adaptation for different languages.

Since handwriting characteristics are inherently interdependent, the AD-HS variables may naturally exhibit correlations. To analyze these relationships, we calculated correlation coefficients using our database of evaluated handwriting samples (HSDetect) [15]. The strongest correlations are presented in Table 4. In general, correlations play a crucial role in regression and cluster analysis, as they allow for dimensionality reduction by eliminating redundant variables or constructing broader composite measures. In our case, the ADI index – introduced in previous publications as an indicator of potential dementia onset – is not a regression model. However, these correlations remain valuable for data analysis and interpretation.

All AD-HS features are normal, non-pathological characteristics of handwriting. Therefore, no single feature in the set indicates a possible dementia condition; rather, it may simply reflect an individual's writing habit. Unlike micrography in Parkinson's disease, there are no defining handwriting characteristics for CI/AD. The impact of CI/AD varies from person to person, making it necessary to consider multiple AD-HS features rather than isolated ones. In other words, the total number of features present is what matters. In previous studies [1, 12], we introduced the ADI index, which quantifies the likelihood of dementia onset. The ADI is calculated as the ratio of AD-HS

Table 2. Participant biodata

Subject	Age	Gender	Handiness	Education
1	59	female	right-handed	tertiary
2	67	female	right-handed	tertiary
3	80	female	right-handed	tertiary
4	64	female	right-handed	tertiary
5	83	female	right-handed	tertiary
6	70	female	right-handed	tertiary
7	60	female	right-handed	tertiary
8	68	male	right-handed	post-secondary
9	68	female	right-handed	tertiary
10	78	male	right-handed	tertiary
11	83	male	right-handed	tertiary
12	71	female	right-handed	post-secondary
13	68	female	right-handed	tertiary
14	65	female	right-handed	tertiary
15	72	female	right-handed	tertiary
16	62	female	right-handed	tertiary
17	70	female	right-handed	tertiary
18	75	male	right-handed	tertiary
19	66	female	right-handed	tertiary
20	63	female	right-handed	tertiary
21	81	female	right-handed	secondary

features detected in a handwriting sample (k) to the total number of AD-HS features (N), expressed as ADI = k/N. This index naturally ranges from 0 to 1, where 0 indicates no signs of CI/AD and 1 represents the highest possible indication. In practice, ADI values range from 0.059 to 0.790, though these figures may evolve as additional data becomes available.

2.2. Participants

The first part of the experiment, previously reported, involved 53 subjects (29 women, 24 men) diagnosed with CI/AD. Their ages ranged from 59 to 85 years, with an average of 70.4 years. Their free-text handwriting samples were collected and analyzed. For the control group, 192 generally healthy individuals from our database were selected. This database provides a robust representation of the normal population, containing hundreds of handwriting samples in different languages with diverse demographic characteristics. These control samples had been evaluated in prior studies but were not part of the current experiment. Selection criteria included high-quality handwriting samples in the same languages as the test subjects (German, English, Russian, and Polish). The comparison demonstrated high reliability and strong discriminative power of AD-HS. The mean ADI for CI/AD participants was $\mu^p = 0.49$ with a standard deviation $\sigma^p = 0.12$, while the control group had a mean of $\mu^c = 0.28$ with a standard deviation $\sigma^c = 0.09$.

The present study consists of two parts. The first part is dedicated to the frequency analysis based on the mentioned 53 subjects. The aim is to analyze the frequency of AD-HS handwriting features in the affected individuals compared to the normal data set.

The main focus of the current work, its second part, is a longitudinal study where we analyze how handwriting features changes with the onset and progression of CI/AD. For 21 subjects, we obtained current and previous handwriting samples. The time difference between them is 10 to 20 years. The earlier samples were written before the diagnosis of CI/AD. The participants are 17 women and 4 men. The average age is 70 years.

The aim is to analyze how handwriting, i.e., typical handwriting characteristics, change with the onset and progression of the disease.

3. Results

In the following paragraphs, there are frequency data of handwriting features and analysis of deterioration of handwriting. An example of comparative samples is given in Figure 2. The subject is a male, by whom no comorbidities were reported by his neurologist. The first sample dates back to 2005, the subject was 68 years old and ADI = 0.34. The second sample belongs to the year 2020, when he was correspondingly 83 with ADI = 0.74.

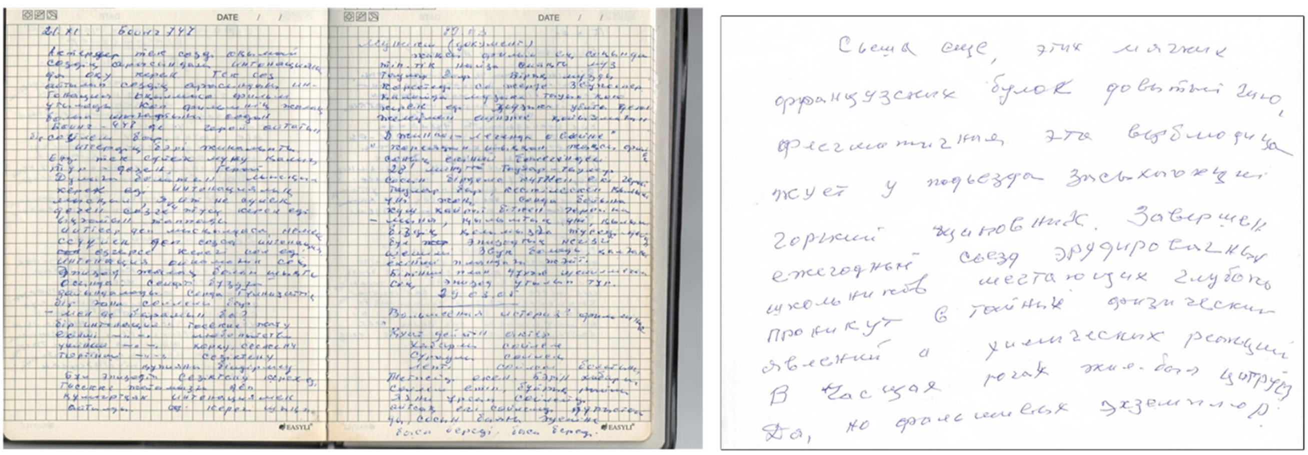
3.1. Frequency analysis of handwriting features

The AD-HS instrument should be understood as a combination of specific handwriting and linguistic features, none of which alone can serve as a definitive marker for CI/AD. However, analyzing how individual characteristics differ between participants and the control group is essential. To statistically compare these differences, the two-proportion *z*-test was applied. Table 3 presents the frequency of each feature, along with their *z*-values (critical threshold: 1.96 for 95%) and *p*-values (critical threshold: 0.05). Linguistic features were excluded, as they had not been assessed for all subjects in the control group. The results show that most handwriting features occur significantly more frequently in the experimental group ($z > 1.96$, $p < 0.05$). The most prominent features (focusing on the simpler ones) include:

- Irregular letter size
- High-placed diacritics
- Non-horizontal baseline direction
- Weak writing pressure
- Slow speed
- Small space between letters
- Lower pressure in diacritics
- Large letter size
- Irregular slant
- Disconnected writing
- Overlapping lines
- Uneven left margin
- Wide left margin
- Irregular line spacing
- Poor line quality

Among the 40 analyzed features, only 10 showed no statistically significant difference. Additionally, 25 features were detected in over 50% of participants' samples.

Given the large number of features analyzed, some degree of correlation is expected. Table 4 presents the statistically



2005 2020

Figure 2. Two handwriting samples of the same subject

Table 3. Frequency of AD-HS variables

No	Handwriting feature	CI/AD group	Control group	z	p
1	Large letter size	0.58	0.38	2.61	0.009
2	Irregular, inconsistent letter size	0.67	0.45	2.84	0.005
3	Irregular, inconsistent letter width	0.51	0.32	2.55	0.011
4	Reduced upper zone of letters	0.28	0.19	1.43	0.153
5	Lower letter zone is bigger than upper zone	0.51	0.25	3.64	<0.001
6	Narrow letter spacing	0.62	0.33	3.83	<0.001
7	Letter spacing is irregular	0.55	0.45	1.29	0.197
8	Disproportional word spaces	0.49	0.48	0.13	0.897
9	Irregular word spacing	0.29	0.27	0.29	0.772
10	Overlapping lines	0.55	0.18	5.44	<0.001
11	Irregular line spaces	0.33	0.16	2.76	0.006
12	Left or vertical slant	0.56	0.41	1.95	0.051
13	Irregular slant	0.56	0.34	2.91	0.004
14	Non-horizontal line direction	0.64	0.14	7.46	<0.001
15	Line form is not straight	0.53	0.15	5.80	<0.001
16	Left margin is wide	0.35	0.15	3.26	<0.001
17	Left margin is uneven	0.53	0.19	4.97	<0.001
18	Right margin is narrow	0.64	0.47	2.19	0.029
19	Printed, block or school-like letter form	0.67	0.35	4.18	<0.001
20	Distorted letter form	0.40	0.32	1.09	0.276
21	Unstable letter form	0.27	0.25	0.30	0.764
22	Oversimplified letter form	0.60	- - - -		
23	Mixed letter form	0.13	0.05	2.06	0.039
24	Disconnected handwriting	0.56	0.24	4.46	<0.001
25	Fullness	0.44	0.37	0.93	0.352
26	Pressure is weak	0.64	0.23	5.67	<0.001
27	Irregular/unrhythmic pressure	0.29	0.21	1.23	0.219
28	Slow speed	0.64	0.30	4.53	<0.001
29	Stroke tenderness, rigidness	0.38	0.22	2.38	0.018
30	Poor stroke quality	0.33	0.12	3.64	<0.001
31	Thin stroke building	0.73	0.66	0.96	0.337
32	Special from elements	0.42	0.06	6.73	<0.001
33	High-placed diacritic marks	0.65	0.16	7.15	<0.001
34	Weak diacritic pressure	0.60	0.33	3.57	<0.001
35	Wide punctuation	0.29	0.11	3.26	<0.001
36	Vertical offset of punctuation	0.16	0.04	3.12	0.002
37	Weak punctuation pressure	0.31	0.02	6.78	<0.001
38	Elongated comma form	0.22	0.06	3.52	<0.001
39	Lack of orderliness	0.27	0.26	0.15	0.881
40	General irregularity	0.53	0.47	0.77	0.441
41	Domination of form over dynamics	0.55	0.40	1.95	0.051
42	Low writing drive	0.53	0.14	6.03	<0.001
43	Spelling and orthographic errors, missing letters	0.17	- - - -		
44	Punctuation errors	0.32	- - - -		
45	Capitalization errors	- - - -	- - - -		

significant correlation values for both the control and experimental groups. However, it is important to note that statistical significance alone is not a strong indicator of correlation strength. It simply implies that the correlation is different from zero and cannot be dismissed as negligible. According to standard interpretation [30], correlation coefficients between 0.2 and 0.4 are considered weak and between 0.4 and 0.6 moderate.

Correlations are generally higher in the experimental group, which can be attributed to two factors. First, the higher frequency of features in this group increases the likelihood of stronger correlations. Second, the smaller sample size results in a greater influence of randomness. Some associations appear in both groups and may be of interest. While much can be speculated about these correlations, most remain weak, with only a few reaching moderate strength. Among the latter, the following relationships seem natural and explainable:

- Large letter size – fullness
- Printed or school letter form – slowness
- Unstable letter form – stroke tension
- Poor stroke quality – stroke tension

Beyond direct correlations, there is also a certain interdependence between features, even if this is not fully captured by correlation coefficients. For instance, general irregularity (feature 37) is the summarization of different irregularities of handwriting, which are partly explicitly present in AD-HS (size, width, slant and line spaces); low writing drive

Table 4. AD-HS variable correlations

No	Handwriting feature	Control group		CI/AD group	
1	Big letter size	Fullness	0.323	Fullness	0.427
				Mixed letter form	0.316
				Slow speed	0.315
				Weak punctuation pressure	0.309
				Irregular letter size	0.308
2	Irregular letter size	Irregular letter width	0.313	Irregular slant	0.364
		Form instability	0.304	Irregular letter width	0.341
				Irregular letter spacing	0.336
				Big letter size	0.308
3	Irregular letter width	Irregular letter size	0.313	Unstable letter form	0.449
		Irregular letter spacing	0.350	Irregular letter spacing	0.359
				Irregular letter size	0.341
4	Reduced upper zone			Irregular line spaces	0.434
				Distorted letter form	0.321
6	Narrow letter spacing	High stroke tenseness	0.337	Irregular letter spacing	0.377
7	Irregular letter spacing	Irregular letter width	0.350	Narrow letter spacing	0.377
				Irregular letter width	0.359
				Left or vertical slant	0.344
				Irregular letter size	0.336
				Stroke tenderness, rigidness	0.320
9	Irregular spaces between words			Weak punctuation pressure	0.341
				Unstable letter form	0.317
				Stroke tenderness, rigidness	0.308
11	Irregular line spaces			Reduced upper zone	0.434
12	Left or vertical slant			Irregular slant	0.378
				Stroke tenderness, rigidness	0.369
				Irregular letter spacing	0.344
13	Irregular slant	Letter form instability	0.391	Left or vertical slant	0.378
				Irregular letter size	0.364
				Left margin is uneven	0.311
15	Line form is not straight			Left margin is uneven	0.391
				Right margin is narrow	0.308
16	Left margin is wide	Left margin is uneven	0.326	Left margin is uneven	0.364
17	Left margin is uneven	Left margin is wide	0.326	Line form is not straight	0.391
				Left margin is wide	0.364
				Irregular slant	0.311
18	Right margin is narrow			Line form is not straight	0.308
19	Printed/school-like letter form	Slow speed	0.363	Slow speed	0.570
				Fullness	0.433
20	Distorted letter form	Unstable letter form	0.491	Reduced upper zone	0.321
21	Unstable letter form	Distorted letter form	0.491	Stroke tenderness, rigidness	0.690
		Irregular slant	0.391	Irregular letter width	0.449
		Poor stroke quality	0.314	Poor stroke quality	0.345
		Irregular letter size	0.313	Irregular spaces between words	0.317
23	Mixed letter form			Big letter size	0.316
24	Handwriting is disconnected			Slow speed	0.528
				Weak punctuation pressure	0.415
				Fullness	0.305
25	Fullness	Big letter size	0.323	Irregular/unrhythmic pressure	0.475
				Printed/school-like letter form	0.433
				Big letter size	0.427
				Slow speed	0.412
				Handwriting is disconnected	0.305
26	Weak pressure			Thin stroke building	0.425
				Weak punctuation pressure	0.322
27	Irregular/unrhythmic pressure	High-placed diacritic marks	0.320	Fullness	0.475
28	Slow speed	Printed/school-like letter form	0.363	Printed/school-like letter form	0.570
				Handwriting is disconnected	0.528
				Fullness	0.412

(*Continued*)

Table 4. (*Continued*)

No	Handwriting feature	Control group		CI/AD group	
				Weak punctuation pressure	0.322
				Big letter size	0.315
29	Stroke tenderness, rigidness	Narrow letter spacing	0.337	Unstable letter form	0.690
				Poor stroke quality	0.478
				Left or vertical slant	0.369
				Irregular letter spacing	0.320
				Irregular spaces between words	0.308
30	Poor stroke quality	Unstable letter form	0.314	Stroke tenderness, rigidness	0.478
				Unstable letter form	0.345
31	Thin stroke building			Weak diacritic pressure	0.461
				Weak pressure	0.425
33	High-placed diacritic marks	Irregular/unrhythmic pressure	0.320		
34	Weak diacritic pressure			Thin stroke building	0.461
35	Wide punctuation			Elongated comma form	0.332
36	Vertical offset of punctuation marks	Weak punctuation pressure	0.324		
37	Weak punctuation pressure	Vertical offset of punctuation marks	0.324	Handwriting is disconnected	0.415
				Irregular spaces between words	0.341
				Weak pressure	0.322
				Slow speed	0.322
				Big letter size	0.309
38	Elongated comma form			Punctuation marks are far from the preceding word	0.332

(feature 40) is a combination of weak pressure, slow speed, absence of end strokes, unfinished loops, and some other indications; domination of form over dynamics (feature 39) is typical with low speed, disconnected writing, printed or school letter form, etc.

However, despite these correlations and interdependencies, the data does not justify reducing the dimensionality of AD-HS by removing variables. Each feature provides distinct information that contributes to the overall analysis.

3.2. Analysis of handwriting changes (deterioration)

The changes in AD-HS handwriting features in the experimental group are shown in Table 5. Naturally, not all handwriting characteristics deteriorate as CI/AD progresses. However, each subject exhibited changes in multiple features. Let m_i represent the number of deteriorated handwriting features of the i-th subject. On average, 8–9 features (the mean value equals 8.5) were affected per participant, with a range from 3 features (subject 18) to 14 features (subjects 4 and 16) (Table 6).

To quantify these changes, we define the change index for each subject (r_i) as the ratio of deteriorated handwriting features (m_i) to the total number of AD-HS handwriting characteristics estimated from their most recent samples (k_i): $r_i = m_i/k_i$. Table 5 lists the subjects in descending order of r_i. As expected, m_i is strongly correlated with k_i, with a correlation coefficient of 0.64.

Not all handwriting features deteriorate at the same rate. Table 7 highlights the most frequently observed changes. The most dominant alterations relate to a decrease in writing drive – specifically, reduced pressure and slower speed, leading to a noticeable decline in handwriting dynamics. These changes were present in more than half of the participants. Additionally, features associated with an increasing lack of self-confidence were prominent. Many participants held their writing hand in the air for longer periods, resulting in more disconnected writing, irregular spacing between letters and words, and imprecise line beginnings and endings.

These handwriting changes may serve as early indicators of CI/AD onset, prompting further medical evaluation. While handwriting analysis alone cannot establish a strong correlation with cognitive status or dementia symptoms, standard diagnostic tools remain essential for confirmation and assessment.

Beyond clinical applications, AD-HS could be particularly valuable in forensic contexts –for example, when assessing a deceased individual's cognitive state, where conventional diagnostic tools are no longer applicable.

4. Discussion

The findings of this study, along with previous research on the AD-HS instrument, demonstrate its strong predictive power, enabling reliable screening for possible CI/AD. The instrument is based on a systematic analysis of handwriting, which is crucial given that the impact of CI on handwriting varies between individuals. Notably, the frequency of AD-HS features in the handwriting of individuals diagnosed with AD is significantly higher than in healthy individuals. Additionally, this study identifies the most common handwriting changes associated with the condition.

These results are encouraging, though a larger sample size is needed for more definitive conclusions. However, obtaining appropriate handwriting samples – particularly older samples – remains a challenge.

It is important to emphasize that handwriting changes reflect cognitive decline, but not necessarily dementia in general or AD specifically. While our subjects were diagnosed with AD, and thus AD-HS is framed as an Alzheimer's-related instrument, handwriting changes do not always directly correspond to the brain changes typical of Alzheimer's. Some individuals may experience cognitive decline without significant brain changes, while others with pronounced brain pathology may not exhibit noticeable cognitive symptoms due to cognitive reserve [7, 31]. In particular, such cases were reported in [32].

Therefore, AD-HS should not be viewed as a diagnostic tool. Instead, it serves as an indicator of potential cognitive issues,

Table 5. Handwriting features deterioration

		Subjects																				
No	Handwriting feature	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Increase of letter size	x	x		x	x		x	x		x	x	x	x								
2	Increase of size irregularity																				x	
3	Increase of width irregularity																				x	
4	Reduction of upper zone																					x
5	Increase of lower/upper zone ratio																					x
6	Decrease of letter spacing																			x		x
7	Increase of letter spacing irregularity																					
8	Increase of word space disproportionality		x		x			x							x							
9	Increase of word space irregularity																					
10	Increase of overlapping lines																					x
11	Increase of line space irregularity																					
12	More left and vertical slant		x	x							x	x				x	x	x	x			x
13	Increase of slant irregularity																					
14	Deterioration of line direction			x		x		x			x		x	x	x		x				x	
15	Deterioration of line form				x	x	x		x						x							
16	Left margin becomes wide	x	x		x					x				x		x	x					
17	Left margin becomes uneven	x			x							x				x		x	x			
18	Right margin becomes narrow	x			x							x			x							
19	Letter form becomes printed or school-like																	x			x	x
20	Distortion of letter form		x	x	x	x	x	x	x	x			x	x	x	x	x	x			x	x
21	Letter form becomes more unstable				x	x	x				x	x									x	
22	Oversimplified letter form	x	x		x	x	x					x					x					
23	Letter form becomes mixed																					
24	Handwriting becomes disconnected							x			x			x		x	x	x				x
25	Increase of fullness																					
26	Pressure becomes weaker	x	x	x	x		x	x	x	x	x	x	x			x	x	x		x		x
27	Pressure becomes irregular and unrhythmic																					
28	Handwriting becomes slower	x	x		x	x	x	x					x				x	x		x	x	x
29	Increase of stroke tenderness, rigidness			x	x	x	x		x		x	x					x			x	x	x
30	Deterioration of stroke quality		x	x	x	x			x			x					x		x		x	x
31	Stroke building becomes thin																	x			x	
32	More knots and covering strokes																					
33	More high-placed diacritic marks																					
34	Diacritic pressure becomes weaker	x			x				x	x												
35	Increase of interval punctuation mark interval				x				x	x								x				
36	Vertical offset of punctuation marks appears																					
37	Pressure in punctuation marks becomes weaker	x	x						x		x	x		x	x	x	x	x				
38	Comma form becomes elongated																					
39	Deterioration of orderliness			x		x	x		x								x					
40	Increase of general irregularity					x			x			x					x					
41	More domination of form over dynamics		x			x	x			x	x		x			x	x	x		x		x
42	Decrease of writing drive	x	x	x	x	x	x	x	x	x		x	x				x	x		x		x

offering valuable insights – especially for individuals who have not yet undergone medical assessment. As a quantitative tool, AD-HS can complement standard neurological tests and provide a useful method for evaluating treatment effectiveness over time.

Some AD-HS features may also appear in older individuals without visible cognitive decline [33]. However, due to limited data, we have yet to investigate this in depth. Given that AD is closely linked to aging, it is crucial to differentiate between age-related handwriting changes and those specifically associated with AD. Achieving this distinction will require a significantly larger sample size. As a preliminary step, we examined the correlation between ADI and age within our dataset. The correlation coefficient was approximately 0 (precisely 0.04), indicating no statistical relationship between age and ADI. In other words, age alone does not appear to influence ADI. However, further investigation is needed to confirm this finding.

It is also important to note that AD-HS validation studies tend to be conservative for several reasons. Firstly, data limitations in the experimental group: some handwriting features in the experiment group (e.g., margins, line direction, or line form) could not always be evaluated due to the nature of the available samples. Not all the texts were written on blank A4 paper; some were from lined notebooks, making it difficult to assess these characteristics. In such cases, these features were marked as not presented, which artificially lowering the ADI for these participants. Second, generally the quality of the samples in the control group was generally higher: the samples were carefully selected from the database and typically are of better quality. As a result, all AD-HS features could usually be assessed, unlike in the experimental group. Third, uncertainty about the cognitive status in the control group: the control group was assumed to represent the normal population. However, some participants may have had

Table 6. Handwriting deterioration in subjects

Subject	k	ADI	m	r
1	17	0.40	10	0.59
4	25	0.58	14	0.56
6	25	0.58	14	0.56
21	22	0.51	12	0.55
2	26	0.60	11	0.42
7	17	0.40	7	0.41
6	20	0.47	8	0.40
17	28	0.65	11	0.39
8	29	0.67	11	0.38
9	16	0.37	6	0.38
5	28	0.65	10	0.36
12	17	0.40	6	0.35
15	20	0.47	7	0.35
11	32	0.74	11	0.34
18	9	0.21	3	0.33
10	23	0.53	7	0.30
13	17	0.40	5	0.29
19	21	0.49	6	0.29
20	25	0.58	7	0.28
14	19	0.44	5	0.26
3	28	0.65	6	0.21

Table 7. Deterioration of handwriting characteristics

Handwriting change	Percent of subjects
Pressure becomes weaker	76
Writing drive becomes weaker	71
Handwriting becomes slower	57
Form stronger dominates over dynamics	52
Increasing letter size	48
Stroke quality deteriorates	48
Weaker pressure in punctuation marks	48
Reducing the letter slant	43
Line direction deteriorates (lines become less horizontal)	43
Left margin becomes wider	33
Letter form simplifies	33
Writing becomes disconnected	33
Left margin becomes uneven	29
Line form becomes not straight, wavy	24
More carelessness and corrections	24
Intervals between words become more disproportional	19
Right margin becomes narrower	19
Weaker pressure in diacritic marks	19
Punctuation marks are placed far from the preceding word	19
Stronger general irregularity	19
Letter form changes to printed or school	14
Interval between letters becomes smaller	10
Strokes become thin	10

undiagnosed CI, as this information was not available. If such cases existed, they could have artificially increased the average ADI in the control group. Despite these potential limitations, the difference between the experimental and control groups remains statistically significant, reinforcing the robustness of our findings.

While the statistical results from handwriting analysis for CI/AD are promising, it is crucial to consider context when making an assessment. A high ADI in an elderly individual may suggest CI, and we can be relatively confident in this interpretation. However, we have encountered cases where young individuals also exhibited high ADIs, but the underlying reason for their handwriting style was unrelated to cognitive decline. These were primarily artists with a strong artistic expression in their writing. Thus, additional contextual information about the individual is often essential to draw accurate conclusions in each case.

The final point to be discussed here is the introduction of weights for AD-HS variables. Currently, all characteristics are assigned equal weight, specifically 1/N (0.022). In general, using uniform weights is reasonable when the number of variables is high. However, since the frequency of occurrence varies among characteristics, introducing differential weighting could be beneficial. Two logical assumptions can be considered. First, handwriting features that appear more frequently in individuals with CI/AD may be more indicative of CI and should carry greater weight. Second, handwriting features that are common in the control group are likely part of normal handwriting variability and should be assigned lower weight, as they are less diagnostically relevant. Alternatively, a different weighting logic may prove more effective. Further investigation is necessary to determine the most appropriate approach.

5. Conclusion

The results presented, along with practical experience using AD-HS, underscore the potential of handwriting analysis in detecting early signs of cognitive decline. Based on the normalized data, the control group exhibited a mean ADI value of 0.28 with a standard deviation of 0.09. Accordingly, the threshold for identifying cognitive decline can be set at 0.37 with 90% confidence and at 0.46 with 95% confidence. ADI values exceeding these thresholds may indicate CI, providing a clear and quantifiable criterion.

However, the most reliable indication remains the analysis of specific handwriting changes over time. The most frequently observed alterations include reduced writing pressure, decreased writing speed and corresponding overall drive, increased letter size, a more vertical slant, and deterioration in stroke quality, etc., (Table 7).

These findings are particularly relevant in clinical diagnostics, where early detection enables timely intervention, and in forensic contexts, where handwriting changes may serve as critical evidence. This study emphasizes the importance of systematic handwriting analysis – an evaluation of multiple dimensions of writing – as a reasonably reliable, non-invasive, and accessible method for identifying cognitive decline.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Yury Chernov: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

References

[1] Caligiuri, M. P., & Mohammed, L. A. (2012). *The neuroscience of handwriting: Applications for forensic document examination*. CRC Press.

[2] Georgakas, J. E., Howe, M. D., Thompson, L. I., Riera, N. M., & Riddle, M. C. (2023). Biomarkers of Alzheimer's disease: Past, present and future clinical use. *Biomarkers in Neuropsychiatry*, *8*, 100063. https://doi.org/10.1016/j.bionps.2023.100063

[3] Khan, T. K. (2016). *Biomarkers in Alzheimer's disease*. Elsevier Academic Press.

[4] Khoury, R., & Ghossoub, E. (2019). Diagnostic biomarkers of Alzheimer's disease: A state-of-the art review. *Biomarkers in Neuropsychiatry*, *1*, 1–7. https://doi.org/10.1016/j.bionps.2019.100005

[5] Ding, Z., Lee, T.-L., & Chan, A. S. (2022). Digital cognitive biomarker for mild cognitive impairments and dementia: A systematic review. *Journal for Clinical Medicine*, *11*, 4191. https://doi.org/10.3390/jcm11144191

[6] Croislie, B. (1999). Agraphia in Alzheimer's disease. *Dementia and Geriatric Cognitive Disorders*, *10*, 226–230. https://doi.org/10.1159/000017124

[7] Vockert, N., Machts, J., Kleineidam, L., Nemali, A., Incesoy, E. I., Bernal, J., . . . , & Delcode Study Group. (2024). Cognitive reserve against Alzheimer's pathology is linked to brain activity during memory formation. *Nature Communications*, *15*, 9815. https://doi.org/10.1038/s41467-024-53360-9

[8] Shulman, K. I. (2000). Clock-drawing: Is it the ideal cognitive screening test? *International Journal of Geriatric Psychiatry*, *15*(6), 548–561. https://doi.org/548-561.10.1002/1099-1166(200006)15:6<548::aid-gps242>3.0.co;2-u

[9] Mendez, M. F. (2021). *The mental status examination handbook*. Elsevier.

[10] Arevalo-Rodriguez, I., Smailagic, N., Roqué-Figuls, M., Ciapponi, A., Sanchez-Perez, E., Giannakou, A., . . . , & Cullum, S. (2021). Mini-Mental State Examination (MMSE) for the early detection of dementia in with mild cognitive impairment (MCI). *Cochrane Database of Systematic Reviews*, *7*(7), CD010783. https://doi.org/10.1002/14651858.CD010783.pub3

[11] Davis, D. H., Creavin, S. T., Yip, J. L., Noel-Storr, A. H., Brayne, C., & Cullum, S. (2021). Montreal cognitive assessment for the detection of dementia. *Cochrane Database of Systematic Reviews*, *7*(7), CD010775. https://doi.org/10.1002/14651858.CD010775.pub3

[12] de Boer, L., Poos, J. M., Van Den Berg, E., De Houwer, J. F. H., Swartenbroekx, T., Dopper, E. G. P., . . . , & Jiskoot, L. C. (2025). Montreal cognitive assessment vs the mini-mental state examination as a screening tool for patients with genetic frontotemporal dementia. *Neurology*, *104*(5), e213401. https://doi.org/10.1212/WNL.0000000000213401

[13] Fernandes, C. P., Montalvo, G., Caligiuri, M., Pertsinakis, M., & Guimarais, J. (2023). Handwriting changes in Alzheimer's disease: A systematic review. *Journal of Alzheimer's Disease*, *96*(1), 1–11. https://doi.org/10.3233/JAD-230438

[14] Petti, U., Baker, S., & Korhonen, A. (2020). A systematic literature review of automatic Alzheimer's disease detection from speech and language. *Journal of the American Medical Informatics Association*, *27*(11), 1784–1797. https://doi.org/10.1093/jamia/ocaa174

[15] Chernov, Y. G. (2021). *Computer methods of handwriting analysis [Компьютерные методы анализа почерка]*. IHS Books.

[16] Cilia, N. D., De Gregorio, G., De Stefano, C., Fontanella, F., Marcelli, A., & Parziale, A. (2022). Diagnosing Alzheimer's disease from on-line handwriting: A novel dataset and performance benchmarking. *Engineering Applications of Artificial Intelligence*, *111*, 104822. https://doi.org/10.1016/j.engappai.2022.104822

[17] Delazer, M., Zamarian, L., & Djamshidian, A. (2021). Handwriting in Alzheimer's disease. *Journal of Alzheimer's Disease*, *82*, 727–735. https://doi.org/10.3233/JAD-210279

[18] Qi, H., Zhang, R., Wei, Z., Zhang, C., Wang, L., Lang, Q., . . . , & Tian, X. (2023). A study of auxiliary screening for Alzheimer's disease based on handwriting characteristics. *Frontiers in Aging Neuroscience*, *15*, 1117250. https://doi.org/10.3389/fnagi.2023.1117250

[19] Van Gallen, G. P. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science*, *10*, 165–191. https://doi.org/10.1016/0167-9457(91)90003-G

[20] Caligiuri, M. P., & Mohammed, L. A. (2020). Signature dynamics in Alzheimer's disease. *Forensic Science International*, *302*, 109880. https://doi.org/10.1016/j.forsciint.2019.109880

[21] Preti, A. N., Diana, L., Castaldo, R., Pischedda, F., Difonzo, T., Fumagalli, G., . . . , & Bolognini, N. (2023). Does cognitive decline influence signing? *Aging Clinical and Experimental Research*, *35*, 2685–2691. https://doi.org/10.1007/s40520–023–02523-7

[22] Behrendt, J. E. (1984). Alzheimer's disease and its effect on handwriting. *Journal of Forensic Sciences*, *29*(1), 87–91. https://doi.org/10.1520/JFS11638J

[23] Nardone, E., De Stefano, C., Cilia, N. D., & Fontanella, F. (2025). Handwriting strokes as biomarkers for Alzheimer's disease prediction: A novel machine learning approach. *Computers in Biology and Medicine*, *190*, 110039. https://doi.org/10.1016/j.compbiomed.2025.110039

[24] Vessio, G. (2019). Dynamic handwriting analysis for neurodegenerative disease assessment: A literary review. *Applied Sciences*, *9*(21), 4660. https://doi.org/10.3390/app9214666

[25] Ho, N. T. N., Gonzalez, P., & Gogovi, G. K. (2025). Writing the signs: An explainable machine learning approach for Alzheimer's disease classification from handwriting. *Healthcare Technology Letters*, *12*, e70006. https://doi.org/10.1049/htl2.70006

[26] Balestrino, M., Fontanella, F., Terzuoli, S., Volpe, S., Inglese, M. L., & Cocito, L. (2012). Altered handwriting suggests cognitive impairment and may be relevant to posthumous evaluation. *Journal of Forensic Sciences*, *57*(5), 1252–1258. https://doi.org/10.1111/j.1556–4029.2012.02131.x

[27] Balestrino, M., Brugnolo, A., Girtler, N., Pardini, M., Rizzetto, C., Alì, P. A., . . . , & Schiavetti, I. (2024). Cognitive impairment assessment through handwriting (COGITAT) score: A novel tool that predicts cognitive state from handwriting for forensic and clinical applications. *Frontiers in Psychology*, *15*, 1275315. https://doi.org/10.3389/fpsyg.2024.1275315

[28] Chernov, Y. (2023). Handwriting markers for the onset of Alzheimer's disease. *Current Alzheimer Research*, *20*(11), 791–801. https://doi.org/10.2174/0115672050299338240222051023

[29] Chernov, Y. G., & Zholdasova, Z. A. (2022). Markers of Alzheimer's disease in handwriting. *Russian Neurological*

Journal, *26*(6), 16–28. https://doi.org/10.30629/2658-7947-2021-26-6-16-28
[30] Taylor, J. (1997). *Introduction to error analysis, the study of uncertainties in physical measurements*.
[31] Gamble, L. D., Clare, L., Opdebeeck, C., Martyr, A., Jones, R. W., Rusted, J. M, . . . , & Matthews, F. E. (2025). Cognitive reserve and its impact on cognitive and functional abilities, physical activity and quality of life following a diagnosis of dementia: Longitudinal findings from the improving the experience of dementia and enhancing active life (IDEAL) study. *Age Ageing*, *54*(1), afae284. https://doi.org/10.1093/ageing/afae284
[32] Snowdon, D. (2002). *Aging with grace: What the nun study teaches us about leading longer, healthier, and more meaningful lives*. Bantam.
[33] Asci, F., Scardapane, S., Zampogna, A., D'Onofrio, V., Testa, L., Patera, M., . . . , & Suppa, A. (2022). Handwriting declines with human aging: A machine learning study. *Front Aging Neuroscience*, *14*, 889930. https://doi.org/10.3389/fnagi.2022.889930

How to Cite: Chernov, Y. (2025). Formalized Assessment of Handwriting Deterioration Caused by Dementia. *Medinformatics*. https://doi.org/10.47852/bonviewMEDIN52025601