Alzheimer's Disease and Signature Execution

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Abstract: *Alzheimer´s disease (AD) is a progressive and irreversible neurodegenerative disease involving the impairment of several cognitive functions. To determine how AD affects signatures, samples from three groups were analysed: DA1 (17 participants with a medical diagnosis of AD; Mini-Mental State Examination Test (MMSE) 20.12 ± 2.00); DA2 (17 participants with a medical diagnosis of AD; MMSE 11.06 ± 3.93) and a control group (30 healthy matched individuals; MMSE 28.07 ± 1.60). General features (Chi-Square Tests Linear-by-Linear Association, p <0,050) and constructional features (Fischer's Exact Test, p <0,050) were analysed. Statistically significant differences between the AD groups and the control group were found in legibility, tremor and line quality, spacing between words and shape and direction of the baseline. Although no statistical differences were found in size among the three groups, cases of micrographia and macrographia were found exclusively in DA2. Statistically significant differences were not found in velocity, level of connection, and pressure. In constructional features, repetitions (often as perseverations or uncontrolled repetitions of strokes or letters), omissions, and substitutions (some in the form of allographic agraphia) were present. Some individuals in the AD groups also included additional writings in their signatures. These results may be associated with the overall cognitive deterioration that occurs in AD. FDEs should be aware that these changes may be common in the handwriting of AD patients, particularly in more severe stages. Therefore, interpreting the occurrence of tremor, decrease in line quality and other changes in the handwriting features mentioned above should be made with caution. Obtaining both earlier and contemporaneous signatures should also assist FDEs to better interpret tremor and other alterations in the handwriting of AD patients, and to evaluate if these are naturally occurring changes due to the progression of the illness or simulations.*

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Key Words: Alzheimer's Disease, Handwriting changes and senility, Signatures, Static features

1. Introduction

Alzheimer's disease is the most common cause of dementia, especially over the age of 65, and was first described by Dr. Alois Alzheimer in 1906 (Castro-Caldas & Mendonça, 2005, Thomas & Fenech, 2007). It is an irreversible neurodegenerative disease, involving the impairment of several cognitive functions, such as memory, attention, language, visuospatial skills and decision making (Castro-Caldas & Mendonça, 2005). The etiology of AD is multifactorial, with both environmental and genetic causes. Histologically, it is characterized by neuronal loss in the cortex and hippocampus regions, as well as the presence of extracellular senile plaques and neurofibrillary tangles (Castro-Caldas & Mendonça, 2005; Dorszewska & al, 2016).

Most research concerning the effect of AD on signatures and handwriting stems from a

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	Control Group	DA1	DA2
Participants	30	17	17
Age (years)	78.60 ± 6.34	80.88 ± 4.26	79.53 ± 8.37
Education (years)	6.47 ± 2.96	6.53 ± 3.02	6.12 ± 3.43
Gender (f/m)	20/10	7/10	12/5
MMSE Scores	28.07 ± 1.60	20.12 ± 2.00	11.06 ± 3.93
Age, Education and MMSE scores are means ± SD			

Table 1. Description of the three groups (Control, DA1 and DA2) regarding age, education, gender and MMSE scores

neuropsychological perspective and has focused on linguistic components (Rapcsak & al, 1989; Platel & al, 1993; Croisile, 2005; Luzzatti & al, 2003). According to Croisile (2005), Alois Alzheimer himself had already described changes in the handwriting of his patient Auguste D. consisting of repetitions and omissions. Other handwriting alterations include perseverations, substitutions, misalignments or misplacements of strokes, incorrect connections and spacing (Croisile, 2005; Huber & Headrick, 1999).

Regarding motor aspects, researchers in kinematic studies have reported a deterioration in fine motor control and coordination in the handwriting movements of AD patients, which were less coordinated and less consistent when compared to the control group (Yan & al, 2008; Schröter & al, 2003; Slavin & al, 1999). AD patients also exhibited a higher variability in velocity and less consistent stroke duration, irrespective of medication (Schröter & al, 2003; Slavin & al, 1999). Another study conducted by Werner & al (2006) on functional tasks revealed higher temporal measures and lower pressure in the handwriting movements of AD patients in comparison with the control group and individuals with mild cognitive impairment.

However, the studies mentioned previously only refer to text or graphic exercises, while most forensic document examiners' (FDE's) casework is composed of signatures. Since a signature is "programmed as a single unit rather than a sequence of individual units", it possesses automatism and unique characteristics (Caligiuri & Mohammed, 2012).

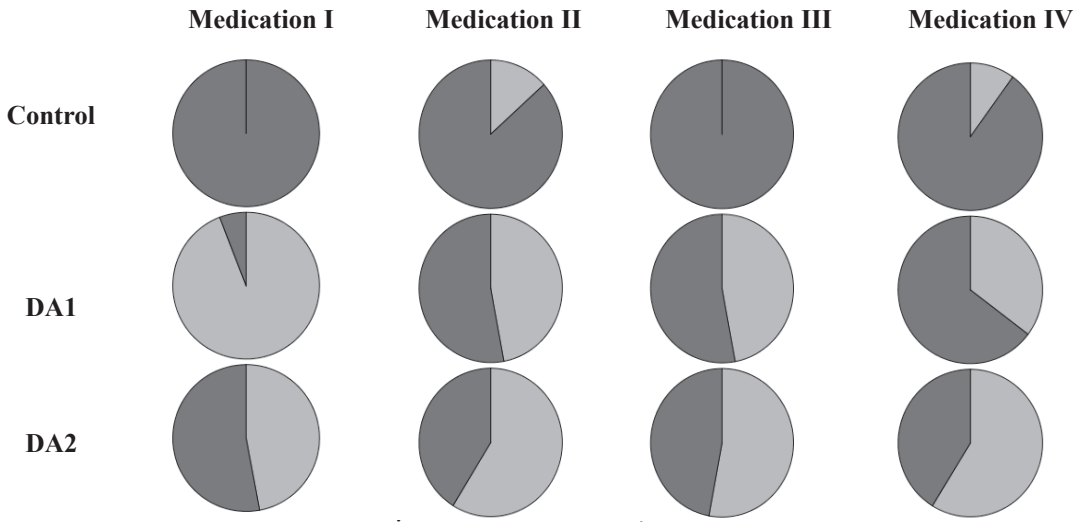
Few studies have addressed signature alterations due to dementia. Behrendt (1984) found that although omissions, repetitions and improper connections may be present in these signatures, little loss in writing skill occurs. Caligiuri (2013) analyzed kinematic movements in sentences and signatures and found apraxic agraphia in sentence or signature writing in 25% of AD subjects. AD patients with more severe clinical parkinsonism exhibited longer stroke duration, and more dysfluency in signatures than others with absent or mild parkinsonism. Caligiuri also reported an association between apraxic agraphia and dementia severity.

The current research was conducted to assist FDEs determine how Alzheimer's disease more specifically affects signatures, as well as to identify any characteristic handwriting features associated with this pathology.

2. Material and Methods

The material for this research consisted of signatures collected from three groups of individuals: DA1 and DA2, with a medical diagnosis of Alzheimer's disease, and a control group that included 30 healthy matched individuals. The three groups were formed according to the results of the Mini-Mental State Examination Test (MMSE), adapted to the Portuguese population by Guerreiro & al (1994). A description of these groups regarding age, education, gender and MMSE scores is presented in Table 1.

No statistical differences were found among these groups regarding age, education and gender (program PASW Statistics 17.0; age: Oneway Anova Test, $p<0,050$; education and gender: Chi-Square Test Linear-by-Linear Association, $p<0,050$).



Graphic 1 - Characterization of the three groups (Control, DA1 and DA2) regarding the presence (▒) or absence (■) of the following medication: medication associated with the treatment of Alzheimer's disease (I); anxiety medication, sedatives and hypnotics (II); antipsychotics (III) and antidepressants (IV).


A Influência da Doença de Alzheimer na Escrita Manual

Formulário 2 – Formulário para recolha de assinaturas

U.PORTO
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UNIVERSIDADE DO PORTO

Amostra n.º

Por favor escreva a sua assinatura nos respectivos espaços

NOTA: Estas assinaturas destinam-se unicamente para pesquisa e não poderão ser utilizadas para qualquer outro fim.

Figure 1- Form designed for signature collection.

This study was approved by the Committee of the Master's Degree in Forensic Medicine of the Abel Salazar Institute of Biomedical Sciences, of the University of Porto, Portugal. Informed consent was obtained from all the non-AD participants or from the caregivers for the AD patients. All the subjects were Portuguese, right-handed, knew how to read and write (the minimum level of education considered for the present study was the 4th grade or elementary school), and had normal or corrected hearing and eyesight. All the participants were asked to write their usual signature ten times as naturally as possible, using the

General Features	*Categories*
Legibility	Legible Partially Legible or Illegible
Tremor	Present/Absent
Level of Connection	Low (letters are disconnected) Medium (letters grouped in pairs) High (groups of 3 or more letters)
Velocity	Slow Moderate Fast
Pressure	Light Moderate Heavy
Slant	To the left Vertical To the right Variable
Curvature	Curved Angular Mixed
Overall size	Large to very large Middle Small to very small
Spacing between words	Regular Irregular
Shape of the baseline	Regular Irregular
Direction of the baseline	Horizontal Ascending Descending Variable

Table 2. General features that were analysed and the correspondent categories.

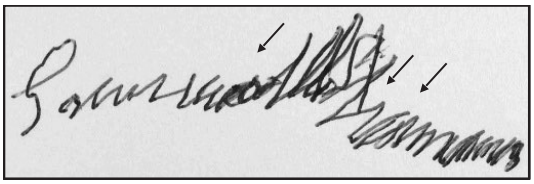


Figure 2 – Sample classified as partially legible in DA2, due to perseverations (→).

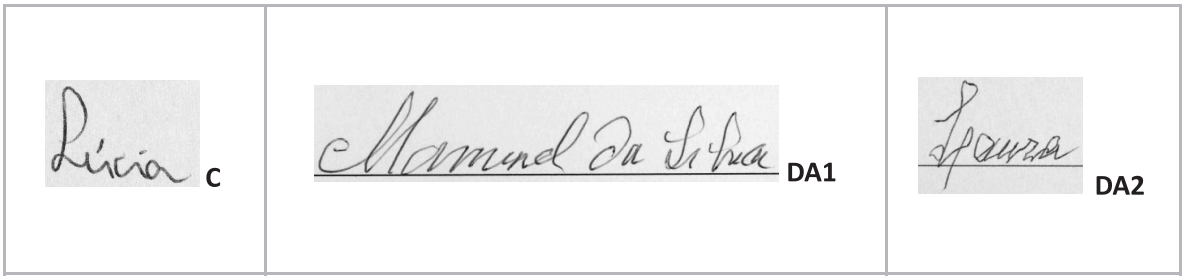


Figure 3 – Samples of handwritten signatures from the control group (C) without tremor, and from the Alzheimer groups DA1 and DA2 with tremor.

Figure 4 – Sample from the control group (C) with a regular and horizontal baseline, and a sample from DA2 with an irregular and ascending baseline.

same type of blue ballpoint pen. They wrote on special forms designed for this purpose seen in figure 1.

The three groups were also characterized regarding medication that may affect their handwriting (Graphic 1). The following types of medication were considered: medication associated with the treatment of Alzheimer's disease (I), anxiety medication, sedatives and hypnotics (II), antipsychotics (III) and antidepressants (IV).

Two categories of handwriting features were analysed: general features (legibility, tremor and line quality, level of connection between letters, velocity, pressure, slant, curvature, overall size, spacing between words and shape and direction of the baseline) and constructional features (shape and letter formation, as well as unusual features in the letter's design).

A trained FDE, using a stereoscopic microscope as well as by direct observation analyzed the handwritten signatures from each participant. Absolute size was determined using a Mitutoyo Digital Caliper, Model CD-15 (measuring range from 0 to 150 mm, 0.01 mm resolution). The examination began with the analysis of general features, followed by constructional features. Regarding general features, the group of samples from each participant was examined qualitatively and classified globally according to the categories adapted from Dziedzic, 2005, detailed in Table 2. After categorizing the handwritten signatures of the participants, each general feature was then statistically compared between the three groups (Control, DA1 and DA2) using Chi-Square Tests Linear-by-Linear Association ($p < 0{,}050$, program PASW Statistics 17.0).

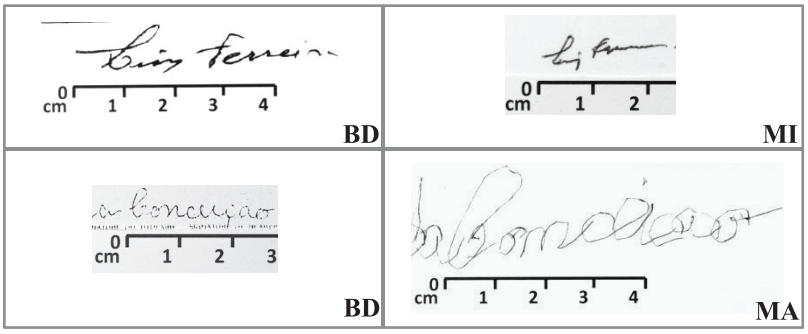


Figure 5 – Samples from Alzheimer group DA2 before the disease (BD)and afterwards, exhibiting micrographia (MI) and macrographia (MA).

Regarding constructional features, the allographs present in the handwritten signatures of each participant were qualitatively analyzed, by direct observation and using a stereoscopic microscope. The allographs were examined regarding shape, design and the occurrence of unusual features, such as repetitions, omissions and substitutions. For each participant, the occurrence and type of alterations in the allographs was registered. This information was then statistically compared between the three groups (Control, DA1 and DA2) using Fischer's Exact Test ($p < 0{,}050$, program PASW Statistics 17.0).

3. Results and Discussion

The general features that were classified as statistically different among the three groups (Control, DA1 and DA2) include legibility, tremor and line quality (defined by Huber & Headrick, 1999 as "the degree of regularity to the written stroke"), spacing between words, and the shape and direction of the baseline. Signatures were more illegible in DA2 because of distortions and repetitions in the allographs, often in the form of perseverations as seen in Figure 2. These perseverations make it difficult to identify the individual letters.

Tremor was significantly higher in the AD groups (23.5% of DA1 samples and 64.7% of DA2 samples) than in the control group (16.7%). The presence of tremor results in poorer line quality as shown in Figure 2, DA2. The medication taken by AD patients, particularly antipsychotics, may also have contributed to poorer line quality. These observations have also been reported in kinematic research that confirmed the presence of apraxic dysgraphia and dysfluency in the handwriting of these patients, as well as less coordination and consistency in their handwriting movements (Caligiuri, 2013; Yan & al, 2008; Schröter & al, 2003; Slavin & al, 1999).

Spacing between words tended to be more irregular in the signatures from the AD groups. The shape and direction of the baseline revealed significant differences compared to the control group whose baselines were more regular and horizontal when compared to these same features in the AD group as seen in Figure 4. This was due to the fact that individuals in the control group used the margins of the rectangles present on the form to provide a guide for their signatures. This strategy was not adopted by the individuals in the Alzheimer groups whose signatures were more irregular and variable in relations to the baselines.

Regarding motor features, velocity was not considered statistically different. These results are similar to that of Schröter & al (2003), who found no significant differences between velocity in the AD group and healthy controls. However, research by Yan & al (2008) suggests that the handwriting movements of AD patients are slower than that of the control group. Other motor features that weren't classified as statistically different include the level of connection and pressure. Regarding the latter feature, the present study differs from that of Werner & al (2006), indicating that the mean pressure was lower in the case of AD patients.

Other general features that didn't reveal significant statistical differences between the handwritten signatures of the three groups (Control, DA1 and DA2) include: slant, curvature and overall size. Although overall size was not considered statistically

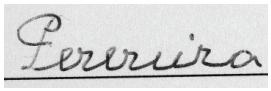
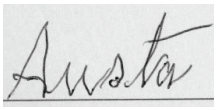
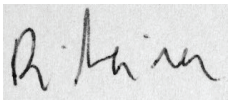
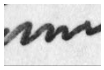
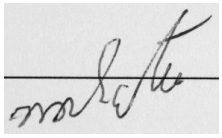
Repetitions	Omissions	Substitutions
 Repetition of letters “re”, in “Pereira”	 Omission of letters “gu”, in “Augusta”	 Letter “o” was replaced by the letter “a”, in “Ribeiro”
 Perseveration of circular motion in letter “o”	 Omission of arches in letter “M”	
 Repetition of arches in letter “r”	 Omission of the bar in letter “t”	 Letter “M” was substituted by the corresponding lower case “m”

Figure 6 – Examples of repetitions, omissions and substitutions in signature samples from the Alzheimer groups DA1 and DA2.

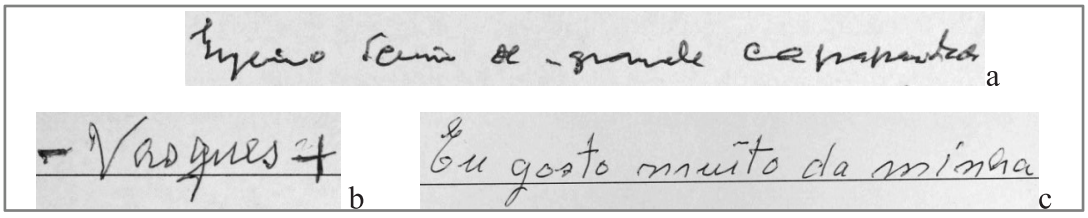


Figure 7 – Additional unrelated writing present in the signature samples from the Alzheimer groups DA1 and DA2. This writing refers to a previous job (a), symbols (b) or cursive writing in a letter (c).

different among the three groups, it should be noted that cases of micrographia (height of lower case letters below 1.5mm) and macrographia (height of lower case letters above 6 mm) were found exclusively in the Alzheimer group DA2 seen in Figure 5. This increase or decrease in the height of letters would indicate that the mechanisms involved in the control of this general feature could be compromised in individuals with more severe cognitive deficits.

The analysis of constructional features revealed repetitions often in the form perseverations, omissions of strokes and letters, and substitutions. Repetitions and omissions affected mostly letters with a repetitive design (e.g. letters M, n), those inserted in sequences involving a similar motion (e.g. letters e, r, u) or letters whose design involves additional strokes (e.g. letters i, t). In substitutions, letters were replaced by the corresponding capital letter, lower case letter or printed form (allographic agraphia), or even by a different letter seen in Figure 6.

The presence of additional writing, unrelated to the signatures themselves, was also present in some

samples from the Alzheimer groups DA1 and DA2. This writing referred to the person's previous job (Figure 7a) or symbols that were introduced, such as plus and minus signs (Figure 7b). In some cases it reflected the inability to focus on the task at hand. For example, one participant began to write her signature and then started to write a letter to her daughter (Figure 7c). In this context, additional writing which constitutes an inappropriate response, may also be associated with attentional deficits and frontal impairment.

4. Conclusion

The present research demonstrates that Alzheimer's disease influences the execution of signatures, especially in individuals with a more severe cognitive deficit. The most significant features in the signatures produced by individuals with Alzheimer's disease were less legibility, the presence of tremor, poorer line quality, irregular spacing between words, irregular shape of the baseline and more variability in the direction of the baseline. Constructional features were also distinctive because of repetitions often in the form of perseverations, omissions and substitutions. Additional writings unrelated to the request for signatures may reflect attentional impairment in some patients.

FDEs should be aware that these changes may be common in the handwriting of AD patients, particularly in more severe stages. Therefore, interpreting the occurrence of tremor, decrease in line quality and other changes in the handwriting features mentioned above should be made with caution. Obtaining both earlier and contemporaneous signatures should also assist FDEs to better interpret tremor and other alterations in the handwriting of AD patients, and to evaluate if these are naturally occurring changes due to the progression of the illness or simulations that result from copying a signature from a model or model signatures.

To confirm these results, additional research involving a more extensive group of patients will be necessary. Since this study was focused on static features and a qualitative analysis of dynamic features, further kinematic studies involving signatures will be equally important to better understand and document the motor deterioration in AD patients. These kinematic studies can also accurately record the velocity and pressure patterns, characteristics that are more subjective for FDEs to evaluate.

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