

Writing difficulties in Alzheimer's disease and Mild Cognitive Impairment

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1 **Abstract**

2 The present study addresses the scope of the writing difficulties observed in
3 patients with Alzheimer’s disease (AD) and Mild Cognitive Impairment (MCI). Patients
4 with AD, patients with MCI and healthy controls performed a written picture-naming
5 task and a direct copy transcoding task in which phonology-to-orthography (P-O)
6 consistency was manipulated. Written latencies, inter-letter durations, mean word pen
7 pressure and number of errors were measured. Results revealed that there was a
8 significant difference between the control group and both groups of patients in written
9 latencies and number of errors. However, in inter-letter interval or mean pen pressure
10 there were significant differences only between the group with AD and the other groups.
11 P-O consistency and the type of task produced similar effects in the three groups of
12 participants, suggesting a general deficit affecting the ability to access/generate
13 orthographic representations. The relevance of these results for understanding the
14 spelling impairment in AD and MCI are discussed.

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17 **Keywords:** handwriting, Alzheimer’s disease, Mild Cognitive Impairment, spelling-to-
18 dictation, copying

1 Although language impairments in Alzheimer`s disease (AD) have been
2 extensively documented, spelling and handwriting deficits have received considerably
3 less attention. Difficulties in writing have often been reported in AD (Alzheimer, 1907
4 cited in Rodríguez-Ferreiro, Martínez, Pérez-Carbajal, & Cuetos, 2014; Cuetos,
5 Martínez, Martínez, Izura, & Ellis, 2003; Onofri, Mercuri, Donato, Ricci, 2015;
6 Rapcsak, Arthur, Bliklen, & Rubens, 1989; Werner, Rosenblum, Bar-On, Heinik, &
7 Korczyn, 2006) but only a few studies have focused on establishing the nature of the
8 underlying deficit and its development throughout the evolution of the disease.
9 Moreover, the scarce empirical evidence so far has been fairly inconclusive. Whether or
10 not writing skills are impaired in early stages of AD and what is the pattern of
11 deterioration in the components of the writing production system have been two of the
12 most controversial topics in this area of research (Hughes, Graham, Patterson, &
13 Hodges, 1997; Luzzatti, Laiacona, & Agazzi, 2003; Silveri, Corda, & Di Nardo, 2007).
14 In this study, we tested kinematic variables of the writing of patients and healthy
15 controls to obtain further information about these questions.

16 It has been claimed that writing abilities are affected only in the later stages of
17 AD (Hughes et al., 1997; Cummings, Benson, Hill, & Read, 1985). However, recent
18 evidence has contradicted this assumption, with writing difficulties being observed at
19 different stages (Cuetos et al., 2003; Werner et al., 2006). As a result, there is no
20 agreement about whether writing deficits appear at an early stage of the disease, nor
21 even about whether they are a constant feature in AD. The study of writing difficulties
22 in mild cognitive impairment (MCI) may shed some light on this issue. MCI is a phase
23 of cognitive decline that may progress to AD. Although not all of those diagnosed with
24 MCI develop AD, research on this cognitive state between normal aging and dementia
25 offers a unique opportunity to identify early indicators of AD. However, if research

1 about writing deficits in AD patients is scarce, the evidence reported about these deficits
2 in mild cognitive impairment (MCI) is even more limited. The few studies that have
3 evaluated writing abilities in MCI have reported inconsistent results (Lambon Ralph,
4 Patterson, Graham, Dawson, & Hodges, 2003; Werner et al., 2006). Werner and
5 colleagues observed that some kinematic measures of the handwriting process were
6 altered in MCI patients. Namely, these patients produced longer writing times and lower
7 mean pen pressure than healthy controls when they copied a paragraph, a grocery list, a
8 bank check or the alphabet. However, Lambon Ralph and colleagues did not observe
9 significant differences in spelling ability between patients with MCI and controls.
10 Conversely, patients diagnosed with mild AD differed significantly from controls in
11 both studies, suggesting that writing may be notably impaired at this stage of the
12 disease.

13 The difference in the findings reported in these previous studies may be due to
14 several factors. First, both studies used different tasks. Werner et al. used several
15 copying tasks, while Lambon Ralph et al. (2003) asked participants to spell to dictation.
16 It is well known that different writing tasks entail different cognitive processes (Bonin,
17 Meót, Lagarrigue, & Roux, 2015). Thus, some tasks may be more sensitive to a given
18 deficit than others. Second, different measures were chosen to assess writing ability in
19 both studies. Werner and colleagues analysed the kinematic measures of the written
20 response, while Lambon Ralph and colleagues (2003) took accuracy as a measure of
21 spelling ability. It is possible that the analysis of writing times is a measure more
22 sensitive to early signs of deterioration of writing production than the number of errors.
23 An increase in writing times might be detected even before the written production
24 system is sufficiently affected to produce more errors. Finally, chronometric variables
25 reported by Werner et al. such as written latencies or writing durations may reveal

1 subtle differences between patients and controls in the ability to access/generate
2 orthographic representations (i.e., *spelling* or *central processes*) or produce letter forms
3 (*handwriting* or *peripheral processes*). However, Lambon Ralph and colleagues seemed
4 to focus on spelling errors. This is an important point, since it has been proposed that
5 the pattern of deterioration in AD would evolve from the most central levels of spelling
6 to the most peripheral aspects of handwriting.

7

8 **Central and peripheral processes on writing production**

9 In order to write a word, one needs to retrieve the appropriate orthographic
10 representation (spelling) and the hand movements required to actually produce the
11 retrieved sequence of letters (handwriting). Based on the influential model of writing
12 proposed by Van Galen (1991), spelling is considered one of the so-called *central*
13 *processes* of writing, while handwriting refers to the motor or *peripheral processes*. The
14 distinction between central and peripheral processes is widely agreed and supported by
15 behavioural and neuroimaging evidence (Graham, Patterson, & Hodges, 1997; Purcell,
16 Turkeltaub, Eden, & Rapp, 2011). Traditionally, central processes had been investigated
17 from a psycholinguistic point of view, while peripheral processes had been of interest
18 mostly for motor theorists. However, during the last decades the availability of
19 digitising tablets that provide precise information about the timing of the written
20 response has led to an increase in the number of studies that analyse chronometric
21 measures to study both type of processes simultaneously (Afonso, Suárez-Coalla,
22 González-Martín, & Cuetos, 2017; Kandel & Perret, 2015; Roux, McKeeff,
23 Grosjacques, Afonso, & Kandel, 2013). In these studies the time required to initiate a
24 response (written latency) is claimed to **mainly** reflect processing at the central levels,
25 while the time dedicated to the actual production of the response (for example, writing

1 durations or inter-letter intervals) are **mainly** considered measures of peripheral
2 processing. **However, evidence is accumulating about the fact that central processes**
3 **continue to affect writing durations after the response has been initiated (Afonso,**
4 **Álvarez, & Kandel, 2015; Delattre et al., 2006; Kandel & Perret, 2015; Lambert,**
5 **Alamargot, Larocque, & Caporossi, 2011; Roux et al., 2013).** Thus, it seems that the
6 **distinction between central and peripheral processes may be less clear-cut than**
7 **originally thought, with both type of processes interacting during writing.**

8 In Van Galen's model, peripheral processes include allographic selection, force,
9 time and size controls and muscular adjustment. Impairment to this level of processing
10 are referred to as *peripheral dysgraphia* and it is characterised by a disturbance in the
11 correct production of the hand-movements and motor programs required to form legible
12 letters (Graham et al., 1997). Although Van Galen conceived an undifferentiated
13 spelling module in which orthographic codes are retrieved to represent utterances, most
14 models of spelling propose different ways to access an orthographic representation.

15 According to the popular dual-route models (Houghton & Zorzi, 2003;
16 Tainturier & Rapp, 2001), spelling may be achieved by means of at least two different
17 routes. The lexical route is thought to give access to the orthographic form of known
18 words stored in the lexicon, while the sublexical route would provide a plausible
19 spelling based on the correspondences between phonemes and graphemes existing in the
20 language (Caramazza, 1988; Tainturier & Rapp, 2001). The sublexical route could
21 provide a correct spelling for words with regular phonology-to-orthography (P-O)
22 correspondences, but lexical access would be required to correctly spell words with
23 irregular P-O correspondences. The existence of both routes is supported by the well-
24 established difference between two types of *central dysgraphia*: surface dysgraphia and
25 phonological dysgraphia (Bub & Kertesz, 1982; Caramazza, Miceli, Villa, & Romani,

1 1987). In surface dysgraphia, the lexical route of spelling is affected, so errors appear in
2 words with non-predictable spellings as a result of overreliance on the phoneme-to-
3 grapheme conversion procedures (Beauvois, & Derouesné, 1981; Patterson, Marshall,
4 & Coltheart, 1985). Phonological dysgraphia refers to an inability to correctly apply the
5 correspondences between phonemes and graphemes, resulting in a selective deficit
6 affecting unknown words and nonwords (Shallice, 1981).

7 An alternative to dual-route models may be found in the parallel-distributed
8 processing (PDP) models (Seidenberg & McClelland, 1989). From this point of view,
9 the spelling system would be a distributed network of connections between three
10 different levels: semantic, orthographic and phonological. Activation would spread from
11 one level to another according to the weight of the connections. Thus, links between
12 phonology and orthography will be mediated by semantics (Graham, Patterson, &
13 Hodges, 2000). This is a difference with dual-route models, which assume that the
14 sublexical route may be used to spell to dictation without any semantic involvement
15 (Cuetos, 1991).

16 In any case, both theoretical perspectives predict larger P-O consistency effects
17 when semantic information is impaired (Cortese, Balota, Sergent-Marshall, & Buckner,
18 2003). In dual-route models, this impairment would lead to overreliance on the
19 sublexical route. In the context of PDP models only connections between phonology
20 and orthography would be available, and these connections are thought to be weaker in
21 P-O inconsistent correspondences than in consistent correspondences (Graham et al.,
22 2000). This is an important issue for research in AD, since semantic deficits are a well-
23 known characteristic of the disease (Chertkow & Bub, 1990; Hodges & Patterson,
24 1995). In line with the predictions of dual-route and PDP models, increased effects of P-
25 O consistency/regularity in the spelling of patients with AD compared to healthy

1 controls have been reported in several studies (Cortese et al., 2003; Croisile, Brabant,
2 Carmol, Lepage, Aimard, & Trillet, 1996; Graham et al., 2000; Hughes et al., 1997).
3 However, Cortese and colleagues (2003) proposed a third possibility to account for this
4 pattern. These authors suggested that particular difficulties with P-O inconsistent
5 correspondences might appear as a consequence of reduced attentional control. They
6 argued that attentional control mechanisms are necessary to select the correct spelling
7 and inhibit the incorrect grapheme in those cases in which a phonological form can be
8 orthographically represented in more than one way. Thus, impaired attentional control
9 mechanisms would affect to a greater extent the spelling of words including P-O
10 inconsistent than consistent correspondences.

11

12 **Central and peripheral processes of writing in AD and MCI**

13 Several studies have tried to determine how the writing difficulties exhibited by
14 AD patients evolve according to the severity of the disease (Forbes, Shanks, & Venneri,
15 2004; Hughes et al., 1997; Luzzati et al., 2003; Silveri et al., 2007). Findings from these
16 studies seem to suggest that surface dysgraphia would be the most likely form of
17 dysgraphia in patients with minimal AD, and sublexical procedures would be
18 increasingly affected as the disease progresses. Peripheral aspects of handwriting
19 production will be affected only at later stages of the disease (Cuetos et al., 2003;
20 Forbes et al., 2004; Hughes et al., 1997). In line with this idea, it has been reported that
21 the majority of spelling errors produced by patients at the initial stages of AD are
22 phonologically plausible (Forbes et al., 2004; Hughes et al., 1997; Rapcsak et al., 1989).
23 However, the claim that phonologically implausible errors do not appear early in the
24 course of the disease has not always been supported by the evidence. Some AD patients
25 have shown a spelling performance consistent with phonological dysgraphia even at the

1 early stages of the disease (Luzzatti et al., 2003), and the existence of a qualitative shift
2 in the error type made by patients has not been confirmed.

3 An important aspect of these previous studies is that they have focused on the
4 analysis of the amount and type of errors made by patients. As discussed above, this
5 may lead to an underestimation of the spelling deficits, which might only be detected
6 once the deficits have reached a level of severity sufficient to produce errors. However,
7 small differences between controls and patients may exist even before the writing
8 difficulties had become apparent. For example, Afonso, Suárez-Coalla, and Cuetos
9 (2015) observed increased written latencies and inter-letter interval (ILI) durations in a
10 group of adults with developmental dyslexia as compared to controls in words that they
11 could spell correctly. Only the study conducted by Werner and colleagues (2006) has
12 reported online measures of the written response in MCI and AD, but this study did not
13 address the locus of the deficits underlying the difficulties observed.

14 In the present study, as well as number of errors, we measured written latencies
15 (as a measure of central processing) and ILI durations (as a measure of peripheral
16 processing) produced by MCI and AD patients in comparison to their healthy peers
17 during writing. Although central processes may also affect writing durations (Kandel &
18 Perret, 2015; Lambert et al., 2011; Roux et al., 2013), effects appearing only in written
19 latencies would be likely to reflect central processing. Similarly, effects observed only
20 in ILI durations would be difficult to interpret as central effects cascading into
21 production. Mean pen pressure exerted by participants was also analysed, as this
22 variable has been found to differentiate between controls and MCI patients and between
23 MCI patients and AD patients (Werner et al., 2006). However, it is unclear if this effect
24 reflects central processing, peripheral processing or emotional factors. As in this
25 previous study, we expect to find reduced pen pressure in the group with AD than in the

1 control group, with the MCI showing an intermediate level of pen pressure. Moreover,
2 we aimed to establish whether or not pen pressure is sensitive to linguistic variables (in
3 this case, P-O consistency) and if it can be taken as a measure of difficulty at the central
4 levels of processing.

5 In order to detect potential differences between controls and patients in the use
6 of the sublexical procedures of spelling, P-O consistency was manipulated in a set of
7 words that were tested in two different writing tasks: a written picture-naming task and
8 a direct copy transcoding task. The comparison of the same set of words in both tasks
9 has several advantages. First, it allows us to establish whether patients with AD exhibit
10 spelling difficulties only in semantic tasks (such as written picture naming) or whether
11 they show spelling problems also when copying (i.e., when the orthographic
12 representation is present). In the written picture-naming task (but not in the copying
13 task) prior activation of semantics is *necessary* to access the orthographic representation
14 (Bonin et al., 2015). Thus, if differences between the control group and the groups with
15 MCI and AD emerge only in the written picture-naming task, this might indicate that
16 writing difficulties in MCI and AD patients may be exclusively due to impaired
17 semantic representations. Second, this design will allow us to obtain information about
18 how the semantic information provided by the picture in the naming task modulates the
19 effects of P-O consistency.

20

21 **Methods**

22 **Participants**

23 Thirty-two outpatients, sixteen of them with probable AD and sixteen with MCI,
24 and sixteen healthy seniors, took part in this experiment. All of them were right-handed
25 native Spanish speakers and they came from a similar socio-economic background.

1 Participants with motor or perceptive disorders were not included in the sample.
 2 Patients were selected by the neurology group of Cabueñas Hospital (Gijón, Spain) on
 3 the basis of their medical history, information from a knowledgeable informant, a CT or
 4 MRI scan, and a neuropsychological evaluation. The diagnosis of probable AD was
 5 made according to the Neurological and Communicative Disorders and Stroke-
 6 Alzheimer’s Disease and Related Disorders (NINCDS-ARDA criteria; McKhann et al.,
 7 1984; revised by McKhann et al., 2011). AD patients also met the DSM-IV criteria for
 8 dementia of the Alzheimer’s type (American Psychiatric Association, 2000). All of them
 9 were mild AD patients. MCI patients met the criteria for mild cognitive impairment of
 10 amnesic type (Petersen, Doody, Kurz, Mohs, Morris, Rabins, et al., 2001), experienced
 11 no deficits in other cognitive abilities and their daily living functional activities
 12 remained intact. Controls were healthy adult volunteers without known psychiatric
 13 history, sensory deficiencies, or medical conditions that could impair performance on
 14 the neuropsychological tests.

15 The three groups were matched by age and years of education, but they differed
 16 in their scores in the MiniMental State Evaluation test (MMSE, Folstein, Folstein, &
 17 McHugh, 1975). A summary of the demographic characteristics of the participants is
 18 given in Table 1. Informed consent was obtained from all participants.

19

20 **Table 1**
 21 *Demographic data of controls, patients with Mild Cognitive Impairment (MCI), and*
 22 *patients with Alzheimer Disease (AD)*

Variable	Control	MCI	AD	T-tests
Mean age	73.94	75.5	72.62	Control vs MCI, $p = .38$; Control vs
(SD)	(8.01)	(6.74)	(9.24)	AD, $p = .80$; MCI vs AD, $p = .37$
Mean years of education	8	7.5	8.12	Control vs MCI, $p = .59$; Control vs
				AD, $p = .71$; MCI vs AD, $p = .34$

(SD)	(1.41)	(1.63)	(1.5)	
Mean MMSE	29.62	27.25	22.62	Control vs MCI, $p < .005$; Control vs
(SD)	(0.62)	(1.84)	(2.63)	AD, $p < .001$; MCI vs AD, $p < .001$

Note. SD = Standard deviation; MMSE = MiniMental Scale Evaluation test.

Materials

The full set of stimuli is given in Appendix A. Experimental stimuli were selected from the LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000). Values for word frequency, word length, orthographic neighbourhood and number of syllables were provided by BuscaPalabras (Davis & Perea, 2005). Age of acquisition values were obtained from the age of acquisition norms for elderly Spanish people (Cuetos, Samartino, & Ellis, 2012). Sixteen words were selected as experimental stimuli and two additional words for the practice phase. Half of them were P-O inconsistent and the other half were P-O consistent. P-O inconsistent words included a P-O inconsistent correspondence (*TIJERAS*, *scissor*) in a position representing a P-O consistent correspondence in its match in the P-O consistent condition (*TENEDOR*, *fork*). Letters in other positions were matched by P-O consistency. P-O consistent and inconsistent stimuli were matched by word frequency, orthographic neighbourhood, age of acquisition and number of letters and syllables. Pictures used as experimental stimuli were selected from the coloured and shaded images set of Snodgrass and Vanderwart-like objects (Rossion & Pourtois, 2004). Coloured images were used to facilitate object recognition and object naming (Price & Humphreys, 1989). Pictures included in both P-O consistency conditions were also matched by name agreement. *T*-tests were conducted to make sure that all the controlled variables did not significantly differ across conditions (all $t_s < 1$).

1

2 **Apparatus**

3 Stimuli presentation and digital recording of the responses were controlled by
4 Ductus (Guinet & Kandel, 2010). The experiment was run on an Asus F9Eseries laptop.
5 A WACOM Intuos 5 graphic tablet connected to the computer and an Intuos Inking Pen
6 were used to register the participants' responses.

7

8 **Procedure**

9 The procedure of this experiment was approved by the Ethics Committee of the
10 Cabueñes Hospital and the Ethics Committee of the Department of Psychology of the
11 University of Oviedo. The experiment was conducted individually in a quiet room. For
12 all the participants the written picture-naming task was conducted in first place.

13 In both the written picture-naming task and the direct copy transcoding task, a
14 trial started with an auditory signal and a fixation point. The fixation point was replaced
15 by the visual stimulus (a picture or a lowercase word) 1000 millisecond after the offset
16 of the auditory signal. Participants had to write the word in upper case (print
17 handwriting was not enforced) on a lined sheet of paper placed over the digitizer as
18 quickly and as accurately as possible. In the direct copy transcoding task, their attention
19 was called to the fact that they had to continue writing the words in upper case, in spite
20 of the fact that they would see the stimulus in lower case. When they finished a
21 response, participants were instructed to hold the pen over the next line of the response
22 sheet but without making any contact with the paper. Then the experimenter clicked the
23 left button of the mouse to start a new stimulus. The whole experiment lasted around 35
24 minutes.

25

Results

Written latencies, critical inter-letter interval (ILI) durations, mean word pressure and number of errors were submitted to different analyses of variance (ANOVAs) with P-O consistency (consistent vs. inconsistent) and task (written picture-naming vs. direct copy transcoding) as within-subjects variables and group (control vs. MCI vs. AD) as a between-subjects variable. Written latencies were measured as the time between the stimulus onset and the first contact of the pen with the tablet. In the P-O inconsistent condition ILI durations for the critical interval were measured as the time between the last pen lift in the letter previous to the letter P-O inconsistent and the first pen down in this particular letter. In the P-O consistent condition the interval in the same position was measured. Mean pen pressure for each word was calculated based on the pressure values given by the tablet Wacom 5 Intuos (1024 pressure levels). Data points where no pressure was detected by the tablet (pressure = 0) were excluded from this calculation. Only correct responses were included in the analyses. Responses containing misspellings, self-corrections or those in which a response was not given or a recording error occurred were considered errors and removed from the analysis. For the analyses on critical ILI durations those responses in which the critical ILI was not produced were treated as error. If writing latencies or ILI durations were above or below 2 standard deviations from the mean by participant were also disregarded. Overall, 12% and 24% of the writing latencies and ILI durations were excluded from the analysis in the direct copy transcoding task and in the written picture-naming task respectively.

Analysis of errors.

Mean accuracy and standard deviations for each group and condition are given in Table 2. The main effect of group was significant, $F(2, 45) = 5.65, p < .01, MSE =$

1 1.89, $\eta_p^2 = .2$. *T*-tests revealed that the control group made significantly fewer errors
 2 than the group with MCI, $t(31) = 1.98, p = .05$, and than the group with AD, $t(31) =$
 3 $3.73, p < .001$. Moreover, the group with AD made more errors than the group with
 4 MCI, $t(31) = 2, p < .05$. The main effect of task was also significant, $F(1, 45) = 26.11, p$
 5 $< .001, MSE = 3.469, \eta_p^2 = .37$. More errors were made in the written picture-naming
 6 task than in direct copy transcoding. P-O consistency was also significant, $F(1, 45) =$
 7 $5.66, p < .05, MSE = .71, \eta_p^2 = .11$. P-O inconsistent words yielded more errors than P-O
 8 consistent words. No other effects were significant, all $ts < 1$.

9 In order to obtain more information about to what extent errors made in the
 10 written picture naming task were due to semantic deficits (namely, to inability to
 11 recognise the picture), the types of errors made by each group in this task were
 12 analysed. Errors were included in three categories: semantic (the name given was not
 13 acceptable for the picture or the participant expressed not to recognise the picture),
 14 phonologically plausible (errors had the same pronunciation than the target words), and
 15 letter errors (including substitutions, omissions, transpositions and intrusions non-
 16 phonologically plausible). Separate *t*-tests were conducted for each category. Results
 17 revealed that the control group produced marginally fewer semantic errors than the
 18 group with MCI, $t(31) = 1.98, p = .06$, and significantly fewer semantic errors than the
 19 group with AD, $t(31) = 3.48, p < .005$. However, there were no significant differences in
 20 the number of phonological plausible errors or letter errors made by the three groups, all
 21 $ts < 1$.

22

23 **Table 2**

24 *Mean accuracy (%) and standard deviations (in brackets) for each group and condition*
 25 *in the written picture-naming and in direct copy transcoding task*

	Written picture-naming	Direct copy transcoding
--	------------------------	-------------------------

Group	P-O consistent	P-O inconsistent	P-O consistent	P-O inconsistent
Control	84 (36)	81 (39)	88 (32)	89 (31)
MCI	84 (37)	70 (46)	85 (36)	84 (37)
AD	66 (47)	66 (48)	85 (36)	77 (42)

Note. P-O = phonology-to-orthography.

Written latencies.

Mean written latencies and standard deviations for each group and condition are given in Table 3. The effect of group was marginally significant, $F(2, 45) = 2.98, p = .06, MSE = 7,070,091.15, \eta_p^2 = .12$. Planned comparisons revealed that there was not a significant difference between the written latencies produced by AD patients and MCI patients ($t = 1.01$). However, written latencies produced by the control group were significantly shorter than those produced by the group with MCI, $t(63) = 2.73, p < .01$, and the group with AD, $t(63) = 4.59, p < .001$. A significant effect of task was observed, $F(1, 45) = 36.72, p < .001, MSE = 32,700,000, \eta_p^2 = .47$. Participants were faster in the copying task than in the written picture-naming task. The interaction between task and P-O consistency was also marginally significant, $F(1, 45) = 2.90, p = .09, MSE = 257,620.25, \eta_p^2 = .06$. *T*-tests showed that P-O consistency significantly affected written latencies in the direct copy transcoding task, $t(47) = 3.33, p < .005$, but had no effect in the written picture-naming task ($t < 1$). No other effects were significant, all t s < 1 .

Table 3

Mean written latencies and standard deviations (in brackets) for each group and condition in the written picture-naming and in direct copy transcoding task

Group	Written picture-naming		Direct copy transcoding	
	P-O consistent	P-O inconsistent	P-O consistent	P-O inconsistent

Control	2835 (713)	2744 (724)	1957 (509)	2037 (597)
MCI	3164 (1211)	3171 (1147)	2475 (881)	2521 (855)
AD	3585 (1029)	3519 (1303)	2456 (844)	2620 (837)

Note. P-O = phonology-to-orthography.

Due to the slowing in written latencies associated to AD and MCI, the effects of the manipulated variables may have been magnified in these groups. To control for group-related slowing we conducted a new analysis on the z-score transform of the written latencies (Faust, Balota, Spieler, Ferraro, 1999). The ANOVA on these standardised latencies revealed a significant effect of task, $F(1, 45) = 45.13, p < .001, MSE = 26.7, \eta_p^2 = .5$. Latencies were shorter in the copying task. The interaction between task and P-O consistency remained marginally significant, $F(1, 45) = 3.08, p = .09, MSE = .24, \eta_p^2 = .06$.

Critical inter-letter interval durations.

Two participants from the group with AD and two from the group with MCI were removed from the analysis of ILI durations because they wrote in lower-case letters and they did not systematically produce ILIs. Two participants from the control group matching them in age and years of education were also removed from the analysis. Mean ILI durations and standard deviations for each group and condition are shown in Table 4. The effect of group was significant, $F(2, 39) = 9.78, p < .001, MSE = 1,305,526.08, \eta_p^2 = .33$. Planned comparisons revealed that ILI durations were significantly longer in the group with AD than in the control group, $t(55) = 6.66, p < .001$, an in the group with AD than in the group with MCI, $t(55) = 5.71, p < .001$. However, the group with MCI and the control group did not differ in this variable, $t < 1$.

1 The main effect of P-O consistency was also significant, $F(1, 39) = 22.68, p < .001,$
 2 $MSE = 64,429.17, \eta_p^2 = .37.$ Longer inter-letter intervals were produced before the P-O
 3 inconsistent segments than before the P-O consistent segments. No other differences
 4 were significant.

5 Another ANOVA was conducted on the z-scores of the ILI durations. The main
 6 effect of P-O consistency remained significant, $F(1, 33) = 17.97, p < .001, MSE =$
 7 $14.57, \eta_p^2 = .54.$ No interactions were significant, all $t_s < 1.$

9 **Table 4**
 10 *Mean critical ILI duration and standard deviations (in brackets) for each group and condition in the*
 11 *written picture-naming and in direct copy transcoding task*

Group	Written picture-naming		Direct copy transcoding	
	P-O consistent	P-O inconsistent	P-O consistent	P-O inconsistent
Control	242 (73)	301 (136)	236 (86)	267 (108)
MCI	257 (113)	289 (109)	299 (154)	328 (128)
AD	463 (234)	484 (104)	409 (215)	461 (227)

12 *Note.* P-O = phonology-to-orthography.

13

14 **Mean word pen pressure.**

15 Mean written latencies and standard deviations for each group and condition are
 16 given in Table 5. The main effect of group was marginally significant, $F(2, 39) = 2.45, p$
 17 $= .099, MSE = 81,842.61, \eta_p^2 = .11.$ Planned comparisons revealed that the group with
 18 AD exerted significantly less pressure with the pen than the group with MCI, $t(55) =$
 19 $2.9, p < .01,$ and less than the control group, $t(55) = 2.28, p < .05.$ No other effects were
 20 significant, all $t_s < 1.$

21

1 **Table 5**

2 *Mean pen pressure (and standard deviations) for each group and condition in the*
 3 *written picture-naming and in direct copy transcoding task*

	Written picture-naming		Direct copy transcoding	
Group	P-O consistent	P-O inconsistent	P-O consistent	P-O inconsistent
Control	416 (97)	408 (99)	425 (82)	430 (85)
MCI	435 (81)	433 (85)	427 (81)	439 (86)
AD	392 (140)	392 (154)	375 (142)	371 (132)

4 *Note.* P-O = phonology-to-orthography.

5

6 **Discussion**

7 In the present study, we aimed to establish whether or not patients suffering
 8 from AD and MCI showed impaired word writing abilities in comparison to their
 9 healthy peers. Participants performed two different writing tasks in which P-O
 10 consistency of the words to be written was manipulated: a written picture-naming and a
 11 direct copy transcoding task. Written latencies, inter-letter interval durations, mean
 12 word pen pressure and number of errors were analysed. Results revealed that the group
 13 with AD produced more errors, longer written latencies and ILI durations and lower
 14 mean pen pressure than the control group. The fact that the control group significantly
 15 outperformed the group with AD in all collected measures confirms that writing is
 16 affected in mild stages of the disease (Cuetos et al., 2003; Werner et al., 2006). The
 17 group with MCI produced similar written latencies to those produced by the group with
 18 AD. Patients with MCI also produced more errors than the control group, but
 19 significantly fewer than the group with AD. It seems that the group with MCI already
 20 exhibits a slowing in the access to the orthographic representations, although they still
 21 have a larger number of spared representations than the group with AD. Interestingly,
 22 the group with MCI did not differ from the control group in ILI durations or pen

1 pressure. Thus, we found no evidence of writing processes taking place after the
2 initiation of the response being significantly affected in the group of patients with MCI.

3 It is widely agreed that increased written latencies reflect increased demands at
4 the central levels of processing (Afonso & Álvarez, 2011; Delattre, Bonin, & Barry,
5 2006; Zhang & Feng, 2017). Thus, the pattern of results reported here may be consistent
6 with an evolution of the writing difficulties from the most central level of processing
7 (which it would be already affected in MCI) that would progress to affect lower levels
8 of processing in mild AD. Consistent with this idea, the three groups did not differ in
9 the number of phonologically plausible or letter errors produced, but only in the number
10 of semantic errors made in the picture naming task. Both group of patients produced
11 more semantic errors in this task (mostly related to inability to recognise the picture).
12 This loss of semantic information may be at least partially responsible for the increased
13 written latencies observed in MCI and AD. However, it is important to notice that
14 reduced writing speed in patients was also observed in the copying task, suggesting that
15 the underlying deficit is not restricted to object recognition.

16 Increased ILI durations observed in the AD group may reflect difficulties at the
17 peripheral levels. As mentioned above, writing durations have been claimed to mainly
18 tap into lower levels of processing. Although some authors have reported compelling
19 evidence of the fact that central processes may cascade to affect writing durations
20 (Afonso et al., 2015; Delattre et al., 2006; Kandel & Perret, 2015; Lambert et al., 2011),
21 it is unlikely that the pattern of results obtained here for ILI durations could be better
22 explained by central rather than by lower processing levels. The fact that the group with
23 MCI showed slowing in written latencies but not in ILI durations is difficult to
24 conciliate with the idea of a common locus of impairment. However, the effect observed
25 in ILI duration could alternatively reflect impaired ability to maintain/retrieve

1 information from the orthographic working memory system (henceforth, OWM). In a
2 study conducted with dyslexic and non-dyslexic adults, Afonso and colleagues (2015)
3 observed that ILI durations were the kinematic variable that was the most sensitive to
4 word length. Word length effects have traditionally been related to additional processing
5 loads in the orthographic working memory system (Caramazza et al., 1987; Miceli,
6 Benvegnù, Capasso, & Caramazza, 1997; Tainturier & Rapp, 2003). The fact that AD
7 patients but not MCI patients showed longer ILI durations than the control group
8 suggests that processes related to letter selection are impaired in mild AD but still
9 spared in MCI. In sum, this effect may be related to difficulties in accessing the motor
10 programs for each letter or to OWM deficits. More research is necessary to establish the
11 underlying cause of this effect. However, it is unlikely that increased ILI durations are
12 due to impairment to central processes.

13 The fact that increased ILI durations and reduced pen pressure were observed in
14 the group with AD but not in the group with MCI diverges from the pattern reported by
15 Werner and colleagues (2006). In this previous study, the group with MCI adopted an
16 intermediate position between controls and AD patients in almost all measures. It is
17 difficult to compare both studies, given the considerable number of differences between
18 them. However, some potential explanations for this discrepancy can be pointed out.
19 First, the group with MCI in Werner et al.'s study obtained a slightly lower MMSE
20 mean score (26.6 versus the 27.2 mean score obtained in the present study), which may
21 translate into greater impairment. Another possibility is that differences in the languages
22 tested in both studies had produced different outcomes. Werner et al. tested Hebrew
23 participants and it might be that handwriting using the Hebrew script is more
24 demanding in terms of motor processes than writing using the Spanish alphabet. It is
25 also possible that the measure of ILI duration measure considered in our study is less

1 sensitive than the measure of whole-word duration reported by these authors. Finally,
2 Werner et al. observed that kinematic variables poorly classified participants in their
3 MIC group, although the same variables together with cognitive functioning allowed the
4 correct classification of around a 70% of the participants in other groups. This might
5 indicate that writing abilities may be particularly variable in patients with MCI. It is
6 important to notice that none of these explanations necessarily challenges our main
7 conclusion. This is, the fact that writing difficulties associated to MCI and AD initially
8 affect higher levels of processing and evolve to affect lower levels of processing. Even
9 if we have failed to detect a real deficit affecting writing durations in MCI, this would
10 only indicate that at this stage of the disease this deficit is more subtle than the
11 impairment affecting higher levels of processing.

12 Patients with AD but not patients with MCI exerted less pressure with the pen in
13 the paper than controls. Decreased pen pressure in the AD group may confirm the
14 presence of an impairment affecting more peripheral aspects of written production that
15 would be absent in the MCI group. Additionally, the fact that neither P-O consistency
16 nor the type of writing task being performed affected the mean pen pressure supports
17 the idea that this variable taps into lower levels of processing. The paucity of studies
18 systematically investigating mean pen pressure makes any interpretation of this effect
19 tentative. Werner and colleagues also found decreased pen pressure in both MCI and
20 AD patients as compared to healthy controls. In contrast, LaBargue and colleagues
21 (1992) reported increased pen pressure in mild to moderate AD patients as compared to
22 controls. What variables may affect pen pressure is an issue that requires further
23 experimental evidence to be settled. Since we are unaware of studies reporting changes
24 in this measure in the same participant depending on the characteristics of the task or

1 the material, it is a possibility that observed differences between groups are merely due
2 to individual differences.

3 The effect of P-O consistency was similar for the three groups and in both tasks
4 (the interaction between consistency and task only approached significance in written
5 latencies). Patients and controls seemed to make use of the phonological information to
6 a similar extent and in a relatively task-independent manner. The fact that phonological
7 information had a similar impact in both tasks apparently contradicts the prediction
8 made by dual-route models (Houghton & Zorzi, 2003; Tainturier & Rapp, 2001), as
9 well as previous findings that evidenced a larger impact of lexico-semantic information
10 in written picture naming than in spelling-to-dictation and copying (Bonin et al., 2015;
11 Bonin, Roux, Barry, & Canell, 2012). This may be explained by the largely transparent
12 nature of the Spanish orthography, which may promote overreliance of Spanish
13 speakers on phonological information to spell. This would also explain that both groups
14 of patients showed a P-O consistency effect similar to the effect obtained for the control
15 group. It is possible that the control group tested in the present study had also over-
16 relied on phonological information to perform the writing tasks.

17 One might think that if the semantic system is impaired in MCI and/or AD
18 patients a larger P-O consistency effect should be observed in participants in these
19 groups than in unimpaired peers, as predicted by dual-route (Houghton & Zorzi, 2003;
20 Tainturier & Rapp, 2001) and PDP (Seidenberg & McClelland, 1989) models. Another
21 possibility is that the increase in number of errors, writing times and pen pressure
22 observed in the group with AD is better explained by general cognitive slowing rather
23 than by specific difficulties with written language (Nebes, Brady, & Huff, 1989).
24 However, the different pattern observed for MCI on the different measures would be
25 difficult to explain from this point of view. In any case, our results do not support the

1 view that semantic deficits have a greater impact on P-O inconsistent spellings in
2 Spanish, at least in the written picture naming and the delayed copying transcoding task.

3 Altogether, our results are in line with previous findings indicating an evolution
4 of the writing deficits in AD from a deficit affecting central processes (which would be
5 already present in MCI) to a later impairment affecting lower levels of processing.

6 However, deficits in the production of individual letters would be more likely to appear
7 in mild states of Alzheimer's disease.

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2

1

Appendix A

2

Experimental stimuli used in the written picture-naming task and in the direct copy transcoding task.

Words	WF	NL	NS	BF	N	AoA	NA
<i>Consistent</i>							
Ce_pillo	5.18	7	3	201	1	3.93	89%
Galli_na	13.04	7	3	517	0	3.43	95%
Le_ón	30	4	2	172	2	5.13	100%
Man_zana	11.07	7	3	39	1	3.03	98%
Mari_posa	6.25	8	4	26	0	3.43	100%
Rue_da	22.86	5	2	39	3	3.93	92%
Te_nedor	3.75	7	3	130	1	2.9	100%
To_mate	6.79	6	3	140	0	4.13	98%
<i>Inconsistent</i>							
Ár_bol	35	5	2	35	0	3.2	97%
Ca_ballo	63.21	7	3	270	2	3.2	100%
Cala_baza	2.5	8	4	24	0	4.27	87%
Ce_bolla	9.46	7	3	74	0	3.17	95%
Cor_bata	17.14	7	3	72	1	4.67	100%
Esco_ba	2.86	6	3	258	0	3.13	97%
Glo_bo	10.18	5	2	20	0	3.04	100%
Ti_jeras	4.82	7	3	24	0	3.4	94%

3

Note. **WF** = word frequency; **NL** = number of letters; **NS** = number of syllables; **BF** = frequency of

4

the critical bigram; **N** = orthographic neighbourhood; **AoA** = age of acquisition; **NA** = name

5

agreement. The underscore symbol (_) marks the position of the critical inter-letter interval.