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Writing abilities and the role of working memory in children with symptoms of attention deficit and hyperactivity disorder

Agnese Capodieci, Alice Serafini, Alice Dessuki and Cesare Cornoldi

Department of General Psychology, University of Padova, Padova, Italy

ABSTRACT
The writing abilities of children with ADHD symptoms were examined in a simple dictation task, and then in two conditions with concurrent verbal or visuospatial working memory (WM) loads. The children with ADHD symptoms generally made more spelling mistakes than controls, and the concurrent loads impaired their performance, but with partly different effects. The concurrent verbal WM task prompted an increase in the phonological errors, while the concurrent visuospatial WM task prompted more non-phonological errors, matching the Italian phonology, but not the Italian orthography. In the ADHD group, the children proving better able to cope with a concurrent verbal WM load had a better spelling performance too. The ADHD and control groups had a similar handwriting speed, but the former group’s writing quality was poorer. Our results suggest that WM supports writing skills, and that children with ADHD symptoms have general writing difficulties, but strength in coping with concurrent verbal information may support their spelling performance.

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ADHD; spelling; writing abilities; types of spelling errors; handwriting

Attention deficit/hyperactivity disorder (ADHD) is a diagnosis that identifies children who exhibit inappropriate levels of inattention and/or hyperactivity (American Psychiatric Association, 2013). The disorder is typically associated with poor scholastic outcomes (e.g., Fischer, Barkley, Edelbrock, & Smallish, 1990). Children with ADHD (Mayes, Calhoun, & Crowell, 2000; Re, Pedron, & Lucangeli, 2010) may have learning disabilities as well, and even those without any such comorbidities may have difficulties at school and be relatively poor in reading and arithmetic. These difficulties may be exacerbated when their impaired self-regulation (in terms of attentional control, planning, organization, monitoring, etc.) is in conflict with the demands of the task, as in writing.

In fact, writing is one of the most complex skills to learn for all children, and even more for children with ADHD (Cornoldi, Del Prete, Gallani, & Sella, 2010), because it involves several cognitive functions, such as planning, generativity, organization, monitoring, attention, and long-term memory, among others, that make the difference between good and poor writers (e.g., Hooper, 2002; Stievena, Michetti, McClintock, Levi, & Scalisi, 2016; Stievena & Scalisi, 2016), and that are typically impaired in
children with ADHD (Biederman et al., 2004; Cornoldi et al., 2010). One such cognitive function is working memory (WM) (Berninger & Swanson, 1994; Swanson & Berninger, 1996), which is crucial during the writing process because it allows to retrieve and maintain words, ideas, linguistic strings and grammatical rules from long-term memory; and to monitor and control irrelevant concurrent information, which is essential in typical everyday-life writing situations (Gathercole, Lamont, & Alloway, 2006; Kellogg, 1996; McCutchen, 2000; Swanson & Berninger, 1996). Writing more efficiently is therefore associated with a better management of WM resources (Olive, 2004). Given that children with ADHD are known to have an impaired verbal and visuospatial WM (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), they can be reasonably expected to have several difficulties in writing tasks, due partly to the role of WM.

However, the writing skills of children with ADHD have received little attention to date, despite their crucial importance at school (Hooper, Swartz, Wakely, De Kruif, & Montgomery, 2002), although some evidence suggests that these children have particular difficulties in the different aspects of writing, such as written expression, spelling and handwriting (Kroese, Hynd, Knight, Heimenz, & Hall, 2000; Mayes & Colhoun, 2007; Mayes et al., 2000; Re & Cornoldi, 2010; Re, Pedron, & Cornoldi, 2007).

In particular, spelling difficulties of children with ADHD have not been thoroughly investigated and research has sometimes focused on specific situations rather than on the general case of writing under dictation, as in the case of a study of Re and Cornoldi (2013) who found that children with ADHD symptoms made more spelling mistakes than typically developing children in a copying task, particularly when they had to write accents and geminates. In another study, Noda and colleagues (2013) studied writing performance in two clinical groups, ADHD and developmental coordination disorder. They considered several aspects, such as spelling accuracy, tracing and copying accuracy, and handwriting. Their results showed that inattention predicted spelling accuracy and handwriting fluency, while a fine motor impairment predicted tracing and copying accuracy. In a subsequent study, Re, Mirandola, Esposito, and Capodieci (2014) argued that the simple writing in a quiet context does not represent the situation typical of everyday school life when children experience concurrent requests or distracting information while writing and therefore writing difficulties of children with ADHD could be underestimated. They therefore examined the case of children writing under dictation while also having to keep verbal information in mind. They administered a dictation task to children with ADHD symptoms and matched controls, with and without a cognitive load on the verbal component of WM. The cognitive load (for the dual task methods see Baddeley, 2001) consisted in a concurrent request that involved retaining in memory a series of orally presented digits that the children heard just before the dictation, and were asked to recall afterwards. The results showed that children with ADHD symptoms have problems with dictation tasks in general, and particularly under verbal WM loading, which makes them produce more phonological errors (PEs). These findings were interpreted with reference to the specific role of the articulatory component of WM (Baddeley, 2001), because spelling involves retaining the material to be written and its orthographic representation, and dividing words into their phonological components, where necessary: If resources in the verbal component are occupied by a concurrent memory request, then spelling performance will deteriorate in children with
ADHD both because their WM is impaired and they have weaker orthographic representations. The study had several limitations, however, as it did not systematically consider the different types of spelling errors, nor the quality of handwriting or the level of the concurrent memory performance. In particular, it was not clear whether the children with ADHD symptoms had a general spelling difficulty anyway, or whether a concurrent verbal WM task produced a specific further difficulty. It was also difficult to interpret the results of the study because a condition involving a concurrent WM task that did not involve the verbal component of WM was not tested. Hence the present study, which adopted the same manipulation with a verbal WM preloading, but also included a visuospatial WM preloading condition obtained with a manipulation that reflected the one used in the verbal concurrent WM task. The dual-task paradigm of the present study, based on the distinction between the verbal and the visuospatial WM components (Baddeley, 2000; Levy & Marek, 1999; Olive, 2004; Olive, Kellogg, & Piolat, 2008; Passerault & Dinet, 2000; Ransdell, Arecco, & Levy, 2001), was thus used to further elucidate how concurrent (verbal or visuospatial) WM tasks interfere with spelling accuracy in children with ADHD symptoms.

If the primary spelling task and a verbal WM loading secondary task compete for the same resources to a greater extent than when the secondary task loads the visuospatial WM, then the impairment in spelling accuracy should be more severe in the case of a verbal WM load. On the other hand, the involvement of WM in spelling may be more general, and/or a concurrent visuospatial WM task might impair spelling performance too, in which case both verbal and visuospatial concurrent WM loading should make spelling accuracy deteriorate by comparison with a control condition with no concurrent load. Furthermore, some aspects of the spelling impairment might also depend on the type of concurrent task, especially as regard the type of spelling errors being made. In fact, the classical distinction proposed by the dual-route model between phonological and non-phonological errors (NPEs; Coltheart, 1984) may be relevant in this setting. Accordingly to the dual route model, regular words can be correctly read and written using either the lexical or the non-lexical reading routes, but irregular words can be read and written correctly only by the lexical reading route: the non-lexical route will get them wrong (Patterson, Marshall, & Coltheart, 2017). PEs represent a violation of the relationship between grapheme and phoneme, so words are written differently from the way in which they were pronounced. Examples of PEs include the exchange of graphemes (e.g., “pox” for “fox”), the omission or addition of letters or syllables (e.g., “diry” for “diary”; “pencicil” for “pencil”), and inversions (e.g., “manechi” for “machine”). NPEs are cases in which the incorrectly-spelled word would necessarily sound right – in a transparent language like Italian– if read aloud, and they occur especially when sentences must be written, rather than single words, as in many cases two different spelling versions may exist in Italian (e.g., “l’una” vs “luna”) and only the context offers the possibility of deciding the correct spelling. Other examples of NPEs that can be found in both English and Italian are incorrect separations (e.g., “con certs” for “concerts”), incorrect fusions (e.g., “thebread” for “the bread”), omissions or additions of the letter “h” when deciding whether it is a form of the verb “to have” or a proposition (e.g., “he as eaten” for “he has eaten”). Control of PEs seems to be related to the activity of the verbal phonological component of WM for coping with phonemes and parts of words and thus should be disturbed to a great extent by a concurrent
verbal WM load. The case of NPEs is more complicated as the orthographic representation of whole words has to be associated (for the English language, at least) not only with phonological processes, but also with the visual representation of how words are written (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Therefore, in the latter case, also a visuospatial WM load could have a disturbing effect.

So, the present study examined whether children with ADHD symptoms, but no comorbid learning disability, have spelling difficulties, and whether any such difficulties are exacerbated when the children’s verbal or visuospatial WM is overloaded. Children from 8 to 12 years of age with ADHD symptoms and typically developing children matched for age, schooling, gender, rated intellectual abilities, and family environment were dictated three sets of sentences, one control without any WM load condition, and two after preloading their WM by asking them to remember a set of digits or a series of locations on a matrix while they wrote. To make the cognitive load comparable for the different tasks and age groups, the concurrent tasks involved 3 digits (in the verbal task) and 3 dots (in the visuospatial task) for children in third and fourth grade, and 4 digits (in the verbal task) and 4 dots (in the visuospatial task) for children of fifth and sixth grade. This was done to take into account the typical improvement in WM during development (Gathercole, Pickering, Ambridge, & Wearing, 2004), and had proved successful in other works (e.g., Cornoldi et al., 2001). The dual task poses, however, the problem of how the performance in a task may affect the performance in the concurrent task. We considered this aspect in the present study by examining not only the writing performance but also the WM performance and correlating the two performances. Opposite predictions could be made on this respect. In fact, on one side, a negative correlation could be predicted as some children could be unable to complete the secondary WM task (even though it is within their capabilities) due to the demands of the primary (spelling) task, or it could be that some children focused excessive resources on the secondary task and their performance in the primary task was consequently impaired. However, also an opposite positive correlation between the performances in the two concurrent tasks could be predicted due to the fact that children who did better in the WM task had a higher WM capacity that also supported them in the spelling task.

The children were involved in writing the dictated material by hand, so the present study also gave us the opportunity to examine the quality and the characteristics of the children’s handwriting. Children with ADHD reportedly (e.g., Borella, Chicherio, Re, Sensini, & Cornoldi, 2011) write less well than typically developing children, and have less motor control, but it is not clear whether these weaknesses relate to difficulties in other cognitive functions, such as WM, or uncertainties associated with spelling. It may be that children with ADHD pay less attention to the quality of their handwriting in order to cope with the dictated material temporarily stored in their WM, or with the overload of WM deriving from the request that they avoid making spelling mistakes. By comparing handwriting quality in the two cognitive loading conditions tested, we could also examine whether a visuospatial WM load typically affecting performance in concurrent visuospatial tasks (Logie, 2014; Stievano et al., 2016) would also impair handwriting quality due to its visuomotor characteristics.

Finally, to investigate the implications of handwriting skills more in general, we also administered a simple speed writing task to shed further light on the controversial issue
of whether children with ADHD write more or less slowly than controls (Adi-Japha et al., 2007; Re, 2006; Ross, Poidevant, & Miner, 1995; Shen, Lee, & Chen, 2012), and to analyze whether a relationship exists between writing speed and spelling accuracy.

**Method**

**Participants**

A group of 26 children (22 males, 4 females) with ADHD symptoms attending third to sixth grade (9 children in third grade, 2 of them females; 8 children in fourth grade, 1 of them female; 6 children in fifth grade, all males; and 3 children in sixth grade, 1 of them female), and a control group of children matched with the ADHD group in terms of age, gender, and family environment. All children in both groups had an average cognitive level, as measured with the Reasoning subtest of the Primary Mental Abilities battery (Thurstone & Thurstone, 1981), and no other serious neurological or psychological problems, as assessed with the COM scale (Capodieci, in press; Marzocchi, Re, & Cornoldi, 2010), or diagnosed learning disabilities. COM scale allows to check for general aspects and symptomatic problems frequently associated with ADHD and consists of 30 items, 5 about general abilities and family environment and the remaining 25 divided into 6 areas that define the disorders most associated with ADHD. The questionnaire has high interjudge and test-retest reliabilities ($r > .90$ in both cases). Table 1 shows the two groups’ mean age, mean scores in the SDAI subscales, and mean sociocultural level, which was assessed with a specific item of the COM scale (Capodieci, in press), and ranged from 0 (high) to 3 (low).

Children were included in the ADHD group on the basis of parents’ reports, teachers’ interviews and the cut-offs on an ADHD scale for teachers, the SDAI ([Scala per i Disturbi di Attenzione/Ipertattività per Insegnanti]; Marzocchi et al., 2010), based on the Diagnostic Manual of Mental Disorders (DSM, American Psychiatric Association, 2013), which has revealed a high reliability and validity (Marzocchi et al., 2010). Before completing the SDAI, teachers were asked to observe the child’s behavior closely for about 2 weeks, and then report the frequency of the symptomatic behaviors described in each item. A score of 14 or higher (the cut-off proposed by the authors; see Marzocchi et al., 2010) on at least one of the two subscales (for inattention and hyperactivity) indicate a child at risk of ADHD. All but 3 of the children in our sample had not been specifically diagnosed with ADHD, which is a condition still rarely diagnosed in Italy at any age (Skounti, Philalithis, & Galanakis, 2007). Between children selected as having symptoms of ADHD, 10 had prevalent inattentive symptoms, 6 had prevalent hyperactive/impulsive symptoms and 10 were of the combined subtype presenting both types of symptoms. Children were not receiving any treatment, including medication. Written consent was obtained from the children’s parents before

| Table 1. Means and standard deviations (SD) for the two groups. |
|-------------------|-------------------|-------------------|-------------------|-------------------|
|                   | ADHD group ($N = 26$) | Control group ($N = 26$) | $F$ (1,50) | $p$ |
| Age (months)      | 116.00 (14.41)      | 115.31 (12.1)      | .04     | .853 |
| Family’s sociocultural level (COM) | 1.95 (1.07) | 1.53 (.96) | .98 | .542 |
| Inattention (SDAI) | 15.42 (5.68) | 1.77 (1.42) | 162.88 | < .001 |
| Hyperactivity (SDAI) | 12.65 (6.95) | 1.38 (1.10) | 79.03 | < .001 |

COM: Comorbidity questionnaire for teachers; SDAI: ADHD scale for teachers;
they took part in the study. The study was conducted in accordance with the recommendations of the Padua University ethics committee and was approved by the university’s institutional review board.

**Materials and procedure**

**Dictation tasks**

Three sets of sentences were dictated to assess the children’s performance in three different conditions: simple dictation, dictation with a concurrent verbal WM task, and dictation with a concurrent visuospatial WM task. Eight sentences were used for each condition. The three sets of sentences were matched for number of words (total 107), proportions of one-, two- and poly-syllable words, difficulty (particularly as concerns accents on the last syllable, apostrophes, the letter “h”, geminates, and so on), and linguistic complexity. Each sentence was divided into 5–7 parts that were each dictated as a short unit to avoid excessive WM loading, but they contained more than one word to enable the emergence of word combination errors. The following sentence is an example (where slashes indicate the pauses between units): “The man/with the red coat/who is at the door/of your house/has rung/the bell/several times” ([L’uomo/con il cappotto rosso/che è sulla porta/di casa tua/ha suonato/più volte/il campanello]). A pilot study in which the sets of sentences were administered without any concurrent task had shown that the three sets of sentences were comparable in terms of their difficulty.

At the end of each dictation, the children also performed a writing speed test, which involved writing as many numbers in letters as possible in 20 s, starting with “one”. The policy of the schools involved in the study prevented us from conducting the tests individually, so the dictations were administered to whole classrooms during normal school hours. The whole process took approximately 90–100 min. The sentences were dictated aloud, at a constant pace, adapted to the children in the classroom, i.e., we waited for almost all the children to finish writing a sentence unit before moving on to the next. No explanations were given before or during the dictation, and the dictated words or other input to be remembered were not repeated.

The procedure for the three conditions was as follows.

**Simple dictation**

The children were given a sheet of lined paper and asked to write the sentences dictated by the experimenter; and – in order to make the intersentence interval similar to the intervals in the other two conditions- after each sentence they had to draw a box around the sentence they had written.

**Dictation with a concurrent verbal WM task**

The procedure was the same as in the simple dictation condition except that, before dictating each sentence, the experimenter pronounced a set of digits (3 digits for children in third and fourth grade, 4 digits for children in fifth and sixth grade) that the pupils had to remember. Then the sentence was dictated and, after writing the sentence, the children had to write the previously heard digits on the sheet, in the same order as they had been pronounced. A trial run was conducted after providing the instructions.
Dictation with a concurrent visuospatial WM task

The procedure was the same as in the previous condition except that the verbal concurrent task was replaced with a visuospatial concurrent task. The children were asked to look for about 4 s at a $3 \times 3$ grid in which there were 3 or 4 dots (3 dots for children in third and fourth grade, 4 dots for children in fifth and sixth grade), and to remember their position. Then, after writing a sentence under dictation, they had to mark the locations of the previously seen dots in an empty $3 \times 3$ grid on their answer sheet. Here again, a trial run was conducted after providing the instructions.

Due to the group administration of the tasks, we could balance the order in which the different conditions were administered, but we presented the different materials always in the same condition. The group administration to the whole classes had the advantage, however, of enabling us to measure WM performance in a large number of children (148 in third grade, 126 in fourth grade; 121 in fifth grade, and 91 in sixth grade), and thus calculate standardized scores for the experimental children using the data collected on the whole sample.

Handwriting speed test

To assess their handwriting speed, the children were administered a test after completing each of the 3 sets of dictations, in which they had to write the numbers in letters, starting from “one”, until the experimenter said the word “STOP” (after 20 s). This procedure was drawn from a battery of tests for assessing handwriting and spelling competence, the BVSCO-2 ([Batteria per la Valutazione della Scrittura e della Competenza Ortografica]; Tressoldi, Cornoldi, & Re, 2013), with a high reliability and validity.

Results

Scoring

Spelling mistakes were assessed according to the BVSCO-2 criteria (Tressoldi et al., 2013), considering PEs, NPEs, and a third category comprising addition or omission of accents and double letters (AD). For dictations in the simple condition, the only aspect to consider was the number of spelling mistakes. For the dictations with concurrent WM tasks, we also considered the recall of digits (in the verbal WM loading condition) and dot positions (in the visuospatial WM loading condition). For the sets of digits, based on the procedure adopted in previous works (Lanfranchi, Cornoldi, & Vianello, 2004; Re et al., 2014), one point was scored for each digit correctly remembered in the right order within the set, with respect to the digit preceding it at least. For instance, if the set of digits dictated was “613”, a child who wrote “628” scored 1 point for remembering one digit out of three and in the right position; a child who wrote “632” scored 2 points because the 6 was in the right position, and because the 3 followed the 6, albeit in the wrong position. As for the recall of dot positions in the grids, one point was scored for each position correctly remembered. The scores for the verbal and visuospatial WM tasks were converted into $z$ scores using the mean and standard deviation of the scores obtained by the whole sample of children in the same school grade.
Handwriting quality was assessed adopting the criteria established in the third edition of the "Handwriting Legibility Scale" developed by Woodcock-Johnson (Woodcock, McGrew, & Mather, 2001). A qualitative analysis of the handwriting was done by two independent judges blinded to the children's groups, who separately awarded three different scores, one for each of the three dictation conditions. The "Handwriting Legibility Scale" envisages scores from 0 to 100, in 10-point steps, with some handwriting judged as: 100: "artistic"; 90: "excellent"; 70: "very good"; 50: "satisfactory"; 30: "adequate"; 10: "poor"; 0: "unreadable". Aspects considered include the slope of letters, the space between letters within and between words, the height of letters such as "p" or "l", the size of letters, the distinction between upper and lower-case letters, and the alignment of the words on the lines on the sheet of paper. Finally, for the handwriting speed measure, we considered the total number of letters written in the three 20-second trials.

**Statistical analyses**

All analyses were conducted using the free R software (R Core Team, 2015). Generalized mixed-effects models were run using the “lme4” package (Bates et al., 2015). Graphical effects were obtained using the “effects” package (Fox, 2003). The distribution of the residuals was assumed to be normal for all measures of interest, except for the spelling mistakes, which were considered as having a “Poisson” distribution because they consisted of a sum of subsequent occurrences, and because the distribution was extremely skewed.

For the dictations, the total number of mistakes in the three different conditions (simple, visuospatial, verbal) for the two groups (ADHD and control) in the different school grades (from third to sixth) were initially considered and analyzed as a measure of spelling performance.

Due to the distribution of the mistakes, the analysis was conducted using generalized mixed-effects models (Baayen, Davidson, & Bates, 2008) with the Poisson distribution, which seems appropriate given the low frequency of the spelling mistakes and the discrete nature of this variable. The number of words written down could also differ across participants because some children had sometimes skipped words, so this number was entered in the models as the offset variable (i.e., the number of spelling mistakes was considered after controlling for the total number of words written down). The fixed effects included in the model were Group (control vs. ADHD; reference category “ADHD”), Condition (simple vs. visuospatial vs. verbal; reference category “simple”), and Grade (third vs. fourth vs. fifth vs. sixth; reference category “third”) and their two-way and three-way interactions. Participants were included in the model as the random effect. Fixed effects were entered in the model in two steps: first only the main effects were considered, then the two-way and three-way interactions were entered. The main effects were considered when assessing the interactions. The significance of the effects was assessed using likelihood ratio tests for nested models (and the relevant distribution is the chi-squared instead of the Fisher-Snedecor F-distribution because mixed-effects models were used; Pinheiro & Bates, 2000).
Results

Figure 1 presents the estimated averages of errors by the two groups (divided for grade) in the different conditions. Concerning the total number of spelling mistakes, we found a significant Group effect, $\chi^2(1) = 23.29, p < .001$. Parameter analysis revealed that the ADHD group made significantly more mistakes than the control group. The estimated average of the total number of mistakes was 8.11 in the ADHD group, and 3.03 in the control group, $B = .99, p < .001$ (where B represents the estimated variation of the value from one group to the other). We also found a significant main effect of Condition, $\chi^2(2) = 8.08, p = .018$, with more spelling mistakes in verbal and visuospatial WM loading conditions than under simple dictation ($B = .20, p = .006$; and $B = .16, p = .034$; respectively). The estimated average of the total number of mistakes was 4.40 in the simple dictation condition, 5.38 under verbal WM loading, and 5.15 under visuospatial WM loading. School Grade had a significant main effect too, $\chi^2(3) = 20.61, p < .001$, with fewer spelling mistakes in fifth and sixth grade than in third and fourth grade. The estimated average of the total number of mistakes was 7.73 in third grade, 5.76 in fourth grade, 3.29 in fifth grade, and 1.98 in sixth grade. As shown in Figure 1, both groups generally made fewer mistakes in the simple dictation condition than in the dual-task conditions. Children with ADHD symptoms made more mistakes than controls in all conditions. None of the interactions were significant. Considering the subtypes of ADHD, we compared children with prevalent inattentive, prevalent hyperactive and combined symptoms. Results must be cautiously considered due to the small sample sizes, but they presented substantial similarities between the subtypes (with the only partial exception of the case of the hyperactive group in the spatial condition) with no significant differences. Estimated average in simple condition was 8.84 for children with prevalent inattentive symptoms, 8.60 for children with prevalent hyperactive symptoms and 9.77 for children with combined symptoms. Estimated average in verbal condition was 11.91 for children with prevalent inattentive symptoms, 10.88 for children with...
prevalent hyperactive symptoms and 11.99 for children with combined symptoms. Estimated average in spatial condition was 11.88 for children with prevalent inattentive symptoms, 8.24 for children with prevalent hyperactive symptoms and 12.16 for children with combined symptoms.

In a second step, we analyzed the children’s WM performance. For the whole sample of children, the correlation between their performance in the two WM loading tasks was low, $r(50) = .24$, but the ADHD group performed less well than the control group for both verbal WM (ADHD: $M = 68.35 \ [19.77]$; control: $M = 77.52 \ [15.60]$, with a medium effect size, $d = 0.51$), and visuospatial WM (ADHD: $M = 88.02 \ [12.22]$; control: $M = 93.39 \ [9.08]$ with a medium effect size, $d = 0.50$), and the difference was significant for both verbal WM ($t = −3.24, p = .002$), and visuospatial WM ($t = −3.26, p = .002$). Maintaining the main effects (of Group, Condition and Grade), performance in terms of the standardized scores (calculated for each Grade with reference to all the children involved in the study) in the verbal, and then in the visuospatial WM loading tasks was added to see how these variables separately influenced spelling performance, and to identify any interactions. Since the ADHD group performed less well in the WM tasks than the control group, considering the effect of Group enabled us to identify the effect of WM on spelling performance after accounting for the effect of ADHD. There was a main effect of verbal WM ($\chi^2(1) = 4.41, p = .036$), but not of visuospatial WM ($\chi^2 (1) = 2.60, p = .107$), and there were no interactions ($\chi^2(1) = 2.38, p = .123$). As the effect was only significant for the verbal concurrent task, we disregarded performance in the visuospatial WM task and focused on the verbal WM task, analyzing the two groups separately. It emerged that verbal WM influenced spelling performance differently in the ADHD group ($\chi^2(1) = 6.05, p = .014$) and the control group ($\chi^2(1) = .12, p = .732$). As shown in Figure 2, although the interaction was not statistically significant, a visual inspection and a separate analysis of the two groups showed that verbal WM influenced spelling performance in the ADHD group, but not in the control group. For instance, in the verbal WM task an estimated average of the total spelling mistakes in the ADHD group was 13.87 at $z = −2$, 10.21 at $z = −1$, 7.52 at $z = 0$, and 5.53 at $z = 1$, whereas for the control group it was 3.18 at $z = −2$, 3.11 at $z = −1$, 3.05 at $z = 0$, and 2.99 at $z = 1$ standard deviation.

The various types of error (PE, NPE, AD) were analyzed together with the fixed effects of Group, Grade and Condition (in the case of the Type of error, the reference category was “AD”). Here again, we found significant main effects of Group, Grade and Condition. The two-way interaction Type of error $\times$ Group was not significant. Parameter analysis revealed that the group with ADHD made significantly more PE, NPE and AD errors than the control group ($B = .67, p < .001$; $B = .36, p = .045$, $B = .55, p < .001$). The two-way interaction Type of error $\times$ Condition was significant, however, $\chi^2(4) = 15.61, p = .004$, with more NPEs in the visuospatial WM loading condition ($B = .60, p = .001$; see Figure 3). Although the three-way interaction was not significant, it is clear from a visual inspection of Figure 3 that the ADHD group’s pattern of errors was more similar in the three conditions than that of the control group, which made few PEs in the simple dictation condition, and many NPEs in the visuospatial WM loading condition, giving the impression that they used a different approach, depending on the resources needed for the second task.
In considering the types of error (with the two-way interactions), we also examined the explanatory power when the interaction between Type of error and performance in the concurrent verbal and visuospatial WM tasks was added to the best model identified. We found that the two-way interaction Type of error × verbal WM was significant, $\chi^2(4) = 63.81, p < .001$, and so was the two-way interaction Type of error × visuospatial WM, $\chi^2(4) = 68.21, p < .001$. In particular, parameter analysis showed that children with a better visuospatial WM generally made fewer NPEs ($B = -0.18, p = .022$), whereas

![Figure 2. Estimated average of total spelling mistakes under dictation with a concurrent verbal WM task as a function of performance in the concurrent verbal WM task.](image)

![Figure 3. Estimated average number of the different types of error (PE vs. NPE vs. AD) for the two Groups (ADHD vs. control) in the different Conditions (simple vs. verbal vs. visuospatial).](image)
children with a good performance in the verbal WM task made fewer PEs ($B = -0.06, p = .048$). We also found a three-way interaction for Type of error $^2$ Group $^2$ verbal or visuospatial WM, but only in the case of visuospatial WM ($\chi^2(3) = 8.23, p = .042$), because the children with ADHD symptoms who fared better in this area made fewer NPEs – an effect not seen in the case of the children in the control group ($B = -.54, p = .008$).

As a final point, when performance in terms of handwriting quality and speed was compared between the two groups, and then considering the importance of WM, the distribution of the residuals was normal, so an analysis of variance for linear models was conducted.

A preliminary examination had shown a good inter-rater reliability (IRR) between the two judges of handwriting quality. IRR was assessed using a two-way mixed, average measures, intra-class correlation (ICC) (McGraw & Wong, 1996) to assess the degree to which the judges were consistent in their ratings of handwriting quality. The resulting ICC was in the “excellent” range ($r = .94$; Cicchetti, 1994), indicating that the judges reached a high level of agreement, and suggesting that their handwriting quality ratings were similar (Hallgren, 2012). We consequently considered the mean rating for a given child as a quality measure, except in the few cases where the ratings diverged, which were discussed by the judges to arrive at a consensus, as recommended in the manual (Woodcock et al., 2001). We then compared the two groups, including Group (control vs. ADHD; reference category “ADHD”), Condition (simple vs. spatial vs. verbal; reference category “simple”), and Grade (third vs. fourth vs. fifth vs. sixth; reference category “third”), and their two-way and three-way interactions, as fixed effects in the model, which were entered in two steps (the main effects first, then the two-way and three-way interactions). The main effects were considered when assessing the two-way interaction. The main effect of Group was significant, $F(1,50) = 7.34, p = .007, \eta^2 = .35$, with the ADHD group obtaining lower scores for handwriting quality than the control group (ADHD: $M = 48.78 \pm 18.84$; control: $M = 57.50 \pm 18.39$), with a medium effect size, $d = 0.47$). So was the main effect of Grade, $F(1,50) = 11.18, p < .001, \eta^2 = .41$, with children in third and fourth grade ($M = 47.89 \pm 18.86$) obtaining lower scores for handwriting quality than children in fifth and sixth grade ($M = 64.54 \pm 16.43$), with a high effect size, $d = 0.94$). The main effect of Condition was not significant ($F < 1$), nor were any interactions. Children with ADHD symptoms had lower scores for handwriting quality than controls in all Conditions and all Grades.

As for handwriting speed, the task did not depend on the WM loading condition because the children had no concurrent task, so we only considered the fixed effect of Group and Grade. The main effect of Group was not significant ($F < 1$), as the ADHD and control children wrote a similar number of letters in 60 s, i.e., 106.65 (30.10) and 104.92 (19.09), respectively. The effect of Grade was significant ($F = 25.30, p < .001, \eta^2 = .38$), with children in third and fourth grade writing more slowly ($M = 94.74 \pm 19.95$) than those in fifth and sixth grade ($M = 126.67 \pm 19.80$), with a very high effect size ($d = 1.61$). No interactions emerged. We also considered the correlations between handwriting speed and number of spelling mistakes, which were significant ($p = .002, p = .017, p = .008$) in all three conditions (simple dictation, with concurrent verbal or visuospatial WM tasks, $-0.41, -0.33, \text{at } -0.36$, respectively).
Discussion

The present study produced new knowledge on the writing abilities of children from third to sixth grade, and specific information on the case of children with ADHD symptoms. The study collected further evidence (Tressoldi et al., 2013) of the important improvements in spelling and handwriting occurring during the latter years of primary school, showing that these improvements affect all types of error. The clear age effect observed in our sample also provides evidence of the discriminatory power of the dictations we used. The study confirmed, moreover, that WM is crucially involved in spelling (Kellog, 1996; McCutchen, 2000), since concurrent WM loading impaired the children’s spelling performance, but did not interfere with their handwriting.

The main goal of the study, however, was to examine the writing skills of children with ADHD symptoms, so the overall results are discussed in terms of the similarities and differences identified between the ADHD and control groups.

One of the main difficulties that children with ADHD encounter in life relates to the academic sphere, but the literature has not paid enough attention to the nature of their difficulties at school, especially in cases of ADHD unassociated with any learning disability. The present study examined writing skills, and produced further evidence of the difficulties of such children in this area (Borella et al., 2011; Re & Cornoldi, 2013). It also clarified some of the mechanisms behind writing abilities, highlighting the role of verbal and visuospatial WM in the writing process. We compared children with ADHD symptoms and a group of typically developing peers on three dictation tasks: one under typical conditions and two with WM preloading, which involved having to remember a set of digits or dot positions while writing the sentences dictated by the experimenter. Our results showed that children with ADHD symptoms in all school grades and in all dictation conditions made more spelling mistakes than controls.

The concurrent WM task prompted much the same increase in the number of spelling mistakes whatever the group or concurrent task (when the overall number of errors was considered at least). It is worth noting that the WM preloading manipulation typically does not severely impair performance in the primary task because individuals can focus on it relatively easily (Re et al., 2014). The fact that WM preloading affected spelling performance (but not handwriting quality) nonetheless suggests that spelling and WM have some resources in common. This assumption is consistent with the notions that the phonological loop is responsible for maintaining and processing sets of both digits and words (Baddeley, 1986), and that an impaired phonological loop affects spelling performance (Re, Tressoldi, Cornoldi, & Lucangeli, 2011). A concurrent visuospatial WM load prompted an increase in the number of spelling mistakes too, suggesting that this component is also involved in writing, presumably to maintain whole representations of written words (Coltheart et al., 2001). In fact, we found that children made more NPE than PE or AD errors in the visuospatial WM loading condition – an effect not seen in the case of a verbal WM load.

It is worth emphasizing that, despite their weaker WM, children with ADHD symptoms were not more severely affected by the concurrent tasks than the controls. It does seem, however, that WM may be crucial for these children, supporting their spelling in some way. In fact, it was only in the ADHD group that a good performance in the concurrent verbal WM task was associated with fewer spelling mistakes. This
probably means that children with ADHD and a good verbal WM can spell better, though this hypothesis needs to be tested in future research by obtaining an independent measure of verbal WM. In the typically developing children, and in the case of visuospatial WM loading, we found no such relationship between performance in the primary and secondary tasks, i.e., there was apparently no explicit tendency to subtract resources from one task in order to complete the other.

The present findings confirmed what we know from the principal writing models, i.e., that WM is crucial during the writing process (Cornoldi et al., ; Kellog, 1996; McCutchen, 1996; Swanson & Berninger, 1996) as it enables all the information needed during the writing process to be managed adequately. In the case in point, an efficient WM enabled the children with ADHD symptoms to keep the digits and dot positions in mind while retrieving the correct spelling of the words being dictated. The fact that visuospatial WM loading interfered with spelling accuracy as well suggests that the phonological loop is not enough to avoid other types of error, when the lexicon stored in the long-term memory is needed (Kellog, 1996). Our children with ADHD symptoms performed less well in the WM tasks than the control children, so it was not that they paid more attention than controls to the WM tasks, at the expense of the dictation task. Generally speaking, the poor overall performance of children with ADHD under WM loading may be due to their impaired WM (Barkley, 1997), and associating two tasks as in the present study (dictation and a WM task) probably overburdened these children’s abilities.

In short, we found that children with ADHD symptoms had a worse spelling performance than their typically developing peers under all test conditions, in all school grades, and for all types of error, with no clear distinctions between the types of error. This picture is inconsistent with the report from Re and colleagues (2013), of children with ADHD making mistakes especially with accents and geminates. The difference may be due to the difficulties posed by the very particular text used for the purposes of the earlier study. As concerns the role of WM loading, we found no specific effects in the ADHD group, even though verbal WM loading influenced their spelling more than in their typically developing peers. Our having included a concurrent visuospatial WM task gave us the chance to shed light on the contribution of different components of WM from those considered in the study by Re and colleagues (2014). We found more NPEs in the concurrent visuospatial loading condition in both groups, and particularly in the controls – presumably because they are better able to use the direct visual pathway in spelling (Coltheart et al., 2001).

As for handwriting, we found that the children’s performance generally improved with aging, and the children with ADHD symptoms had a worse handwriting quality in all test conditions, confirming previous reports (Langmaid, Papadopoulos, Johnson, Phillips, & Rinehart, 2014; Luisotto, Borella, & Cornoldi, 2011; Noda et al., 2013). It is worth noting, however, that concurrent WM loading did not affect handwriting performance, so WM does not seem to be very strongly involved in handwriting (even in its visuospatial component). The same conclusion was reached by several other authors (Brossard-Racine, Majnemer, Shevell, Snider, & Bélanger, 2011; Kaiser, Albaret, & Doudin, 2009; Langmaid et al., 2014), who mainly stressed the role of other neuropsychological functions, such as motor control and visuomotor coordination, rather than WM. No difference emerged between our two groups in terms of writing speed,
confirming previous evidence (Re, 2006; Ross et al., 1995). It seems that a difference can only emerge in certain circumstances, apparently relating to prolonged tasks during which fluctuations in children’s performance may be more evident (Borella et al., 2011). Spelling performance correlated with writing speed, however. This may be due to the nature of the writing speed task (which involved writing numbers in letters, and consequently demanded competence in spelling too). On the other hand, it may be that writing more quickly subtracted fewer resources from the writing process as a whole, enabling the writer to cope better with the demands of the task. In fact, it has already been suggested (Berninger & Abbott, 1994) that handwriting skills influence other aspects of writing, and in particular expressive writing.

Our findings offer a new, coherent description of certain facets of the writing skills of typically-developing children and those with symptoms of ADHD, but the study suffers from a number of limitations that need to be considered in future research. In particular, it would be important to replicate this study with larger, clinical samples of children with ADHD and other disorders (e.g., children with learning disabilities and behavioral disorders), though it is not easy to collect a group of children with an explicit diagnosis of ADHD. In Italy, at least, ADHD is generally diagnosed with caution, and typically only in very severe cases, in children who usually have several comorbidities. Another aspect of our study to point out is the small number of females in the sample, which made it impossible to examine any gender-related effects (although the gender distribution reflected the characteristics of the ADHD populations). In addition, if schools had given the permission to test the children on other measures, it might have been possible to examine the role of other aspects potentially involved in spelling accuracy, such as reading decoding ability, or intelligence. It is also important to consider that the context may have influenced our results. At the request of the schools involved, the tasks (dictations and WM loading tasks) were assigned in class, for all students at the same time. This enabled us to examine the children’s behavior in a situation reflecting typical everyday school activities, but it may be that the results would have been different if the children had been tested individually in a quiet room. A broader array of written materials should be used in future research too, because the fact that some of our results did not replicate previous findings (i.e., the higher frequency of accents and geminates; Re & Cornoldi, 2013) may be due to the specific material used in this study, which focused on distinguishing between phonological and NPEs and had a relatively small number of words that might elicit other errors. Including another primary task with the same concurrent task effects would also offer a further information for examining the nature of the interference caused by concurrent tasks. Similarly, as concerns the secondary task, it would be worth considering the effects of other WM tasks, e.g., simultaneous tasks, for example, instead of preloading manipulations. Or spatial sequential rather than spatial simultaneous material (Pazzaglia & Cornoldi, 1999) could be used to mirror the sequential presentation of the verbal material.

Albeit with the above limitations, the present study sheds light on the important role of WM in sustaining the spelling process (one of the most important academic abilities), and on the difficulties encountered by children with ADHD symptoms. The findings of this study add an important piece to the puzzle concerning the role of WM in the spelling accuracy and handwriting of children.
with ADHD symptoms faced with a typical writing task such as dictation. Schoolchildren typically have to write in conditions that affect their WM capacity, when they are disturbed by concurrent ambient noise, or when they must write while remembering other verbal or visuospatial information, instructions, and so on. Such conditions may foster the occurrence of spelling mistakes – even in the absence of any learning disability in spelling. Limiting such concurrent loads should attenuate the difficulties of children with ADHD symptoms. Various interventions can also help children with ADHD to write better. For instance, Re, Caeran, and Cornoldi (2008) showed that giving children with ADHD guidelines on how to plan a text they have to produce (which involved dividing the text drafting process into separate sentences, and reducing the memory load), not only improved the quality of the text, but also reduced the number of spelling mistakes the children made.

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