RESEARCH PAPER

Introducing Handwriting Assessment to Multiple Sclerosis

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ABSTRACT

Patients with Multiple Sclerosis (MS) suffer from various disabilities concurrently affecting their daily functions. One of these disabilities is upper extremity dysfunction and dexterity deficits. Handwriting was long considered an essential upper limb daily function for diverse purposes. A sufficient reason for being heavily studied with all its physiological central, and peripheral processes from conception to execution. The scientific craving has extended beyond to include studying the essential skills needed for handwriting acquisition. In view of that, immense research was carried out to rationalize and validate the use of handwriting as an assessment method. The present advancements in handwriting evaluation have broadened the focus from simply describing the writing or drawing style to detailed spatiotemporal and kinematic parameters of these tasks. Consequently, the outcomes of these latest parameters quantify handwriting legibility, readability, and fluency. Currently, handwriting assessment is involved as an objective upper extremity functional assessment, especially in some cognitive and neurodegenerative disorders, e.g., Parkinson's Disease and Alzheimer's Disease. Currently, its role is not exclusive to supporting diagnosis or follow-up, but it is involved in the evaluation of the efficacy of some interventions on the upper extremity of different patients. However, researches concern with MS patients that incorporate handwriting assessment seems to be scanty, especially with the creative innovations applied in this domain, such as various software on digitizing tablets and artificial intelligence. The authors of this review aim to discuss, highlight, and ease this method for medical and healthcare professionals. Definitely, they recommend the widened practice of handwriting assessment software or artificial intelligence applications as objective, up-to-date measures for the functional level of hand dexterity, as well as the upper extremity.

Keywords: Multiple Sclerosis, Dexterity, Upper limb Function, Motor Control, Handwriting Assessment

How to cite this article: Hassanin MA, Ahmed GM, Elkholy SH, Atteya AAAF, Mohamed AMF. Introducing Handwriting Assessment to Multiple Sclerosis. Int J Drug Deliv Technol. 2026;16(58s): 1581-1588. DOI: 10.25258/ijddt.16.58s.168

Source of support: None

Conflict of interest: None

INTRODUCTION

Multiple Sclerosis (MS) is a chronic autoimmune disease that primarily affects the myelinated nerves of the central nervous system, leading to various psychological, sensorimotor, and autonomic deficits (Tafti et al., 2024). Hand dexterity has been proven to be affected by the demyelination process of the disease and is linked to disability and functional levels among people living with MS (Yozbatiran et al., 2006; Ytterberg et al., 2008; Holper et al., 2010; Lamers et al., 2013). Impairments underlying hand abnormal dexterity are numerous and include sensory impairments, power deficits in proximal or grip muscles, and tremors (Pittock et al., 2004; Guclu-Gunduz et al., 2012; Lamers et al., 2013). Handwriting represents one of the most important intellectual functions, and its analysis has been used to identify deficits in hand dexterity for people living with MS (Wellingham-Jones, 1991; Alusi et al., 2000). In response to this fact, the researchers' focus on analyzing handwriting has shifted over time from subjective gradings to objective machinery measures in this context (Fırat et al., 2025; Yang et al., 2025).

Motor Control for Handwriting acquisition and development

Handwriting is an elaborate blend of cognitive, kinesthetic, and perceptual-motor components that involves multiple brain areas. Handwriting disorders such as micrographia, agraphia (pure motor, apraxic, central, spatial, and mixed types), writing arrests or perseverations, letter substitutions were the findings associated with vascular insults or tumor excisions in numerous brain lesion studies (Linton A. Mohammed & Michael P. Caligiuri, 2012).

Moreover, several functional magnetic resonance imaging studies correlated their findings with the handwriting abnormalities. The following brain areas were emphasized: left-sided supplementary motor area, primary motor and sensory areas, middle and inferior frontal gyrus, superior parietal lobe, supramarginal gyrus, insula, thalamus, and basal ganglia (Wing, 2000; Scarone et al., 2009).

Meanwhile, the right posterior cerebellar hemisphere was assumed to play an important role in the early stage of motor acquisition and retention, as well as error correction (Planton et al., 2017). Besides, the left fusiform gyrus was found to be consistently activated in spelling tasks, suggesting its role in the orthographic long-term memory (Planton et al., 2013).

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Handwriting acquisition is a process that spans over years while the brain is developing. The early stage of handwriting learning is mainly mediated by the cortico–cerebellar network, during which slow, imprecise movements are dependent on sensory feedback (especially visual feedback); however, performance progresses rapidly. In contrast, the late stage, mediated by posterior brain areas, is recognized by faster, more accurate movements with less feedback, indicating long-term memorization and automaticity with decreased executive and attention control (Palmis et al., 2017).

In general, the written word production is guided by a system that consists of central and peripheral processes. The central processes of written words include phonological processing for novel words, visual object processing, the semantic system integration, and orthographic long-term memory for memorized words or phoneme-grapheme (sound-to-letter) conversion for new words. While the allographic (letter form) conversion (that is used to select a font or style of handwriting) or graphic motor planning (that converts letters into hand or finger movements) are considered as peripheral processes of writing (Breining & Rapp, 2019) (Purcell et al., 2011).

Skill Integration for Handwriting

Handwriting requires cognitive skills like attention, planning, working memory, phonological and orthographic coding (spelling) for sentence construction, and text elaboration. Moreover, spatial skills (like visual-spatial relationship analysis and memory, spatial organization, and imagery) are essential prerequisites for intact handwriting (Lu et al., 2024).

Visual inputs play a critical role in writing as sensory inputs to initiate the whole process. Besides, research found that their waning or absence increases writing reaction time (delayed initiation) and spatial trajectories, regardless of the number of replications. This highlights the increase in processing load (time taken to perceive the way to do something) before writing (Van Doorn & Keuss, 1992).

Some perceptual-motor skills are incorporated in handwriting, for example, visual recall of a sequence of stimuli (letters, shapes, symbols) in the correct order (visual sequential memory), recognition of a complete figure when only fragments are present, which is called visual closure (Brown et al., 2003). Also, visual-motor integration perception (i.e., VMI) – a key graphomotor skill – is also required to coordinate visual perceptual skills with fine motor movements (Kaiser et al., 2009) (Abou-El-Saad et al., 2017).

Furthermore, peripherally handwriting is accomplished by the coordinated performance of different effectors (most commonly those of preferred-to-use fingers, wrist, and arm) and controlled by nerves in chief, which is witnessed as motor skills (e.g., finger-hand movements, fine-motor control, upper limb coordination, unimanual dexterity) (Lu et al., 2024). In-hand manipulation controls the adequate writing tool grip, and its pattern monitors handwriting ease to a greater extent (Guven & Atasavun Uysal, 2022) .

The principle of motor equivalence is quite representative of handwriting, in which the outcome remains the same irrespective of effectors, joints, or patterns. This means that whether one writes by dominant hand, non-dominant hand, or toes, the brain activation pattern is standardized (Wing, 2000). Last of all, proprioception is important for the adjustment of pressure applied to the writing tool, writing within boundaries, and letter directional tuning (Feder & Majnemer, 2007).

Handwriting Evaluation

Models used for handwriting evaluation can be classified into computational and cognitive. Computational models assess the final result of the handwriting movements, in terms of velocity, acceleration profiles or stroke shapes, by means of various sciences, based on kinematic theory to reproduce the full velocity pattern of handwriting (Carmona-Duarte et al., 2017), or geometry-based elliptical forms for various analysis models (Bezine et al., 2004), or oscillatory models of hand-pen systems that produce simulated oscillations to that of handwriting (Gangadhar et al., 2007).

Cognitive models attempt to exhibit the generative processes of cognitive or motor acts such as learning, movement memory, planning, and sequencing. Some researchers focused on cortico–cerebellar interactions for imitation and predictive learning. Meanwhile, others developed basal ganglia neural network models based on anatomical and clinical data for Parkinson's Disease. Further studies embrace the concept of learning in parallel by an interaction between both or by combining the two systems (De Stefano et al., 2019).

Tasks of handwriting analysis were continuously upgraded over the decades, seeking more objectivity within different eras. These tasks include mainly the creation of standardized shapes and handwriting analysis.

a) Creation of standardized shapes, then evaluating some observed features, e.g., neglected letters, decreased size, line adherence, and tremors. Shapes like spirals and circles involve most upper extremity joints during drawing or tracing, making them useful for characterizing tremors that distort the controlled coordination of these joints. It can also indicate some neurological disorders, e.g., Parkinson's disease, as well as ataxia (Bain et al., 1993).

b) Handwriting analysis to study the forms of letters (allographs) and words (Schiegg & Thorpe, 2017). The study of the forms of letters and words has been enhanced to include not only naked eye observation but also microscopic examination (Ali Mwaheb et al., 2022) Recently, artificial intelligence and many software applications on digitized tablets were developed to facilitate the analysis of these tasks for different purposes (Mergl et al., 1999; Fırat et al., 2025). Some, like the Handwriting Analysis Tool (HAT), compare different handwriting styles for the same language (Mohammed et al., 2017). Others, such as MovAlyzer, are evaluating the features of writing, such as pen pressure, jerks, and stroke speed, with the advantage of the possibility of training (Harralson et al., 2007).

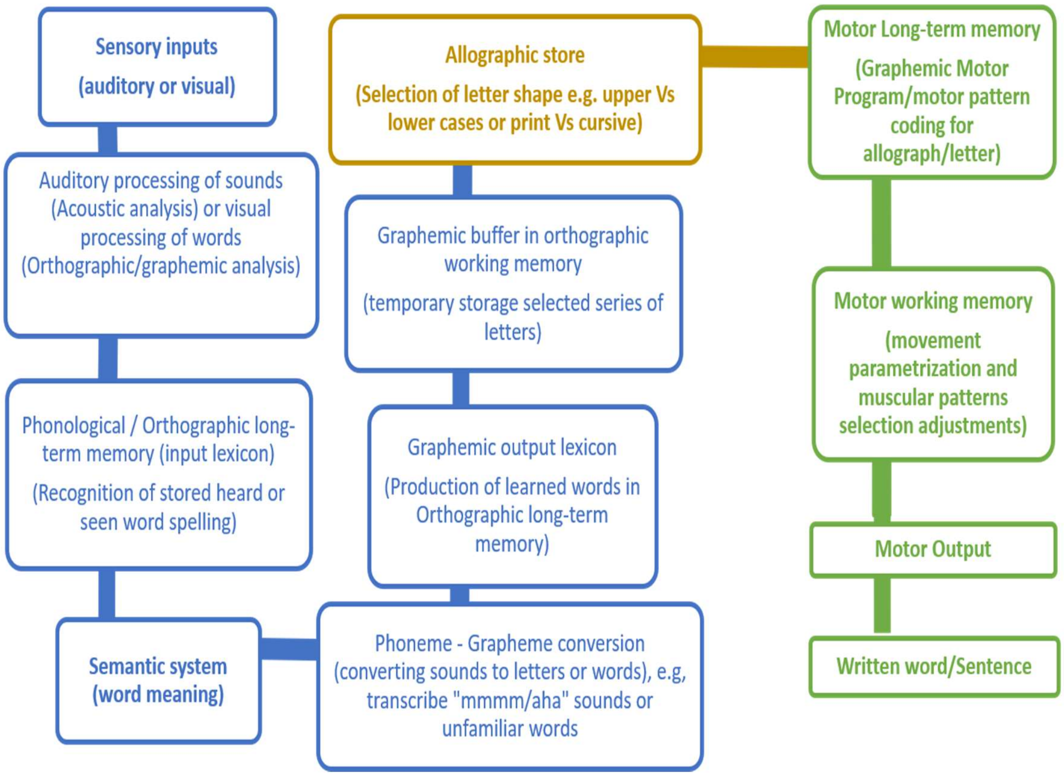

Figure 1 The flow diagram shows the stages of writing a word adopted from literature. Stages in rounded rectangles are of cognitive-level, those in dashed rectangles are cognitive-motor interface, and those in ovals are motor-level stages. At First, auditory inputs for hearing sounds or visual inputs for reading are analyzed. Next, the analyzed data are recognized in the input lexicon and understood in the semantic system. Then, the heard sounds are converted to letters. Afterwards, stored words or letters are matched, and their sequencing is temporarily stored during writing. Subsequently, choosing the desired letter shapes is followed by converting the word or serial letters of definite shapes into the corresponding motor code. Therefore, this motor code or pattern is tuned to the desired writing parameters. Lastly, the muscles execute writing of letters or words.

Handwriting performance measures

Handwriting legibility and Fluency were studied to identify factors affecting each. The clear writing or the quality of writing to be easy to read is defined as legibility, a description that is more reflective of the spatial characteristics of the script layout, and constitutes one of the evaluation points of text readability (Dragan et al., 2013) (Lu et al., 2024).To identify text legibility, analysis of visual features of handwriting is carried out, including size, slant, alignment, letter form (accuracy), size, and spacing (Babushkin et al., 2025).

Furthermore, fluency is the ability to write a legible text rapidly and smoothly. Therefore, it reflects handwriting proficiency, which depends on handwriting temporal characteristics that include determining the speed of handwriting (the number of written letters per unit time), pen pressure, or by counting pauses or detecting rhythm (Downing & Caravolas, 2023).

However, handwriting analysis has progressed to be more thorough, incorporating additional kinematic and spatiotemporal measures. In accordance, the authors tried, in the sake of interest satisfaction as well as topic documentation, to collect some of the measures of legibility or fluency in Table 1 that were reported in recent studies (Thomas et al., 2017; Caligiuri et al., 2018; Vessio, 2019).

Table 1. shows some of the reported dynamic parameters of handwriting (Thomas et al., 2017; Caligiuri et al., 2018; Vessio, 2019)

Parameter	**Definition of term**
Stroke	Single trait of the connected and continuous handwritten pattern between two consecutive pen-lifts.

Stroke Duration	The time difference between the beginning and the end.
Slant	The angle or tilt of letters relative to the perpendicular or to the baseline of the writing (in radians).
Straightness Error	A dimensionless spatial accuracy measure defined as the RMS deviation of a stroke trajectory from its best-fit straight line, normalized by stroke length; it quantifies trajectory deviation independently of stroke orientation. 0 = perfectly straight stroke.
Pen Down Duration	The ratio of time during which the pen is in contact with the writing surface to the total task duration, yielding a dimensionless value between 0 (no contacts) and 1 (never lifts).
Loop surface	The non-normalized area (cm^2) enclosed by the intersection of a stroke with its immediately preceding stroke; if no such intersection occurs, the loop surface is defined as zero.
Displacement	The straight-line distance between two consecutive sampled points.
Velocity	The rate of change of position with time.
Acceleration	The rate of change of velocity with time.
Absolute velocity and absolute acceleration	The velocities and accelerations of both horizontal and vertical directions are considered.
Jerk	The third derivative of position with respect to time can be calculated for all 3 axes. It can be a measure of fluency or a kinematic feature.
Absolute size	The straight distance from beginning to end.
Number of peak velocity or acceleration points or number of inversions in velocity (NIV) and acceleration (NIA).	The number of reaching maximum velocity during a stroke then decays to a local minimum. The ideal number of maxima for a single upstroke is 1, and the greater the number of extrema, the more dysfluent the writing.
Submovement analysis	A technique for studying fluency, first described in MovAlyzeR, breaks down each stroke into 3 segments: the primary, secondary submovements and total stroke.
Primary submovement	Initial ballistic segment of feedforward control from stroke onset to the second zero-crossing of the acceleration profile after peak velocity. All movements have a primary submovement.
Secondary submovement	The corrective segment of a stroke that is under feedback control, which begins at the end of the primary submovement and ends at movement offset.
Total stroke	The sum of the primary and secondary submovements.
Ratio of deceleration phase RDP	It is the percentage ratio of the difference between total movement duration and duration till peak velocity of the movement to the total movement duration. The greater the ratio above 50%, the less efficient the movement control.
Pen pressure	Force applied to the writing surface (related but sometimes considered separately).

Handwriting in the diagnosis of different neuropsychiatric disorders

Although the exact start of using handwriting as a diagnostic or supportive tool is vague, it is suggestive that Emil Kraepelin, the psychiatrist, in the 19th century, used patients' writings in the diagnosis of their conditions by analyzing form and content with an associated scale for examining the progression of certain psychiatric diseases. However, neurologists have not used handwriting in isolation as a diagnostic tool historically, but they have linked handwriting abnormalities of historically well-known patients with their disease reports. Perhaps the perplexing coexistence of diseases, varied writing styles, environmental conditions, and writing technologies can affect handwriting-based diagnosis (Schiegg & Thorpe, 2017).

Handwriting Deficits Associated with Multiple Sclerosis

Clinical characteristics of Multiple Sclerosis (MS) include changes in hand sensation, muscle weakness or spasms, leading to manual dexterity malfunction even among patients with low-scoring MS severity scales. Manual dexterity deficits are quite common, that 75% patients with MS manifesting them on examination (Johansson et al., 2007).

Tremors are relatively common in MS. Possible exhibited forms of tremors are postural tremors that are present when maintaining a position against gravity voluntarily or slow, intentional tremors of high amplitude similar to those associated with cerebellar disease that are most noticeable in the hands and worsen at the end of an intended movement. They can affect handwriting, especially with increased writing time (Koch et al., 2007).

For handwriting assessment in Multiple Sclerosis, various traditional methods were used. One of them was an adjustable analysis of Roman-Staempfli graphomotor psychogram that was used in a study by Willingham-Johns, in which decrements of measures of legibility and fluency manifested among patients with MS (8).

Compared to healthy subjects, MS patients were found to have handwriting kinematic deficits among different tasks, including drawing spirals or writing sentences. For example, lower values were recorded for speed, pressure, and accuracy at higher speeds on drawing a spiral. In contrast, more movement time was needed to increase the spiral, i.e. closed-loop strategy is more required to be recruited (Longstaff & Heath, 2006). For writing sentences, deficits are shown as an increase in word spacing, word duration, stroke duration, vertical size, normalized jerk, and number of peak velocity points (Bisio et al., 2017).

Lately, the rise of handwriting evaluation among patients with MS has reached another dimension in evaluating the effects of certain interventions on hand functions. For example, the tremors observed during spiral drawing were involved as one of the measures of the effect of cannabis on manual dexterity among multiple sclerosis patients (Fox et al., 2004). Another example was recruiting the stroke duration of the writing task to study the effect of a certain medication (Fampridine-PR) on manual function (Savin et al., 2016)

CONCLUSION

Handwriting assessment using traditional methods, as well as digitized tablets, was widely used as an objective tool for the examination of manual dexterity among several studies of neuropsychiatric and neurodegenerative diseases, e.g., Parkinson's Disease. However, studies concerned with Multiple Sclerosis are fewer compared to these neurodegenerative diseases, especially those that study the effects of a specific intervention, whether it is a rehabilitative one or other types of procedures. The authors of this review expect a greater recruitment of handwriting measures in prospective studies after being highlighted in this review, in association with the advances of artificial intelligence in this prospect.

ADDITIONAL INFORMATION

Competing Interests: The authors declare that they have no conflicts of interest.

Credit authorship contribution statement

Mohamed Ahmed Hassanin: Content collection and Writing – original draft. Gehan M. Ahmed: Content curation, and Supervision. Saly Hassan Elkholy: Investigation and Supervision. Abd El Alim Atia: Supervision, Writing–review & editing. Amr Mohamed Fouad Mohamed: Supervision, and Writing – review & editing.

Funding: No financial support for authorship and/or publication of this article.

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