

Towards a Digitized Protocol based on Handwriting for the Assessment of Neurodegenerative Disorders

Donato Impedovo¹, Giuseppe Pirlo¹, Maria Teresa Angelillo² and Gennaro Vessio¹

¹ Department of Informatics, University of Bari, Bari, Italy

² I.R.C.C.S. Maugeri, Cassano delle Murge, Italy

{donato.impedovo, giuseppe.pirlo, gennaro.vessio}@uniba.it,
mtangelillo@gmail.com

Abstract. Kinematic features of the handwriting process are promising for discriminating patients probably affected by neurodegenerative disorders from healthy controls and potentially for identifying the stage of the illness. Many tasks have been proposed and tested, however the scientific community still lacks a complete protocol able to collect different traits useful to the research community and at the same time to be of real use for doctors in their daily activities. This paper collects all the different tasks already applied and proposes a protocol for handwritten traits acquisition to be integrated into standardized cognitive and functional tests already accepted, tested and used by the medical community working on the assessment of neurodegenerative diseases.

Keywords: Neurodegenerative disorders, Handwriting, Acquisition protocol.

1 Introduction

Neurodegenerative disorders, such as Alzheimer's disease (AD) [1] and Parkinson's disease (PD) [2], affect the structure and functions of brain regions resulting in a progressive cognitive, functional and behavioral decline. In this context, the assessment of signs and manifestations of the disease is crucial for at least three main reasons:

1. The early diagnosis of the disease;
2. Monitoring and tracking of its progression;
3. The diagnostic differentiation of the disease with respect to similar disorders.

Recently, a growing research interest has arisen towards the possibility to automatically discriminate between impaired subjects and healthy controls on the basis of kinematic features obtained through simple and easy-to-perform handwriting tasks, e.g. [3–5]. Handwriting, in fact, is a complex activity entailing cognitive, kinesthetic and perceptual-motor components [6], whose changes seem to be a prominent biomarker for the assessment of some neurodegenerative diseases.

However, although encouraging results have been obtained, there are several open issues that demand further research [7]. Among the others, one problem is connected

to the possibility of collecting a big amount of samples involving a statistically significant number of patients. Current available datasets, e.g. [4], are typically composed by very few subjects. Another problem deals with the acquisition tool and protocol, since data are typically obtained from different devices and different handwriting tasks. The number and periodicity of sessions should be also taken into account in order to understand the evolution of the illness over time. The final aim is the development of a Computer Aided Diagnosis (CAD) system, similarly to those already available in other fields [8, 9].

To address these issues, the present paper aims to propose a suitable protocol for handwriting data acquisition. It is important to note that, since a handwriting-based decision support system is not expected to replace standard techniques, but to strengthen them by providing precise and quantitative measurements, the proposal here presented is designed to integrate standardized cognitive and functional tests (already accepted, tested and used by the medical community). To this end, the protocol focuses on:

- Handwriting tasks for the extraction of kinematic features;
- Standard routine tests that are suitable to be carried out in a digitized way.

The rest of the paper is structured as follows. Section 2 concerns a literary review that focuses on the most employed handwriting tasks for clinical assessment. Section 3 advances our proposal which takes into account both standard and handwriting tasks. Section 4 concludes the paper and sketches future developments of our research.

2 Literary Review

Among the various methodological approaches, those related to Alzheimer’s disease and Parkinson’s disease have been considered: being the two most widespread neurodegenerative disorders, they have been the most widely investigated by researchers.

As mentioned above, writing is a skill that involves a complex feedback system and implicates the participation of several cognitive processes. For this reason, most of the works in literature focus on tasks such as the Archimedes spiral, single letters or simple words/sentences writing in order to investigate purely motor aspects of handwriting. These tasks have been extensively used in studies based on static features of handwriting and significant differences between impaired subjects and healthy controls, based on these features, have been revealed [10, 11].

Similar findings have also been reported in papers focusing on the kinematic features of the handwriting process. The Archimedes spiral is probably the most popular handwriting exercise. Spiral, as well as circle drawing, in fact, have been frequently used for the evaluation of the motor performance in various movement disorders, including AD and PD, e.g. [12, 13, 4]. The works of Pullman [14], in particular, pioneered the application of spiral analysis to the measurement of tremor.

Words containing one or more repetitions of the cursive letters “*l*” and “*e*” are the second-most common exercises in handwriting assessment, e.g. [15–18]. This because such letters are easy to write in a recursive and continuous way; moreover, their use minimizes the linguistic-comprehension processes.

In addition to these tasks, writing simple words and short sentences have also been widely adopted, e.g. [19, 20]. Typically, the words/sentences used in these tasks are chosen on the basis of their simple orthography and easy syntax.

In [21] and [22], the authors asked the participants of the studies to perform functional writing tasks, such as copying the details of a bank check into the appropriate places and copying an address. These tasks are particularly indicated for the analysis of AD, as this disease is primarily characterized by cognitive deficits. Note that, in [22], participants are asked to write their name as additional task.

Finally, in [3] the authors suggest considering also handwritten signature, as a signature conveys several information about the signer [23].

3 Protocol Proposal

The goal of this paper is to propose a digitized protocol for the early assessment of neurodegenerative disorders, including handwriting tasks for a subsequent extraction and analysis of kinematic features of the handwriting process. The protocol is made up of three parts: an initial screening; a battery of a digitized version of standard cognitive and functional tests; finally, some of the most relevant handwriting tasks already reported in the literature. The first two parts mostly require the examiner to provide a data entry; the last one requires the patient to perform the tasks. An overall model of the protocol is depicted in Fig. 1.

It is worth noting that the proposal is conceived to be deployed on inexpensive and commercially available digitizing tablets. Typically, these tablets are able to capture not only temporal and spatial variables of handwriting, but also the pressure exerted over the writing surface, the azimuth, i.e. the angle of the pen in the horizontal plane, the altitude, i.e. the angle of the pen with respect to the vertical axis, and so on. Moreover, these devices can capture pen movement not only while the pen is on the writing surface, but also when the pen is in close proximity of the surface, i.e. in-air.

In the following, the three parts are described.

3.1 Initial Screening

The first part consists in a simple screening routine allowing the examiner to collect personal and clinical information of the patient. In addition to general questions, the family history of the patient and the presence of risk factors, such as diabetes, hypertension, obesity, etc., can be evaluated. Caregivers are then asked to answer questions about the most common symptoms of dementia. The interview is mainly concerned with memory deficit. If at least one question is answered positively, the protocol continues; otherwise, it ends. In the former case, the patient is asked to provide his/her signature as first handwritten trait captured by the device. The signature is acquired both in this initial stage and at the end of the second stage, as signature may vary depending on the emotional state of the signer.

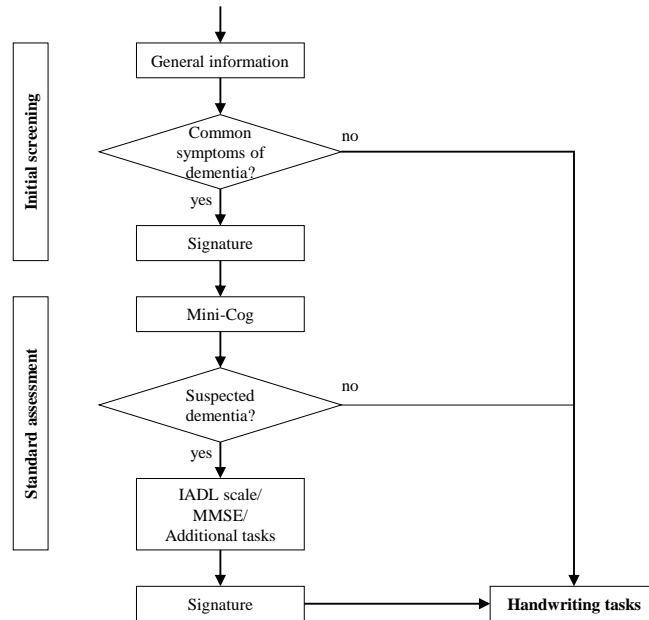


Fig. 1. Overall model of the proposed protocol.

3.2 Standard Assessment

A standard assessment typically includes cognitive and functional tests. The tests suitable to be carried out in a digitized way included in our proposal are: Mini-Cog [24]; the Instrumental Activities of Daily Living (IADL) scale [25]; and Mini-Mental State Examination (MMSE) [26]. These three tests were chosen since they are the most widely used in clinical settings.

Mini-Cog is a short screening test, as it lasts no more than 3 minutes. The test is composed of two parts: a 3-item recall test and a simple clock drawing test. The score is calculated as follows: 1 point for each word recalled without cues, and 2 points for a normal clock drawing. A total score of 3, 4 or 5 indicates lower likelihood of dementia. One may proceed with the administration of the following tests only after obtaining a low Mini-Cog score.

The IADL scale is an instrument to assess independent living skills. More precisely, it provides information about 8 skills necessary for living in a community, for example food preparation, housekeeping and laundering. Individuals are scored according to their highest level of functioning in a specific category. A summary score, therefore, ranges from 0 (low function, dependent) to 8 (high function, independent).

Then, MMSE may be administered. It consists in a 30-point questionnaire including questions and problems in many areas: orientation to time and place; repetition of lists of words; attention and calculation; registration recall; speaking back a phrase; basic motor skills, such as drawing figures previously shown. Any score greater than or equal

to 24 points indicates a normal cognition. Below this, the score can indicate severe (≤ 9 points), moderate (10-18 points) or mild (19-23 points) cognitive impairment.

In conclusion of the second stage, additional well-known tasks, not included in standard tests, may be administered, for example matrix and trail making tests. Then, a second signature of the subject is acquired.

It is worth noting that all these tests already include handwriting tasks, and their contribution and importance within the tests has been already clinically validated. In this case, the use of a digital on-line (real-time) acquisition tool gives the possibility to acquire kinematic features.

Furthermore, it is worth remarking that the inclusion in the proposed protocol of standardized cognitive tests helps in specifying the stage of disease of the example acquired, resulting in a multiclass classification problem.

3.3 Handwriting Tasks

The tasks described within the previous two paragraphs have three major advantages:

- They are useful for doctors to perform the assessment as they usually do;
- They can provide the so called “ground truth” to be used in the research activities;
- They provide a set of extra data to be combined (for analysis and classification aims) to those related to handwriting.

Among the various tasks proposed by the literature, the following ones were observed to be the most employed and discriminant:

- Archimedes spiral drawing;
- Copying the details of a check into the appropriate places;
- Repetitions of the cursive letters “*l*” and “*e*”;
- Writing a dictated word and sentence. Note that, in order to keep the dictation speed constant, an audio trace should be preferred to the examiner’s voice. Moreover, note that, according to [9], words or sentences without linguistic or spelling difficulties should be chosen.

In addition, following (with the pen) a trajectory drawn on the screen may be of interest to assess the hesitation of the subject in performing such a task.

Clearly, the handwriting tasks have to be administered not only to impaired patients but also to healthy controls, in order to provide examples for both kinds of subjects.

A summary of the handwriting tasks included in all the three stages of the protocol is reported in Table 1.

4 Conclusion

In this paper, an integrated protocol for the assessment of neurodegenerative diseases has been proposed. It integrates handwriting tasks to a digitized version of standard cognitive and functional tests.

Table 1. Handwriting tasks.

Stage	Tasks
Initial screening	Signature
Standard assessment	Clock drawing test Spontaneous writing Copying geometric shapes Matrix test Trail making test
Handwriting	Signature Archimedes spiral Copying the details of a check Repetition of “ <i>l</i> ” and “ <i>e</i> ” Word/sentence writing Trajectory following

On one hand, the protocol may be useful, to the research community, to collect different handwritten traits. One main open issue, in fact, concerns the development of a large benchmark database so that different pattern recognition tools can be effectively evaluated and compared. At the same time, the protocol may be of real use for doctors to support their daily activities. The inclusion of standardized tests is also important to specify the stage of the illness of the patterns acquired: indeed, the main open problem is to support the early diagnosis of the disease.

Future developments of our research should face some open issues. First, the protocol must be implemented and validated in a real-world scenario. The use of a digitizing tablet may be unfamiliar to elderly people; therefore, a comparative study between this acquisition modality and the usual one based on pen and paper should be carried out in order to evaluate if any bias is introduced. Second, other characteristics of the participants, for example the medical treatment, should be taken into account.

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