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**The role of working memory in learning difficulties of children with symptoms  
of Attention Deficit and Hyperactivity Disorder: the case of writing abilities**

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## **1. GENERAL INTRODUCTION ABOUT MY PhD COURSE**

In these three years of my PhD course I have followed and deepened different lines of research about Attention Deficit and Hyperactivity Disorder (ADHD) and difficulties that these children meet during their life. I have analyzed different impairments in children of different ages with symptoms of ADHD in academic abilities, executive functions and social skills and considered possible strategies of intervention to help these children to address everyday life difficulties.

One first area, a part of which I chose for my PhD project and that I will widely analyze in this thesis, was about writing difficulties in particular orthographic and handwriting abilities in children with symptoms of ADHD. Another aspect of academic difficulties that I investigated and studied during my period abroad at University of Toronto was about math difficulties in adolescent with ADHD, in particular patterns of errors in math calculation. Participants included adolescents with ADHD and typically developing peers between 14 and 17 years old matched in age and IQ. All youth completed standardized measures of math calculation and fluency as well as two tests of working memory and processing speed. Math fluency error patterns were examined. Adolescents with ADHD showed less proficient math fluency despite having similar math calculation scores as their peers. Group's differences were also observed in error types with youth with ADHD making more switch errors than their peers.

Another area of studies was about training in preschool children at risk for ADHD. I have analyzed the effects of training on executive functions (EFs) and specifically working memory (WM) in children of the last year of kindergarten. In these studies children with symptoms of ADHD were randomly divided into two groups: one was assigned to the EFs or WM training condition, and the other continued normal class activities. The training was provided at school in small groups that also included typically developing (TD) children. The trained groups showed a significant improvement whereas no significant improvement was found in the control groups.

Finally, a third area of research was about social difficulties of children with symptoms of ADHD and cooperative learning in class to help these children to better integrate with peers. A study

involved children with symptoms of ADHD of second, fourth and fifth grades and analyzed if they are more rejected in class by their peers and how this situation changed across ages. The study then examined the positive illusory bias (PIB) in children with ADHD and the influence on self-concept and loneliness compared to children with low social abilities but without ADHD. To do that children's self-perception and teachers' perception on social difficulties were compared and finally self-concept and loneliness were analyzed in these two groups also compared with TD children.

Results confirmed the presence of PIB in children with ADHD on social skills but showed that this phenomenon did not protect their self-concept that was similar to children with low social abilities without ADHD.

The other study about social difficulties analyzed if trained teachers using cooperative learning procedures with children in their classroom (aged from 6 to 10 years) can influence the social skills of children with ADHD symptoms and their acceptance by their peers. The study involved children with symptoms of ADHD attending 12 different classes, where cooperative learning was adopted in some, and standard practices in others. ADHD children's symptoms, social skills, and cooperative behavior were assessed by means of a teacher's questionnaire, and the social preferences of the children in their class were collected. Changes emerged in teachers' assessments of the children's cooperative behavior in the experimental classes. Improvements in the sociometric status of children with ADHD symptoms were only seen in the cooperative learning classes. These results show the importance of well-structured intervention in classes that include children with ADHD symptoms.

In my PhD thesis I'm going to focus on a specific aspect considered during the PhD period, i.e. the role of WM in writing abilities of children with symptoms of ADHD, in particular orthographic (study 1) and handwriting (study 2) difficulties, issues poorly developed in literature.

This thesis tries to add to our theoretical and empirical understanding of the writing abilities and the relationship between them and WM in children with symptoms of ADHD. Literature has shown that children with ADHD may fare worse in spelling but few works analyze the difference in writing in

cognitive loading conditions between children with ADHD and their TD peers. Furthermore there is still scarce evidence or even conflicting results regarding the performance of children with ADHD in terms of handwriting, especially in the case of speed, but researchers have yet to consider this issue in depth, in situations under time pressure and memory concurrent requests (as in everyday life and at school, where the child's WM may be overloaded). WM is a relevant variable and has a fundamental role in all writing processes. It is known from the literature that children with ADHD have difficulties in various executive functions, and verbal and spatial WM in particular, and this may affect their spelling, writing speed as well as their writing legibility. In a typical classroom situation, children need to write quickly, generating a WM overload that may be accentuated by the presence of numerous distractors that also affect WM. Until now, however, few studies had systematically examined writing, spelling, speed, and quality in a context involving a WM overload.

In the first chapter of the thesis I focused on the characteristics of ADHD and the academic and executive function difficulties of children with this disorder. Then the particular aspect concerning the interaction between writing and WM was deepened considering literature on this issue.

The second and third chapters focused on experiments conducted during my PhD course about the relation between WM and writing abilities in children with symptoms of ADHD. Finally, in the last chapter the results were summarized, considering limitations and suggestions for future research.

### **1.1. A brief history of research and criteria on Attention Deficit and Hyperactivity Disorder**

ADHD is a common and well-recognized behavior disorder that affects millions of children, adolescents and adults. ADHD has a long and exceptionally rich history of clinical and scientific publication since the initial description of clinical patient by Weikard in 1775 (Barkley & Peters, 2012). Early conceptualization of ADHD focused on inattention, impulsive behavior, and excessive activity as well as defective moral control of behavior (Still, 1902). Later views emphasized ADHD's association with brain damage, particularly to the frontal lobe (Blau, 1936; Levine, 1938), followed by an emphasis on brain dysfunction (Strauss & Lehtinen, 1947). In the 1970s numerous clinical and scientific textbooks appeared (Cantwell, 1975; Wender, 1971; Safer & Allen, 1976), a special journal issue was devoted to the topic along with numerous scientific gatherings (Barkley, 1978; Douglas, Parry, Marton, & Garson, 1976). The exponential increase in research on hyperactivity characteristics of the 1970s continued in the 1980s, making hyperactivity the most well-studied childhood psychiatric disorder. This decade would become known for its emphasis on attempts to develop more specific diagnostic criteria (American Psychiatrist Association, 1980; Sergeant, 1988), the differential conceptualization and diagnosis of hyperactivity versus other psychiatric disorders (Loney, 1983; Quay, 1988) and, later in the decade, critical attack on the notion that an inability to sustain attention was the core behavioral deficit in ADHD (Barkley, 1989).

Advances in developing diagnostic criteria have resulted in more precise specification of symptoms, along with two symptom lists; an emphasis on childhood or early adolescent onset of the disorder in most cases and requirement for both cross-setting pervasiveness of symptoms and evidence of impairment in one or more major life activities (American Psychiatrist Association, 1994).

More recent theories of ADHD have viewed deficits in self-regulation as central to the disorder (Douglas, 1999), while also suggesting that deficits in executive functioning and biologically based motivational difficulties that undergird self-regulation are likely to account for most or all of the symptoms associated with the disorder (Barkley, 1997). Research using neuroimaging techniques



has served to isolate particular brain regions (especially the frontal-striatal-cerebellar network, and possibly other regions) as underlying the disorder, and particularly as involved in the difficulties with inhibition and executive functioning (Castellanos et al., 1996). Increasing research on heredity and genetics has clearly shown a striking hereditary basis to ADHD, along with the identification of numerous candidate genes or chromosomal locations that hold some promise in explaining the disorder (Cook, Stein, & Leventhal, 1997).

Research into the neuropsychology of ADHD has also increased substantially in the past decade; it supports the view that ADHD is not only an inhibitory disorder but also one associated with deficit in the major executive functions that underlie self-regulation (Barkley, 2014).

Numerous longitudinal studies now support the conclusion that ADHD is a relatively chronic disorder affecting many domains of major life activities from childhood through adolescence and into adulthood (Lasser, Goodman, & Asherson, 2012; Molina et al., 2009; Seidman, 2006). Within the past decade, new medications and new delivery systems for older medications have been developed that both broaden the range of treatment options for managing the heterogeneity of clinical cases and sustain medication effects for longer periods across the day (with less need for in-school dosing; Faraone, Biederman, Spencer, & Aleardi, 2006).

Advances in psychosocial treatment research have revealed specific subsets of individuals with ADHD who may be more or less likely to benefit from these empirically proven interventions. They have also revealed the limitations of these approaches for generalization and maintenance of treatment effects if they are not specifically programmed into the treatment protocol (Antshel & Barkley, 2008; Castle, Aubert, Verbrugge, Khalid, & Epstein, 2007).

ADHD is now recognized as a universal disorder, with an ever-growing international acceptance of both its existence and its status as a chronic disabling condition, for which combination of medications and psychosocial treatments and accommodations may offer the most effective management approach (Barkley, 2014).

Diagnostic and Statistical Manual of Mental Disorder (DSM) is an authoritative volume that defines and classifies mental disorders in order to improve diagnoses, treatment, and research. The fifth edition (DSM-5) is the 2013 update to the American Psychiatric Association (APA). The diagnostic criteria used to recognize ADHD in the DSM-5 are the most scientifically validated to date and are based in hundreds of studies, as well as expert consensus opinion. DSM-5 no longer conceptualizes ADHD as comprising three separate types; instead, it is presented as a single disorder that can vary in the population in each of its two symptom dimensions, leading to the creation of three kinds of “presentations” of ADHD rather than subtypes. Although the symptom lists for ADHD in DSM-5 remain the same, qualifier symptoms have been added to help clinicians understand the expression of symptoms at older ages beyond childhood. The age of onset for ADHD have been adjusted upward to age 12 but remains primarily a rough guideline to follow rather than a firm demarcation in what is otherwise the “shifting sands” of development.

So long as cases meet all other criteria for the disorder, clinicians should be flexible in imposing an age onset, recognizing that recall of onset is unreliable.

Although ADHD is presented as a categorical condition in DSM taxonomy, it is actually a dimensional disorder whose symptoms vary in severity across the entire human population and may become a disorder (produce impairment) at excessive levels of severity. The prevalence in children appears to be on average between 5 and 7%, whereas in adults it ranges from 3 to 5%.

#### **Criteria of ADHD (DSM-5)**

**A.** A persistent pattern of Inattention and/or hyperactivity/impulsivity that interferes with functioning or development, as characterized by (1) and/or (2):

**1. Inattention:** Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities.

Note: The symptoms are not solely a manifestation of oppositional behavior, defiance, hostility, or failure to understand tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.

- a) Often fails to give close attention to details or makes careless mistakes in schoolwork, at work, or during other activities (e.g. overlooks or misses details, work is inaccurate).
- b) Often has difficulty sustaining attention in tasks or play activities (e.g., has difficulty remaining focused during lectures, conversations or lengthy reading).
- c) Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere, even in the absence of any obvious distraction).
- d) Often does not follow through on instructions and fail to finish schoolwork, chores, or duties in the workplace (e.g., starts tasks but quickly loses focus and is easily sidetracked).
- e) Often has difficulty organizing tasks and activities (e.g. difficulty managing sequential tasks; difficulty keeping materials and belongings in order, messy, disorganized work, has poor time management, fails to meet deadlines).
- f) Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (e.g., schoolwork or homework; for older adolescents and adults preparing reports, completing forms, reviewing lengthy papers).
- g) Often loses things necessary for tasks or activities (e.g., school materials, pencils, books, tools, wallets, keys, paperwork, eyeglasses. mobile telephones).
- h) Is often easily distracted by extraneous stimuli (for older adolescents and adults may include unrelated thoughts).
- k) Is often forgetful in daily activities (e.g., doing chores, running errands: for older adolescents and adults returning calls, paying bills, keeping appointments).

**2. Hyperactivity and impulsivity:** Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities.

Note: The symptoms are not solely a manifestation et oppositional behavior, defiance, hostility, or failure to understood tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.

- a) Often fidgets with or taps hands or feet or squirms in seat.
- b) Often leaves seat in situations when remaining seated is expected (e.g., leaves his or her place in the classroom, in the office or other workplace, or in the other situations that require remaining in place).
- c) Often runs about or climbs in situations where it is inappropriate (in adolescent or adults may be limited to feeling restless).
- d) Often unable to play or engage in leisure activities quietly.
- e) Is often “on the go”, acting as in “driven by a motor” (e.g., is unable to be or uncomfortable

being still for extended time, as in restaurants meetings; may be experienced by others as being restless or difficult to keep up with).

f) Often talks excessively.

g) Often blurts out an answer before a question has been completed (e.g., completes people's sentences: cannot wait for turn in conversation).

h) Often has difficulties waiting for his or her turn (e.g., while waiting in line).

i) Often interrupts or intrudes on others (e.g., butts in to conversations, games, or activities; may start using other people's things without asking or receiving permission; for adolescents and adults, may intrude into or take over what others are doing).

**B.** Several inattentive or hyperactive-impulsive symptoms were presented prior to age 12 years.

**C.** Several inattentive or hyperactive-impulsive symptoms are present in two or more settings (e.g., at home, school, or work; with friends or relatives; in other activities).

**D.** There is clear evidence that the symptoms interfere with, or reduced the quality of, social, academic, or occupational functioning.

**E.** the symptoms do not occur exclusively during the course of schizophrenia or another psychotic disorder and are not better explained by another mental disorder (e.g., mood disorder, anxiety disorder etc.)

**Specifications:**

**Whether:**

- **Combine** presentation: if both criterion A1 and A2 are met for the past three months.
- **Predominantly inattentive** presentation: if criterion A1 (inattention) is met but criterion A2 (hyperactivity-impulsivity) is not met in the past 6 months.
- **Predominantly hyperactive/impulsive** presentation: if criterion A2 (hyperactivity-impulsivity) is met but criterion A1 (inattention) is not met in the past 6 months.

**If:**

- **In partial remission:** when full criteria were previously met, fewer than the full criteria have been met for the past 6 months, and the symptoms still result in impairment in social, academic, or occupational functioning.

**Current severity:**

- **Mild:** few, if any, symptoms in excess of those required to make the diagnosis are present, and symptoms result in no more than minor impairments in social or occupational functioning.
- **Moderate:** symptoms or functional impairment between mild and severe are present.
- **Severe:** many symptoms in excess of those required to make the diagnosis, or several

symptoms that are particularly severe, are present, or the symptoms result in marked impairment in social or occupational functioning.
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Figure 1. Table with criteria of DSM-5 (APA, 2013).

ADHD severity may fluctuate somewhat across settings and time of the day, and as consequence of various factors in the situation, such as the schedule of consequences for behavior, novelty, adult supervision and other factors.

Mild delays in language, motor, or social development are not specific to ADHD but often co-occur. Associated features may include low frustration tolerance, irritability or mood lability. Even in the absence of a specific learning disorder, academic or work performance is often impaired. Inattentive behaviour is associated with various underlying cognitive processes, and individuals with ADHD may exhibit cognitive problems on tests of attention, executive functions, or memory, although these tests are not sufficiently sensitive or specific enough to serve as diagnostic indices. By early adulthood, ADHD is associated with an increased risk of suicide attempt, primarily when comorbid with mood, conduct or substance use disorder.

Children with ADHD have significant deficits in cognitive, neuropsychological and developmental functioning compared with their peers without ADHD (Barkley, 2014).

These are summarized and listed below:

➤ Summary of cognitive and neuropsychological functioning

1. Intellectual functioning (Ek, Westerlund, & Fernell, 2013; Frazier, Demaree, & Youngstrom, 2004; Mariani & Barkley, 1997; Jepsen, Fagerlund, & Mortensen, 2009; McConaughy, Ivanova, Antshel, & Eiraldi, 2009):

- Children with ADHD often perform lower on IQ tests than children without the disorder, and the difference can be as much as 9 points.
- Children with ADHD, however, generally have IQ scores in the average range and not substantially below average.

- Levels of intelligence vary among individuals with ADHD just as they do in the general population.
- Symptoms of inattention and hyperactivity-impulsivity may affect cognitive test performance in all children, not just those with ADHD.
- Profile analysis, although common practice among school psychologists, is controversial and largely criticized by psychometric theory.

2. Executive functions (EFs; Biederman et al., 2007; Gordon, Barkley, & Lovett, 2006; Rajendran et al., 2013; Toplak, West, & Stanovich, 2013; Weyandt et al., 2013)

- EFs encompass a variety of cognitive abilities that allow for impulse control, strategic planning, cognitive flexibility, and goal-directed behavior.
- EFs deficits are characteristic of many, but not all, individuals with ADHD and are present in other childhood disorder.
- Evidence suggests that children with EFs deficits have lower academic achievement.
- EFs deficit are likely to emerge early in life in children with ADHD, and the impairments tend to persist into adolescence and young adulthood.
- EFs deficit are routinely more common and more severe on rating scale than in psychometric tests.

3. Planning (Barkley, 2011; Gau & Chiang, 2013; Weyandt et al., 2013; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005):

- The EF construct of planning has been conceived in a number of ways, including visual-spatial and strategic planning.
- Deficit in planning is characteristic of some, but not all, children with ADHD.
- Planning deficits are also found in children with other types of clinical disorder and are neither unique to nor diagnostic of ADHD.

4. Inhibition (Corbett, & Constantine, 2006; Skogli, Egeland, Andersen, Hovik, & Øie, 2014; Van Mourik, Oosterlaan, & Sergeant, 2005):

- The literature indicates that a variety of EFs tasks have been used to measure behavioral inhibition, and the psychometric properties of these tasks vary.
- Many, but not all, children with ADHD perform more poorly on the inhibition tasks than do children without the disorder.
- Inhibition tasks do not differentiate reliably between different subtypes of ADHD, although findings are inconclusive, and they are not diagnostic of ADHD.

5. Working memory (WM; Åsberg Johnels, Kopp, & Gillberg, 2014; Martinussen & Tannock, 2006; Thissen et al., 2013):

- Many studies have found that children with ADHD perform more poorly than their nondisabled peers on WM tasks that require memory for digits forward and backward.
- Differences between children with and without ADHD in WM are larger when tasks are complex.
- Verbal WM problems are not unique to ADHD; children with other disorder show similar difficulties. Some studies suggest that nonverbal WM of children with ADHD may be substantially more impaired than verbal WM.

6. Sense of time (Plummer, & Humprey, 2009; Walg, Oepen, & Prior, 2015):

- Individuals with ADHD may have deficient time perception (e.g. estimation passage of time processing time, and time discrimination).
- Findings relative to time perception in individuals with ADHD have been mixed, however, and studies are often characterized by methodological problems.

#### ➤ Summary of Developmental Functioning

1. Adaptive functioning (Barkley, Fischer, Edelbrock, & Smallish, 1990; Reynolds & Kamphaus, 2004; Ware et al., 2012):

- Adaptive functioning is generally poorer in children with ADHD than in typically developing children.
- Deficits are common in the areas of daily living and social communication.

- Difficulties appear to be related to ADHD symptomatology and not limited to externalizing symptoms of Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD).

2. Motor coordination (Brossard-Racine, Shevell, Snider, Bélanger, & Majnemer, 2012; Harvey & Reid, 2003; Waternberg, Waiserberg, Zuk, & Lerman-Sagie, 2007):

- A large percentage of children with ADHD exhibit some types of motor coordination problems.
- Impairments often appear in the motor skills domains of strength, visual motor coordination, adjusting speed, and dexterity.
- Evidence suggests that ADHD inattentive or ADHD combined subtypes are more likely to display motor coordination difficulties compare to those with the ADHD hyperactive-impulsive subtype.
- Manual dexterity difficulties are often the most impaired domain of motor coordination (e.g. writing, drawing, and playing a musical instrument).
- Stimulant medication and physical therapy are often effective at improving motor deficits in children with ADHD.

3. Language abilities (Kim & Kaiser, 2000; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Staikova, Gomes, Tartter, McCabe, & Halperin, 2013; Wassenberg et al., 2010):

- Linguistic difficulties are prevalent in children with ADHD and may be identified as early as during the preschool years.
- Difficulties are often evident with receptive, expressive, and pragmatic language skills.
- Linguistic deficits may cause difficulty comprehending instruction, making inferences about social context, and initiating, maintaining, and ending a conversation.
- Language abilities may have an impact on the social functioning of children with ADHD.
- Social difficulties may further exacerbate the language deficits associated with ADHD.
- Subtypes of ADHD may be differentially associated with difficulties in different domains of language ability.



4. Learning difficulties (DuPaul, Gormley, & Laracy, 2013; Mayes, Calhoun, & Crowell, 2006; Reuben, 2008; Scholten, Rydell, & Yang-Wallentin, 2013; Washbrook, Propper, & Sayal, 2013; Weyandt, 2007):

- Learning disabilities (LDs) and academic underachievement are more common in children with ADHD than in the general population.
- Comorbidity rates of LDs and ADHD may be as high as 45%.
- Children with ADHD who do not meet diagnostic criteria for LDs often have some degree of learning difficulties.
- Common coexisting learning problems include lower academic achievement, use of special education services, grade retention, higher rates of high school dropout, and lower rates of postsecondary education.
- Evidence suggests behavior-based strategies are the most effective in addressing the academic difficulties of children with ADHD.

5. Self-perception (Corkum, Humphries, Mullane, & Theriault, 2008; Hoza et al., 2004; Hoza, Pelham, Dobbs, Owens, & Pillow, 2002; Kopecky, Chang, Klorman, Thatcher, & Borgstedt, 2005):

- Studies suggest that children with ADHD often display an inflated self-esteem.
- Internalization of speech may be an important component of self-regulation.
- Children with ADHD appear to demonstrate a different, potentially less developed pattern of private speech than children without ADHD.

## **1.2. Attention Deficit and Hyperactivity Disorder and academic difficulties: the case of writing abilities**

As suggested in the previous chapter, although the primary characteristics of ADHD are inattention, hyperactivity and impulsivity, there are other secondary characteristics frequently associated with the disorder; between these impairments there are in particular academic difficulties.

### **Academic difficulties and ADHD**

The impulsiveness and inattention characteristics and the deficits of EFs inevitably interfere in a negative way with the child's school performance. The main repercussions are in reading skills, writing skills, understanding of written texts, and solving math problems (Graham, Fishman, Reid, & Hebert, 2016). Children with ADHD are unable to implement effective strategies to use the knowledge that they had acquired, failing to properly organize the study material, and failing to maintain concentration on the same task for the time it takes to complete it. In addition, they are easily attracted to distracting elements and are unable to inhibit irrelevant information for the purpose of the activity to be performed. Among subjects with ADHD there are some that also meet the criteria for a specific LD, so it is possible to formulate a double diagnosis. In a recent review of 17 studies assessing the comorbidity of ADHD and LD, DuPaul, Gormley and Laracy (2013) concluded that the comorbidity rate is as high as 45%, that is higher than previous estimates have indicated (Cantwell & Baker, 1991), probably for changes to DSM-5 criteria of LD and ADHD. Furthermore the results suggested that many children with ADHD who did not meet the criteria for an LD had some degree of learning difficulties (Mayes, Calhoun, & Crowell, 2000). In a longitudinal study (Scholtens, Rydell, & Yang-Wallentin, 2013) ADHD symptoms measured in grades 6, 11, 12, were stable over time and negatively associated with both concurrent and future academic outcomes. Studies have indeed shown that children with ADHD are more likely to demonstrate lower academic achievement, require special education services, experience grades retention, have higher rates of high school dropout and lower rates of postsecondary education than

their peers without ADHD (Barkley, 2014; Barkley, Fischer, Edelbrock, & Smallish, 1990; Biederman et al., 2004; Manuzza, Gittelman-Klein, Bessler, Malloy, & LaPadula, 1993).

### **ADHD and writing abilities**

Between the academic abilities, writing represents an important and complex activity for everyday life of children at school. Writing is not simply a transcription of thoughts or concepts but requires the involvement of complex cognitive processes, such as the production of ideas, organization, transcription, and review. The competent writer must pay attention to different actions simultaneously, keep them in memory and regulate their correct execution at the right time (Casas, Ferrer, & Fortea, 2013). Writing is not just goal-directed and self-sustaining; it requires managing the writing environment and the constraints imposed by the writing topic, as well as the self-regulatory processes (planning, evaluating, monitoring, drafting, and revising), knowledge (topic, genre, linguistic, and semantic), and skills (handwriting, typing, spelling, and sentence construction) that make writing possible (Bereiter & Scardamalia, 1987; Graham, 2006). Kellogg (1986) reported that writing required more cognitive effort than mentally challenging tasks like reading complex text, and it approached the cognitive effort expended by expert chess players.

Given the difficulties in EFs (such as planning, organizing) and WM of subjects with ADHD (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Martinussen & Tannock, 2006), it could be expected that it is likely to result in specific problems with writing. In fact, students with ADHD experience difficulty with many of the general cognitive processes and capacities that underlie effective composing (Graham, Harris, & Hebert, 2011; Hayes, 2012; Kellogg, 1986).

Problems with either executive functioning or WM likely make it more difficult for students with ADHD to act in a strategic and goal-directed manner when writing; access and manage the various processes, strategies, skills, and motivational dispositions underlying effective writing; or access ideas from memory as well as act upon them while they are held in WM (Lienemann & Reid, 2008).

Until now, most of the studies on the relationship between ADHD and LD have focused mainly on reading and math difficulties. The relationship between ADHD and writing skills (intended as written expression, spelling and handwriting), however, began to be investigated only in recent years. The cause of this "delay" has to be found in a fundamental theoretical reason: written language has always been subordinate to spoken language, therefore, especially from a didactic point of view, learning to read is considered important and preparatory to learn to write (Re, 2006): for this reason, reading studies have hitherto preceded those on writing.

One of the first researches dealing with the relationship between ADHD and writing was carried out by Resta and Eliot (1994) who investigated the differences in the readability of writing between students with ADHD and students without any problems. This study included 32 pupils aged 8 to 13, of which 10 with ADHD of the combined type, 11 with ADHD of inattentive type and 11 without any problems. The aim of the research was to ascertain, as mentioned above, the differences in the readability of writing between the 3 groups of subjects and to verify their written expression. The writing test consisted of writing 3 short texts on 3 different themes. The results showed that subjects with ADHD, compared with the control group, had poorer performance with regard to readability of the handwriting and lower productivity, using fewer words in the texts.

In another study Ross, Poidevant, and Miner (1995) compared the writing speed of 48 primary school children diagnosed with ADHD and the same number of children without any disorder. The task of the children was to write the numbers from 0 to 9 and the letters of their name for a minute. The obtained results did not find any differences between the two groups of subjects. This demonstrates that the fluidity and speed of writing are not typical problems of children with ADHD: the difficulty of writing is rather related to the spelling and written expression (as evidenced in the work of Resta & Eliot, 1994). A recent meta-analysis (Graham et al., 2016) and studies in the last twenty years shown that children with ADHD underachieved on different measures of writing skills: handwriting (Adi-Japha, Landau, Frenkel, Teicher, Gross-Tsur, & Shalev, 2007; Brossard-Racine, Majnemer, Shevell, Snider, & Bélanger, 2011; Luisotto, Borella, & Cornoldi, 2011; Shen,

Lee, & Chen, 2012; Fliers et al., 2009), spelling (Alloway, Gathercole, & Elliot, 2010; Cornoldi et al., 2001; Re & Cornoldi, 2015; Re, Mirandola, Esposito, & Capodieci, 2014; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011) and written expression (Barry, Lyman, & Klinger, 2002; Mayes & Calhoun, 2007; Molitor, Langberg, & Evans, 2016; Re, Pedron, & Cornoldi, 2007; Rodríguez et al., 2015). In fact, writing skills could be considered to include three different aspects that will be described deeply below:

- Handwriting abilities;
- Spelling abilities;
- Written expression abilities.

**Handwriting abilities.** Handwriting is an important and complex skill that combines different components, and involves integrating cognitive, psychomotor and biophysical processes acquired over an extended period of time (Adi-Japha et al., 2007) and also interacts with the linguistic processes involved in maintaining and processing the verbal to-be-written material (Berninger & Abbott, 1994). Handwriting skills are needed to cope with many tasks at school. Despite the introduction of computerized writing systems, handwriting is still a prerequisite for most classroom activities. Consider handwriting per se, excluding the expressive and orthographic components, the two fundamental aspects of handwriting are quality and speed. Graphic quality is obviously crucial in order to meet the main functions of writing concerning maintenance and transmission of knowledge. However speed is also very important because it not only affects efficiency in performing classroom activities, but also enables children to keep up with classwork (by copying from the blackboard, for instance, taking notes, or writing under dictation). Writing speed develops in a rather linear manner during primary school, and the overall development of graphic skills continues during secondary school (Feder and Majnemer, 2007). In this respect, it is particularly important for children to acquire automatized processes in writing graphic signs that can be written quickly and accurately without the need for conscious attention. A low level of automaticity when

writing by hand generates a poor performance, in qualitative and quantitative terms (Connelly & Hurtst, 2001).

There are many aspects to consider when examining children's handwriting, including the quality and accuracy of the text produced, the graphic quality of the handwriting, the speed and rate variability of its production. Few studies have investigated the relationship between ADHD and handwriting, however, and the results appear unclear and mainly associated with qualitative observations concerning poor quality mentioned by teachers who report that written productions of children with ADHD are often disordered and illegible (Cornoldi, Gardinale, Masi, & Pectenò, 1996), further supported by research showing the poor quality of handwriting of children with ADHD (e.g. Langmaid, Papadopoulos, Johnson, Phillips, & Rinehart, 2014). However, in the case of handwriting of children with ADHD, also speed appears particularly relevant as writing slowly can be a crucial issue for children with ADHD because they find it difficult to comply with the time constraints on school work (Amundson & Weil, 1996), but evidence on differences in handwriting speed between children with ADHD and matched controls is unclear and even contradictory. For example, the study by Ross and colleagues (1995) showed no difference between the ADHD and the control groups. Similarly, Re (2006) investigated whether ADHD affected the writing skills of secondary school students, finding that those at risk of ADHD had more difficulty in dictation, but not in writing speed. Other authors did find differences in writing speed between children with ADHD and their TD peers, but with results pointing in opposite directions. For example, Adi-Japha and collaborators (2007) found that children with ADHD wrote more slowly, while other authors found they wrote more quickly and hurriedly (Brossard-Racine, Majnemer, Shevell, & Snider, 2008; Shen et al., 2012). Such inconsistent results concerning the writing speed of children with ADHD may be partly due to the type of task proposed, which varied in the different studies. In particular, it should be noted that writing by hand in a laboratory context may differ from writing during everyday school activities, when children's WM may be loaded with other demands while they are writing (such as holding in mind complex instructions, committing information to memory,

organizing the space on the paper, etc.), and there may be several contextual distractions: these aspects were not considered in previous studies. Examining handwriting performance in contexts where the cognitive system is overloaded may be therefore important.

**Spelling abilities.** The spelling correctness is an important aspect of writing that is often deficient in children with ADHD. According to a spelling error classification, which is widely recognized in Italy, being based on the reading and writing learning model proposed by Uta Frith (1985), the child learns to read and write through different stages, each one characterized by the acquisition of skills that are consolidated and automated with the transition to the successive stage.

During the first stage, the logographic one, the child is only able to associate a graphic configuration with a certain concept, recognizes and is able to read a few words globally, because they contain letters or elements that she/he has learned to distinguish; however, she/he has no spelling or phonological knowledge on the words. The alphabetical stage coincides with the acquisition of the mechanism of grapheme-phonemic conversion, which allows the child to learn to associate each phoneme with the corresponding graphic sign, allowing them to read even the unknown words. Typical phonological errors are associated with this stage, due to the inability to link each phoneme to its graph. During the spelling stage children learn the spelling and syntactic rules; the reading unit is the syllable and the child can read and write more quickly. The last stage is the lexical one, which coincides with the formation of a more complex vocabulary that allows them to read and write words without necessarily recovering the phoneme associated with the grapheme (so it is no longer necessary to perform the grapheme-phonemic conversion). Examples of errors that can be attributed to this stage are uncorrected fusions or separations.

The most common spelling error classification in Italy (Tressoldi & Cornoldi, 1991; Tressoldi, Cornoldi & Re, 2013) distinguishes 3 types of errors:

- phonological errors: the relationship between graphemes and phonemes is not respected, so words are written differently from how they should be pronounced. These mistakes include the exchange of graphemes (such as "blane" for "plane"), omission or addition of letters or syllables (such as

"tale" for "table", "homeme" for "home"), inversion (such as "enreti" for "entire") and inexact grapheme (such as "ouse" for "house").

- non-phonological errors: the spelling representation (visual) of the words is incorrect, so the words are written incorrectly, but the pronunciation tone is the same as the correct one. Errors belonging to this type are uncorrected separations (such as "to gether" for "together"), uncorrected mergers (such as "thedor" for "the door"), addition or omission of the apostrophe (such as "parent's" for "parents"), omission or addition of "h" in case that is necessary to decide whether or not the verb is to have or a proposition (such as "he as" for "he has") and exchange of homophonic graphemes (such as "sqhool" for "school").
- errors of accents and double letters: omission or addition of accents (such as "cafe" for "café") or double letters (such as "potery" for "pottery").

In research carried out by Re (2006), spelling accuracy (in a dictation writing task) and speed of writing were investigated in first grade secondary school children at risk for ADHD profile and control subjects. The results showed that subjects with typical symptoms of ADHD made on average more errors than the control group in the dictation task: the difference in phonological errors was not significant, as well as for the non-phonological errors. As regards the errors of accents and double letters the difference instead was significant. Once again no differences were detected for writing speed, confirming the results previously obtained by Ross et al. (1995).

A wider research carried out by Re and colleagues (2007), checked the quantity and kind of spelling errors and has also investigated other important aspects related to the writing process. The study analyzed performance in spontaneous writing tests in children with typical ADHD symptoms compared with TD subjects. The results obtained showed that the performance of subjects with ADHD compared to TD peers was worse for all the qualitative aspects and a great number of errors was present, especially regarding the use of accents and double letters. The authors hypothesized that the difficulties encountered in producing a proper, correct and organized text are due to the complexities that children with ADHD typically encounter (Re et al., 2007).



In addition to making spelling errors in spontaneous production of a text or under dictation, subjects with ADHD often experience difficulties even when asked to copy a text. In a recent study, Re and Cornoldi (2015), presented to children with dyslexia, children with ADHD and children without any disorder, a writing task that required them to copy as many words of a text as they could within 5 minutes of time. In general, the performance of children with ADHD and dyslexia was lower than that of control subjects, but with a significant difference only in the case of errors related to accents and double letters. There were no significant differences in the total amount of errors made by the subgroup with dyslexia and the subgroup with ADHD: it can only be noted that children with dyslexia tend to commit more phonological errors in comparison with subjects with ADHD. As for the amount of words copied in the expected time, the difference is significant between the ADHD and dyslexia group and the control group, while there was no apparent difference between the ADHD subgroup and the dyslexia subgroup (Re & Cornoldi, 2015).

Another interesting study about spelling abilities was carried out by Re and colleagues (2014) and considered the role of the phonological component of WM in writing process. Authors compared the performance of children with ADHD with TD peers in two tasks: the first was a simple dictation task and the second a dictation that required to keep in mind a series of numbers while the phrase was dictated (condition of overload phonological WM). The results showed a greater percentage of errors in general for ADHD patients, but above all in the dictation with overload of the phonological component, where a significant increase in phonological errors was found. These outcomes seem to confirm the fundamental role of the phonological loop (and therefore of the WM) in maintaining and processing both words and numbers.

**Written expression abilities.** This third type of writing skill is not an area of investigation in the thesis being one of the most studied areas in the last years (Rodríguez et al., 2015). Nevertheless I will give an overview about what written expression abilities are and the principal results in this area. As confirmed in many models of writing (Hayes, 2012; Kellogg, 1986), in order to write an essay, it is necessary not only to produce ideas but also to organize them in line with the objectives

of the task. Producing ideas is the first step of the planning phase of writing, which includes generation of ideas, organization of the produced material, and goal setting. Moreover, goal setting becomes better defined and more specific during the transcription and revision of the essay (Bereiter & Scardamalia, 1987). The revision phase of writing is very important not only for better definition of the goals of the essay, but also for correcting orthographic errors (Swanson & Berninger, 1996).

Owing to its complexity, expressive writing is a difficult skill to acquire for all children, but it may present a number of particular difficulties for ADHD children in view of their problems with the underlying processes (Berninger & Rutberg, 1992; Hooper, 2002). The difficulties displayed by ADHD children with planning and monitoring (for a review, see Seidman 2006) and also with phonological and orthographic skills (Kroese, Hynd, Knight, Hiemenz, & Hall, 2000; Re, 2006; Casas et al., 2013; Re et al., 2007) are well documented in the literature. Even if our current understanding of how writing normally develops is not complete, enough is known to be certain that the path to competence depends on (1) mastering foundational writing skills such as handwriting (or typing), spelling, and sentence construction; (2) acquiring effective processes and strategies for planning, drafting, monitoring, evaluating, and revising text; (3) obtaining relevant knowledge about different types of writing, vocabulary, audiences, and grammar and usage; and (4) developing motivational dispositions that facilitate good writing, such as positive sense of efficacy about one's writing capabilities (Graham, 2006; Graham & Harris, 2000). So as it can be understood, expressive writing needs the other two writing skills discussed before: handwriting and orthographic abilities, together with strategies for planning, drafting, monitoring, evaluating, revising text and knowledge about writing. Various studies analyze the performance of children with ADHD compared to TD peers in these abilities (Rodriguez et al., 2015), and they found an underachievement of these children in all the activities related to expressive writing skill.

In the study cited before by Re, Pedron and Cornoldi (2007), they have investigated important aspects related to the writing process. The study analyzed performance in spontaneous writing tests

in children with typical ADHD symptoms compared with control subjects. Four qualitative parameters were considered for the purpose of the evaluation: the appropriateness of the written text in relation to the delivery, structure (based on the organization), grammar and amplitude of the lexicon, that is the amount of different words used (BVSCO - Batteria per la valutazione della scrittura e della competenza ortografica nella scuola dell'obbligo, Tressoldi & Cornoldi, 1991). The results obtained showed that the performance of subjects with ADHD compared to controls was worse for all the qualitative aspects: the texts produced were shorter, were not effectively organized, the vocabulary used was very limited and a great number of errors was present, especially regarding the use of accents and double letters. These deficits seemed to be independent from the type of task (description or narration) and the type of presentation (verbal item or image) despite the performance of children with ADHD being slightly better with verbal deliveries rather than with instructions requiring the use of images.

Another study by Casas and colleagues (2013) asked children with ADHD to write a short story about a personal experience, a journey. When they finished composing the text, the children had to revise their work and to correct any errors they thought that they had committed with a red pen, or to make some changes that could improve their story. For the evaluation, different indicators were used to reflect the aspects of the planning, translation and review phases that are typical of the writing process. Subjects with ADHD proved to be "less capable" writers because their performance was lower than that of the control group.

As regards text structuring, students with ADHD had difficulty in articulating an organized plan; they wrote shorter texts, with few words and subordinate phrases. Also, in the phase of translation children with ADHD got worse results than their class-mates. In addition, the time sequence of events in the story was not consistent and there were many digressions and phrases not relevant to the subject. Therefore, children with ADHD experience difficulties both in the planning process and in the translation and review processes, that is in the organization of the information to be included in the text to be composed.

There are some studies in the literature that show how the use of certain procedures can improve the writing process of children with ADHD. In a study, De La Paz (2001) examined whether instructing the children to use a planning strategy to write a text, they would have gotten an improvement in the quality of the written expression: after training, the children wrote longer and better texts from a qualitative point of view. To deepen written expression skills in children with ADHD and to evaluate any benefit of using facilitations Re, Caeran and Cornoldi (2008) carried out further research that showed that support during text planning could help children in the writing activity.

### **1.3. Attention Deficit and Hyperactivity Disorder and working memory**

Another important secondary difficulty found in the majority of children with ADHD, as stated before, are EFs, in particular WM.

#### **Executive functions and ADHD**

EFs are a set of general-purpose control processes that regulate one's thoughts and behaviors, inside of this set there are different skills and abilities like WM, capacity to suppress inappropriate responses or behaviors, and to shift between different activities (Miyake & Friedman, 2012). These varieties of cognitive processes (inhibition, planning, problem-solving, WM, flexibility, etc.) aim at applying complex behaviors that allow individuals to achieve certain goals.

In everyday life, it is important to be able to coordinate a number of cognitive functions that ensure behavioral flexibility and allows an individual to distribute the attentive resources to coordinate sequences of various actions to be performed. These skills are controlled by frontal brain regions, involved in planning and performing complex behaviors and related to other areas that govern motivation and emotions (ventral areas of the frontal lobe and limbic system; Stuss & Alexander, 2000). Compared to their TD peers, children with ADHD have been shown to perform poorly on an array of neurocognitive tests (Ware et al., 2012; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) as demonstrated from important meta-analyses that showed impairment of children with ADHD in several EFs (e.g., Reid, Trout, & Schartz, 2005; Willcutt et al., 2005). As above-mentioned, children with ADHD have difficulty in inhibiting inappropriate behaviors and to organize, rather, appropriate behaviors and strategies for achieving a predetermined goal. In addition, they have poor problem-solving skills, with difficulties in analyzing problematic situation and, consequently, to implement behaviors that will lead to a solution.

Among the many cognitive deficits that have been linked to ADHD, considerable attention has focused on WM impairments (Kasper, Alderson & Hudec, 2012; Martinussen et al., 2005). For example, the meta-analysis of Martinussen et al. (2005) highlighted an ADHD impairment in WM

that was greater in visuospatial WM than in the verbal one. A study carried out by Cornoldi and colleagues (2001), found that children with ADHD are unable to ignore some information that, initially, for the purpose of the task should be processed but that later should be excluded from memory to focus on the processing of new elements. Even this inhibition deficit is one of the difficulties associated with WM. Finally research analyzed how EFs and WM are related with future outcomes in young females with ADHD and showed that childhood EFs – particularly measures of global EFs and WM – predicted academic and occupational functioning across the entire sample (independent of diagnostic group status), but diagnostic status (ADHD versus comparison) moderated the association between WM and reading achievement and a global EFs measure and suspensions/expulsions. That is, in the ADHD group, low WM predicted poor reading scores and impaired global EF predicted higher suspensions/expulsions, but this was not the case in the comparison group (Miller, Nevado-Montenegro, & Hinshaw, 2012). It is clear the importance of EFs, and in particular WM on the functioning of the individual with ADHD.

### **Working memory**

Memory is the ability to assimilate, retain and recall learned information. The three fundamental mnemonic processes are encoding, which regulates information acquisition, storage, destined to retention, and retrieval, which allows have access to some information that has previously been stored. The most common and sustained memory classification criterion is based on the duration of retention and retrieval of the information. It is therefore possible to distinguish the sensory memory system, short-term memory, and long-term memory (Atkinson & Shiffrin, 1968).

In the sensory store, the environmental information captured by the sense organs is deposited for a very limited period of time; hence, the information that has been selected by the attention processes passes to the short-term store, which temporarily keeps small amounts of information for short periods of time; finally, if they are consolidated through repetition, they arrive at the long-term

memory store, which contains all the information that is available, and whose capacity is therefore unlimited (Atkinson, Atkinson, & Hilgard, 2003).

The WM system has often been associated with the short-term memory system since, in addition to allowing temporary storage of information; it also allows the manipulation of the stored information, so that it is available for complex cognitive activities such as reasoning, learning and understanding. Several models of WM have been developed, but it is a rather concordant opinion among researchers that the WM is a kind of "mental space" that can provide a basis for thought (Baddeley, 2009). Research with children supports the distinction between short-term memory tasks that involve the storage of information and WM tasks that demand attentional control (Alloway, Gathercole, & Pickering, 2006; Martinussen & Major, 2011). This distinction seems to be crucial in the case of children with ADHD, who are weak in controlled WM, but not in short-term memory (e.g. Cornoldi, Giofrè, Calgaro, & Stupiggia, 2013). Finally Cornoldi (2007) have shown that the differentiation between passive (low controlled) and active (high controlled) WM processes may vary along a continuum also including intermediate cases.

### **Multi-componential model of working memory**

The idea that short-term memory could be considered as a global work space derives from the work of Atkinson and Shiffrin, who in 1968 elaborated the modal model, reflecting the majority of the most accredited models developed for memory operation at the time.

The model argues that the memory system is divided into sensory store, short-term store and long-term store, but that short-term memory, besides sending information to the long-term memory, also serves as a crucial component for complex cognitive tasks such as reasoning, choice of strategies and decision-making.

A few years later, in 1974, Baddeley and Hitch theorized a new model, the multi-component model of WM, alternative to that proposed by Atkinson and Shiffrin, with the purpose of giving greater

importance to the functional role of the WM system in carrying out complex cognitive activities, such as understanding, reasoning, and learning (Baddeley & Hitch, 1974).

The proposed model provides the existence of three components: one related to a general-domain type, called central executive, which coordinates the activity of two specific-domain stores, the phonological loop and the visuospatial sketchpad.

***Phonological Loop.*** The phonological loop is responsible for the storage of sequences of verbal and acoustic items. In turn, it is subdivided into two components: a short-term phonological store, or a kind of fast-paced auditory memory, capable of maintaining verbal information, and a vocal or sub-vocal articulatory repetition system which, through a continuous repetition mechanism of the tracks contained in the phonological store allows them not to decay within a few seconds but to continue to be renewed. The phonological loop is able to explain some of the characteristics of verbal STM, which provide a proof of its existence:

- the effect of phonological similarity, according to which the serial memory of a list of phonologically similar words is more difficult than the recall of phonologically dissimilar words; the span of letters decreases when the items have a similar sound (Conrad, 1964).

- the effect of the length of the word, so that the more the length of the words increases, the worse the performance in the memory of the words, since increasing the length of the words also increases the time that is necessary both to recall and also to pronounce them (Cowan, 1992; Baddeley, Chincotta, Stafford, & Turk, 2002).

Baddeley, Thomson & Buchanan (1975) affirm that the relationship between recall and articulatory speed can be summed up by saying that it is possible to remember as many words as the number of words that can be pronounced in 2 seconds.

- the articulatory suppression effect, so the pronunciation of irrelevant material interferes with performance in verbal tasks: the recovery of verbal material shows a deficit when, during the retention phase, it is requested to repeat aloud non-relevant words.



**Visuospatial Sketchpad.** The visuospatial sketchpad is responsible for the temporary maintenance and manipulation of visual and spatial information, which reach the sketchpad through the senses or through the long-term memory (Baddeley, 2001). It is also essential in spatial orientation and in solving visuospatial problems. Some studies carried out by Logie at the end of the 1980s have led to the hypothesis that the visuospatial sketchpad was more complex than previously considered: according to the model proposed by Logie (1995) there would be two separate components inside the visual sketchpad (as it happens for the phonological loops in the model developed by Baddeley and Hitch). The visual component of the sketchpad, called "visual cache", is similar to the phonological store, since the information, if not reiterated, would decay shortly, while the spatial component, called "inner scribe", acts as an active reiteration mechanism

**Central Executive.** According to the model, the central executive works as a careful control system rather than as a memory system, allowing the focus of attention and concentration on the task that has to be performed. Indeed, it works essentially as hypothesized by Norman and Shallice (1986), who have postulated the existence of two systems: a selective system that acts automatically and is based on existing learning and an attentive supervisory system that enters in action in the presence of new situations and allows a more flexible use of the information that is already available.

The central executive system is primarily responsible for the coordination of the phonological loop and the visuospatial sketchpad, but also plays an important role in controlling some cognitive processes such as the use of strategies and the transition from a strategy to another, the ability to divide the attention for multiple activities at the same time and the inhibition of non-relevant information (Baddeley, 1986).

**Episodic Buffer.** Although the multicomponent model of WM developed by Baddeley and Hitch seemed to have been successful, it had a series of problems: it did not explain the interaction existing between WM and long-term memory and did not postulate the existence of a component that could put in relation the two subsystems, the phonological loop and the visuospatial sketchpad.

For these reasons, more recently, the multicomponent model has been expanded with the addition of a new component, the episodic buffer, a storage system capable of integrating information coming from different systems of WM with data derived from the long-term memory, both verbal and visual, combining them into a single multidimensional code (that is the episodic buffer) and to process them into a single and new cognitive representation (Baddeley, 2000).

The episodic buffer allows an individual therefore, not only to model the surrounding environment, but also to create new cognitive representations that can facilitate troubleshooting. Baddeley also distinguishes between "crystallized" cognitive systems, capable of retaining long-term knowledge, and 'fluid' skills (attention and temporary retention), which cannot be modified by learning new knowledge. The new component, the episodic buffer, integrates information from both servo systems and WM into a unitary representation.

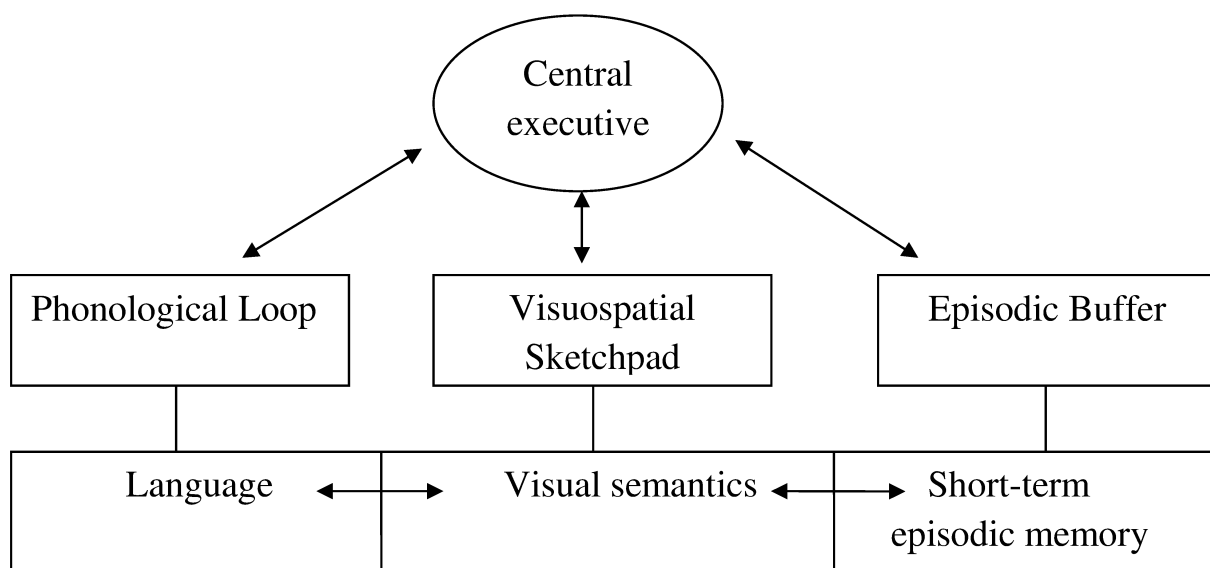


Figure 2. Multicomponent model of WM (Baddeley, 2000).

### Working memory and ADHD

The main functions of WM seem to be highly dependent on the frontal regions of the brain (Smith & Jodines, 1999; Martinussen et al., 2005). The frontal area most involved in cognitive and behavioral processes is the prefrontal cortex, which through numerous connective fibers communicates with almost all encephalic areas and plays an essential role in many brain functions

such as behavior planning, organization, maintenance of attention, ability to judge and abstraction, ability to move from one task to another, choice of a strategy, and inhibition of inappropriate impulses and/or behaviors.

In children with ADHD, morphological and functional abnormalities in these brain areas have often been found, i.e. those that are most heavily dependent on regulation of attention and behavior.

Many neuroimaging studies have shown that the prefrontal cortex, the nuclei of the base (caudate nucleus and pale globule) and the cerebellum have a smaller volume in children with ADHD compared to children in a control group (Castellanos et al., 1996; Castellanos & Tannock, 2002).

Barkley, in 1997, proposed the hybrid model, specific for ADHD, which believes that the main problem of subjects with the disorder is a deficit of both inhibitory and EFs. Barkley argues that this inhibitory difficulty involves deficits that affect WM, regulation of emotions, motivation, and understanding of events. Furthermore, the psychologist believes that there is a strong similarity between the performance of children with ADHD and those of adult patients with prefrontal lesions. Since the functioning of WM is responsible for many of the cognitive processes described above, which are known to be deficient in children with ADHD, and since the brain areas responsible for such functions are often compromised in subjects with the disorder, the WM has been included in many models that seek to explain the nature of ADHD (Barkley, 1997). For these reasons, many studies have investigated the performance of subjects with ADHD in WM tasks.

The first research that investigated the relationship between ADHD and WM was conducted between the late 1990s and the beginning of the 2000s: the data obtained was not always consistent or coherent. For example, Pennington and Ozonoff (1996) did not detect poor performance in verbal WM tasks in children with ADHD, whereas the opposite was observed in a study carried out by Rucklidge and Tannock (2002). Barnett and colleagues (2001) identified difficulties in spatial WM; Kerns and collaborators (2001) did not find significant differences in WM tasks among children with ADHD and subjects of control.

To seek greater clarity in the scope of study, Martinussen and colleagues (2005) conducted a meta-analysis on the relationship between WM and ADHD, including 26 research studies conducted between 1997 and 2003. The main purpose of the meta-analysis was to determine if subjects with ADHD had deficit of WM, verbal, visuospatial, or both components. In addition, the possible impact of other variables on performance determinations was examined (in particular, the presence of other disorders in comorbidity, such as language impairment or intellectual disability). The results in general have made it clear that the performance of children with ADHD in visuospatial WM tasks is markedly lower than that achieved by control groups, while the differences with regard to verbal WM tasks, albeit present, are modest.

The authors attempted to find possible explanations for the major impairment of the visuospatial component of WM in children with ADHD:

1. The visuospatial WM requires the activity of the right hemisphere: the right hemisphere is normally larger than the left hemisphere, but in subjects with ADHD there has been a reduction in this asymmetry (Giedd, Blumenthal, Molloy, & Castellanos, 2001).
2. Visuospatial WM tasks may be more challenging than verbal ones because they require processes that are not automated and familiar;
3. There may be another disorder that contributes to the deficit: children with ADHD can often also have a motor coordination disorder, strongly associated with deficiency in visuospatial processing (Wilson & McKenzie, 1998).

In 2012 Kasper, Alderson and Hudec, also carried out another meta-analysis that, in addition to investigating WMs in subjects with ADHD, also examined the potential influence that some subjective factors (sex, age) and/or factors related to the task (number of trials, response modes, resource expense, etc.) can exert on the WM deficit. The meta-analysis took into account 45 studies that included verbal and/or spatial WM tasks, presented to subjects with ADHD between 8 and 16 years of age.

From previous studies it has been found that females have less severe difficulties in WM than males (Seidman et al., 1997) and the reduction of the neural activity of frontal regions is less marked (Valera et al., 2010). From the meta-analysis, in fact, there is a significant difference in WM performance (both verbal and visuospatial) between males and females.

Some variables seem to be associated with a significant difference between the ADHD group and the control group: higher number of trials, remembrance tasks and a high amount of resources invested in the task; while other variables seem to suppress these differences: reduced number of trials, recognition tasks, demand for a limited processing quantity. Finally, as expected and as widely reported by other previous studies, subjects with ADHD get a lower performance than the control group in both verbal and visuospatial tasks.

Cornoldi and colleagues (2001) carried out a study to ascertain whether difficulties related to the WM in subjects with ADHD are of a specific type and whether they can be attributed to a general memory deficit or rather to a difficulty in inhibiting information. The authors compared the performance of children with ADHD and control subjects in two different tasks. The Categorization listening span task has a double request: to process a string of heard words, punching with a hand on a table every time an animal's name is pronounced and, at the same time, remembering the last word of the heard string. In addition, as a control test, children have run a Dual word span task, which consists in the presentation of strings of ever-longer words that have to be entirely remembered. The Visuospatial WM selective task, on the other hand, requires the subject to indicate whether the 3 positions shown by the experimenter on a 4x4 matrix are aligned or less along the vertical, horizontal or diagonal dimensions.

Subjects with ADHD had lower performance than the control group in both tasks (categorization listening span task and visuospatial WM selective task). However, these results have shown that children with ADHD demonstrate WM deficit only when the task requires high active control, such as when only items belonging to a specific category must be remembered while the irrelevant ones must be ignored: in the 'dual word span task', in which subjects had to memorize the entire sequence

of words, no special difficulties were found. Thus, it is also possible to argue that the memory deficit, which is present in many children with ADHD, has not been found in all memory tests, but it belongs to specific situations where it is necessary to control the interference of some information that was previously elaborated but that then becomes irrelevant for the purpose of the task (skill that is, in fact, disadvantageous in subjects with ADHD).

So, substantial research has demonstrated that, as a group, children with ADHD have poorer WM as compared to their TD peers (Bedard, Martinussen, Ickowicz, & Tannock, 2004; de Jong et al., 2009; Gau, Chiu, Shang, Cheng, & Soong, 2009; Kasper et al., 2012; Kerns, McInerney, & Wilde, 2001; Martinussen et al., 2005). Some data have suggested that children with ADHD manifest deficits both in verbal and visuospatial modalities (Fair, Bathula, Nikolas, & Nigg, 2012; Gau and Chiang, 2013; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Nikolas & Nigg, 2013), yet other studies have indicated differentially greater weakness in visuospatial relative to verbal WM (Martinussen et al., 2005; Simone, Marks, Bédard, & Halperin, 2017).

Despite group-level differences in WM between children with and without ADHD, the disorder is characterized by considerable phenotypic and neurocognitive heterogeneity (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Castellanos and Tannock (2002) posited that WM, among other neurocognitive processes, might represent a distinct endophenotype of ADHD, which may help to parse the vast heterogeneity of the disorder. A recent empirical study investigated the role of different EFs as potential endophenotypes for ADHD by comparing TD children to unaffected siblings of youth with ADHD and found that WM weaknesses were evident in some, but not nearly all of the unaffected siblings (Nikolas & Nigg, 2015). These findings suggest that WM weaknesses could represent a potential endophenotype for a subset of children with ADHD; however other children with the disorder may exhibit different neurocognitive deficits (or potentially none).

While WM deficits are clearly evident in some children with ADHD, the etiological role of WM in ADHD has remained elusive. Barkley (1997) has suggested that WM deficits in ADHD are largely secondary to a core deficit in inhibitory control. Others have suggested that WM weaknesses are

characteristic of only a subgroup of children with the disorder (Castellanos & Tannock, 2002; Nikolas & Nigg, 2015). In contrast, Rapport and colleagues (Alderson, Rapport, Hudec, Sarver, & Kofler, 2010; Rapport, Chung, Shore, & Isaacs, 2001) have hypothesized that impaired WM is the core underlying neurocognitive deficit leading to the dysregulated behavior typical of children with ADHD (i.e., deficits in attention and behavioral inhibition). While cross-sectional studies supporting their model have identified a possible mediating role of WM vis-à-vis ADHD and response inhibition (Alderson et al., 2010), and ADHD and activity level (Rapport et al., 2009), a more definitive demonstration of mediation would require a longitudinal design (Selig & Preacher, 2009). Rapport and colleagues have also suggested that WM impairments are evident in as many as 81–98% of children with ADHD (Kasper et al., 2012; Rapport, Orban, Kofler, & Friedman, 2013), yet the methodological approach employed also resulted in 50% of TD children falling below the average score. Taken together, there is evidence to suggest that many children with ADHD present WM weaknesses. However, due to inconsistencies in the literature, it remains unclear how many children with the disorder actually have deficient WM, and the extent to which this specific neurocognitive weakness contributes to difficulties in daily functioning.

#### **1.4. Working memory and writing abilities in children with Attention Deficit and Hyperactivity Disorder**

After analyzing the academic functioning, in particular the writing abilities of children with ADHD and the impairment in WM of children with this disorder, I'm going to connect all this aspect to highlight the important role of WM in the orthographic and handwriting performance of children with ADHD.

##### **Working memory and writing**

There is now substantial evidence that EFs, in particular WM, plays an important role in learning during childhood (Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006). Children with poor WM have been found to make frequent errors in a range of learning activities including remembering and carrying out instructions, writing while formulating text, and carrying out mental arithmetic (Gathercole, Lamont, & Alloway, 2006).

As stated above, writing is one of the most complex cognitive activities that human beings must accomplish during their lives. Writing involves a large number of cognitive components operating at different levels of representation (Olive, 2004). In general, the diverse models of writing (Hayes & Flower 1980; Kellogg 1996) concur in the fact that writing is a cognitive task that requires the coordinated deployment of a relevant set of cognitive abilities that are used during the process of writing, one of which is WM (Berninger, 2011). As anticipated, composing a text involves at least three cognitive components (Hayes & Flower, 1980; Olive, Kellogg, & Piolat, 2008):

- planning allows you to prepare the contents of the text by organizing the ideas coming from WM;
- translation makes it possible to convert the content of ideas into sentences (including the motor execution, that is, the graphic transcription of the text, programming the movements and putting them into action);
- review allows you to reexamine what has been produced and, if necessary, to modify it in the light of the text representation that was previously created.



Each stage can interrupt one of the others at any time during the writing process (Hayes & Flower, 1980). It is clear that the WM plays a crucial role in producing a text (McCutchen, 1996). Many writing processes, in fact, require the processing and temporary storage of information.

*"In summary, working memory is the cognitive space in which the writing processes take shape"* (Olive & Passerault, 2012).

### **Kellogg: component model of working memory in the writing process**

The WM model implicated in the writing skills of Kellogg (1996), which is based on the multi-component model of Baddeley (1986), tries to outline the existing relationships between each single writing process and the phonological loop, the visuospatial sketchpad, and the central executive system. According to Kellogg, the planning phase primarily requires access to the visuospatial sketchpad, since it is necessary to display images and organize ideas; the phonological loop, on the other hand, supports the generation of text (translation) and the revision of what has been produced. The phase of motor execution, on the contrary, does not seem to involve the activity of the two servo-systems in a clear way. In addition, each stage of the writing process requires the central executive to activate large resources.

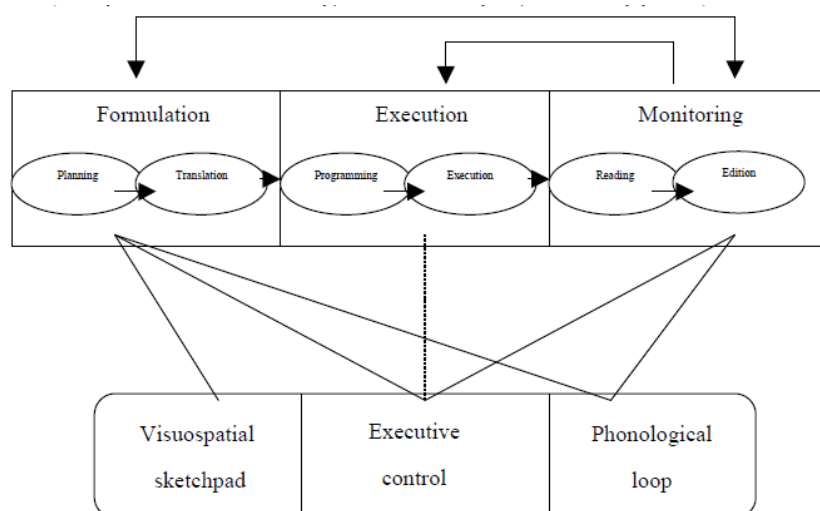


Figure 4. Kellogg's writing model (1996)

### **McCutchen: capacity theory of working memory**

McCutchen, Covill, Hoynes and Mildes (1994) have found that subjects who demonstrate good WM capacities in a writing task produce more effective texts than subjects with poor WM capacities. In particular, a high efficiency in the text translation process is associated with good capacities of WM and, therefore, better performance in activities that require written text.

To support these results, McCutchen (1996) proposed the 'Capacity theory of writing', according to which, in order to allow an effective interaction between the different writing processes, it is necessary to be able to manage the WM capacity and, furthermore, the change in the effectiveness of one of the writing processes may also affect other processes.

For example, if a writing motor execution is automated, skilled writers are able to activate high-level writing processes (planning, translation and revision) simultaneously to the motor action of writing. The less skilled writers, on the other hand, can only adopt a strategy that consists in thinking and only transcribing later. In fact, the transcription, in the early stages of the writing process, requires many cognitive resources, and also the generation of text is still not so fluent. By 9-10 years, however, the transcription begins to require fewer resources.

The production of text continues to require a great expense of energy at all ages. Therefore, since the transcription and generation of a text require many cognitive resources already in the early stages of writing, they could also influence the development of planning and review processes.

### **Verbal and visuospatial WM in the writing process**

The most common technique used to investigate the involvement of WM in the writing process is the 'dual task technique', since it has been widely recognized that the WM plays a crucial role in conducting complex cognitive activities (Olive, 2004).

The dual task requires two different tasks (primary task and secondary task) simultaneously, so that the cognitive resources used in the solution of both tasks are the same. If the resources that the two tasks use individually are no longer available, the performance in both activities should get worse.

Several studies have shown that visual WM and spatial WM in composing a text require as many resources as the verbal system (Olive et al., 2008).

Some researchers have confirmed that the visual component in the writing process plays an important role, especially in the production of text content, while the spatial component seems to be more involved in structuring the text (Galbraith, 2009; Kellogg, 1996). The visuospatial representation of the text also facilitates the successive revision, providing insights for quick access for the evaluation of the information that was written so that it is possible to detect any errors (Piolat, Roussey, & Thunin, 1997).

In their study, Marek and Levy (1999), investigated the involvement of the phonological loop in the 3 writing processes in 3 different tasks: generation of a sentence from few words (requiring planning), copy a text (requiring execution), and production of a text (requiring review). During the execution of these tasks the participants heard a conversation to which they did not have to pay attention to (unattended speech). The authors found that the presence of the conversation only interferes with the planning process, concluding that this process requires greater access to the phonological loop that is needed for execution and revision.

Hayes and Chenoweth (2006), instead, used articulatory suppression to explore which writing process makes use of WM. They found that in the articulatory suppression condition typing rate was significantly reduced and the number of errors significantly increased. The authors conclude, in contrast with Marek and Levy (1999) that WM is involved both in transcription and editing.

Kellogg and colleagues (2007) argue that both visual WM and spatial WM are involved in planning: the visual component is involved in the processing of visual material during the generation phase, while the spatial component is important for organizing the information.

Galbraith and colleagues (2005) tested these hypotheses in a research study by submitting to the participants a text composition task, in three distinct phases: generation of ideas, organization of ideas, and production of the text. The subjects during the first two phases also had to perform simultaneously other tasks (secondary tasks) involving the visual and spatial WM. The findings

revealed that visual WM tasks do not interfere with the planning process, while spatial WM tasks influence the stage of organizing ideas, reducing the quality of their content.

In another study, Galbraith (2009) examined the effect of a secondary task involving the spatial WM in planning an article on a specific topic. The purpose of authors was to test whether the interference of a secondary task diminished the capability to form ideas about the type of text to write and reduced the quality of the text subsequently produced. Participants had 5 minutes to write ideas about the article theme, 10 minutes to arrange a draft and 30 minutes to actually write the text. The subjects were randomly assigned to one of the four conditions: control condition, visual condition, spatial condition, and interference condition. In the control condition the subjects had to carry out the primary task (to write an article) without the presence of a secondary task. In the other three conditions, during the drafting phase of the text, the secondary task, which consisted of expressing judgments (through a button) about some stimuli presented on a computer screen, was assigned to the participants. The results indicated that a secondary task that requires many spatial WM resources reduces the ability to differentiate content in different ideas during the sketch phase and decreases the quality of the written text.

In another study, Olive, Kellogg, and Piolat (2008) analyzed the degree to which the verbal, visual and spatial components of the WM are involved in the writing process during the production of sentences. The participants composed a text and, at the same time, executing a secondary task (visual, spatial or verbal), which required to determine if an item presented visually or orally was the same as the previous one. Olive and colleagues found that in the absence of a secondary task, the participants wrote faster and more fluently than subjects performing the verbal or visual secondary task, but not those who had performed the spatial task.

These results indicate that the verbal component requires many cognitive resources, as it happens for the visual WM, while the spatial WM needs a lesser amount of resources. In fact, both the verbal and visual WM appear to be more involved in the text composition process than the spatial component that, therefore, does not involve significant interference in the text composition.

By distinguishing visual WM tasks and spatial WM tasks, it has been shown that text composition is a process that requires resources from these two WM components in a different way. In fact, numerous evidence indicates that the verbal, visual, and spatial systems of the WM may be dissociated. Behavioral studies and neuroimaging studies argue that the visuospatial sketchpad can be split into two components, the visual one and the spatial one (Logie, 1995; Hecker & Mapperson, 1997). For example, as Logie argues, the visual cache is a passive system that stores information in the form of a visual representation, while the spatial component (inner scribe) is an active repetition system that maintains positions and movements in the memory allowing refreshing the material in the visual cache that otherwise would decay.

### **Working memory and academic difficulties in children with ADHD**

Many children with ADHD, as I mentioned earlier, have been shown to have poor academic functioning, even in the absence of a frank LD. As WM has also been linked to poor academic achievement in children (regardless of ADHD diagnosis; Alloway & Alloway, 2010), some investigators (Rogers et al., 2011; Sjowall & Thorell, 2014) have begun to examine whether WM ability mediates the relation between ADHD symptoms and academic outcomes in school-aged children. Specifically, Rogers and colleagues (2011) found that in adolescents with ADHD, verbal and visuospatial WM partially mediated the relation between inattentive symptoms and performance on tests of reading, but not mathematics, achievement. Similarly, Sjowall and Thorell (2014) found that WM (collapsed across verbal and visuospatial tasks) partially mediated the relation between ADHD symptoms and teacher ratings of children's math and language skills. Given the heterogeneity of WM impairment in samples of children with ADHD, it is still unclear whether ADHD and WM ability uniquely contribute to poor academic outcomes. Thus, it is important to examine within a single sample of children whether ADHD symptoms and WM ability both, or differentially, contribute to objective tests and subjective ratings of academic achievement.

To date, two studies (Alloway et al., 2010; Holmes et al., 2014) have compared children with ADHD to TD peers with low WM and found that the groups did not appear to differ on tests of academic achievement. Alloway and colleagues (2010) divided their sample based on teacher ratings of WM (irrespective of ADHD diagnosis) and found that the low WM group performed substantially poorer on all academic achievement measures relative to those with average WM, but that the groups did not differ on teacher ratings of classroom functioning. In contrast, Holmes and collaborators (2014) found that teachers rated children with ADHD as having significantly more hyperactivity and impulsivity than their TD low WM peers. Based on these findings, it would appear that WM is contributing to poorer academic achievement in children (regardless of ADHD status), and the contribution of WM to behavioral dysfunction in children with or without ADHD is unclear. Further, it remains uncertain whether both ADHD symptom domains (inattentive and hyperactive/impulsive), as well as WM ability significantly contribute to poorer academic and behavioral functioning in school-aged children.

A recent study (Simone et al., 2017) examined whether WM ability (verbal and visuospatial), inattentive symptoms, and/or hyperactive/impulsive symptoms significantly contribute to academic, behavioral, and global functioning among 8-year old children. Authors found that both verbal and visuospatial WM but not ADHD symptoms severity, significantly and independently contributed to measures of academic achievement. In contrast, both WM and inattention symptoms, but not hyperactivity-impulsivity significantly contributed to teacher-ratings of academic functioning. Further, inattention and hyperactivity/impulsivity but no WM were significantly associated with teacher rating of behavioral functioning and clinician-ratings of global functioning. It appears clear from literature that the analysis of the relation between symptoms of ADHD, WM and academic underachievement need to be studied in depth, and in particular in the case of writing abilities.

## **Working memory and writing abilities in children with ADHD**

As stated above, underachievement in children with ADHD is a persistent problem that begins in the preschool years and endures throughout childhood and adolescence. Academic difficulties are observed across subject areas and regardless of the type of measurement or sample studied (Frazier, Youngstrom, Glutting, & Watkins, 2007) and are evident even for children who are below the clinical threshold for a diagnosis of ADHD (Breslau et al., 2009; Currie & Stabile, 2006). Significant effects remain after controlling for comorbid learning disabilities (Currie & Stabile, 2006) and behavioral problems (Giannopulu, Escolano, Cusin, Citeau, & Dellatolas, 2008).

Mounting evidence from cross-sectional (e.g., Dally, 2006; DuPaul et al., 2004) and longitudinal (Breslau et al., 2009; Rabiner & Coie, 2000) studies suggest that the academic impairments seen in children with ADHD are primarily related to symptoms of inattention, rather than symptoms of hyperactivity and impulsivity. Children who exhibit purely inattentive behavior are likely to underachieve in reading (Warner-Rogers, Taylor, Taylor, & Sandberg, 2000; Willcutt & Pennington, 2000) and mathematics (Marshall, Hynd, Handwrek, & Hall, 1997; Raghobar et al., 2009). Despite the established link between inattention and learning problems, the mechanisms that underlie this association remain poorly understood. Developments in child neuropsychology suggest that WM may be an important player in this relationship. Deficits in WM (Baddeley & Hitch, 1974) have been well documented in children with ADHD (Martinussen et al., 2005; Willcutt et al., 2005). Even children with subclinical levels of inattention exhibit WM deficits (Alloway, Elliot, & Place, 2010). There is substantial evidence that WM plays an important role in the development of academic skills in TD children (Alloway & Alloway, 2010; Gathercole, Pickering, Knight, & Stegmann, 2004). Studies using both experimental (e.g., Swanson & Kim, 2007) and classroom-based designs (e.g., Gathercole & Alloway, 2008; Gathercole, Durling, Evans, Jeffcock, & Stone, 2008) have shown that deficits in WM are strongly related to academic underachievement. More specifically, the verbal and visuospatial WM system has been linked with the ability to acquire new knowledge and skills, particularly in the development of reading and

language (Acheson & MacDonald, 2009; Barkley, 2003) but also in mathematics (Ashcraft & Krause, 2007; Swanson, 2006; Swanson & Kim, 2007). For instance, St. Clair-Thompson and Gathercole (2006) found visuospatial WM to be associated with academic attainment in English, mathematics, and science and these findings have been confirmed in children and adolescent with ADHD (Alloway et al., 2010; Rogers et al., 2011).

Nevertheless, it remains unclear how each type of WM (i.e., verbal and visuospatial) is linked to the academic domain of writing. Few studies considered these three variables together. A first study conducted by Alloway, Gathercole, and Elliott (2010) found that children with ADHD have a lower performance in spelling compared to a control group but a little bit better than a group of children with low WM. The relationship between the three variables remains unclear. Another work that analyzed the role of WM in writing abilities of children with symptoms of ADHD, that was a first step of the research presented in the next chapter, is the one by Re and colleagues (2014). To test a more ecological situation and the impact of cognitive loading, authors examined whether or not the spelling difficulties of children with ADHD are emphasized when children's verbal WM is overloaded. A group of 19 children with ADHD symptoms (between 8 and 11 years of age), and a group of typically developing children matched for age, schooling, gender, rated intellectual abilities, and socioeconomic status, were administered two dictation texts: one under typical conditions and one under a preload condition that required the participants to remember a series of digits while writing. The results confirmed that children with ADHD symptoms have spelling difficulties, produce a higher percentage of errors compared to the control group children, and that these difficulties are enhanced under a higher load of verbal WM. An analysis of errors showed that this holds true, especially for phonological errors. The increased errors in the verbal WM condition was not due to a tradeoff between WM and writing, as children with ADHD also performed more poorly in the verbal WM task.

Finally, a recent work by Simone and colleagues (2017) examined whether WM, inattentive symptoms, and/or hyperactive/impulsive symptoms significantly contributed to academic,



behavioral, and global functioning in 8-year-old children. One-hundred sixty 8-year-old children completed subtests to assess WM and academic achievement. Teachers and clinicians rated children's academic and behavioral functioning. Authors found that socioeconomic status, verbal and visuospatial WM significantly contributed to spelling scores accounting for 8.8%, 24.4% and 11.5% of the variance, respectively. Neither of the ADHD symptom domains nor their interactions significantly predicted spelling scores.

What differentiates the work presented in this thesis from previous research (Alloway et al., 2010; Simone et al., 2017) is the fact that the verbal and visuospatial WM were not tested separately from writing skills but were analyzed together, proposing a dual task that required children a cognitive load during the writing task. This aspect permits to have a more ecological task that simulates the class context and analyzes exactly the role of WM during a writing task and not the performance in writing and WM separately. As can be understood from the previous chapters, the analysis of the role of WM in spelling and handwriting of children with ADHD still needs to be deepened and this is what I have tried to do through my thesis work.

## **2. STUDY 1: WRITING ABILITIES AND THE ROLE OF WORKING MEMORY IN CHILDREN WITH SYMPTOMS OF ATTENTION DEFICIT AND HYPERACTIVITY DISORDER**

### 2.1. Introduction

ADHD is a psychiatric diagnosis that identifies children who exhibit inappropriate levels of inattention and/or hyperactivity (APA, 2013). The disorder is typically associated with poor scholastic outcomes (e.g., Fischer, Barkley, Edelbrock, & Smallish, 1990). Children with ADHD (Mayes et al., 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.

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, organization, monitoring, attention, and long-term memory, among others, that make the difference between good and poor writers (e.g., Hooper, 2002), and that are typically impaired in children with ADHD (Biederman et al., 2004; Cornoldi et al., 2010). One such function is working memory (WM; Berninger & Swanson, 1994; Swanson & Berninger, 1996), which is crucial during the writing process because it enables us: to maintain linguistic strings and retrieve words, ideas 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 et al., 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 et al., 2005), they can be reasonably expected to have several difficulties in writing tasks, due partly to the role of WM. The writing skills of children with ADHD have received little

attention to date, however, despite their crucial importance at school (Hooper, Swartz, Wakely, De Kruif, & Montgomery, 2002). Some evidence suggests that these children have particular difficulties in certain aspects of writing, such as written expression, spelling and handwriting (Kroese et al., 2000; Mayes et al., 2000; Mayes & Colhoun, 2007; Re et al., 2007; Re & Cornoldi, 2010). Among the various aspects of writing, spelling difficulties in children have not been thoroughly investigated. Research has sometimes focused on specific situations rather than on the general case of writing under dictation. In one recent study, for example, Re and Cornoldi (2015) found that children with ADHD symptoms made more spelling mistakes than TD children in a copying task, particularly when they had to write accents and geminates. 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. A subsequent study by Re, Mirandola, Esposito, and Capodieci (2014) examined the case of children writing under dictation while also having to keep verbal information in mind (a situation typical of everyday school life when children experience concurrent requests or distracting information while writing). They administered a dictation task to children with and without ADHD symptoms, with and without a cognitive load on the verbal component of WM (see Baddeley, 2001). The cognitive load 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. 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 because their WM is impaired and they have weaker orthographic representations. The study had several limitations, however, and 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; Olive, 2004; Olive et al., 2008; Ransdell, Arecco, & Levy, 2001; Passerault & Dinet, 2001; Levy & Marek, 1999), was thus used to further elucidate how concurrent (verbal and 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 will be more severe. In addition, children with ADHD symptoms who can cope with the concurrent verbal WM load just as well as TD children will presumably be able to avoid its disrupting effect on their spelling. 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 as well, 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. Some aspects of the impairment might also depend on the type of concurrent task, especially as regards the type of spelling mistake being made. In fact, the classical distinction between phonological and non-phonological errors (Coltheart, 1984) may be relevant in this setting. Phonological errors (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'; 'pencil' for 'pencil'), and inversions (e.g. 'manechi' for 'machine'). Non-phonological errors (NPEs) are cases in which the incorrectly-spelled word would sound right if read aloud, and they occur especially when sentences must be written, rather than single words. 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. The case of NPEs is apparently more complicated as the orthographic representation of whole words has been 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).

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 TD children matched for age, schooling, gender, rated intellectual abilities, and family environment were dictated three sets of sentences, one under typical conditions, 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 a problem, however, in that some children may 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 may be

that some children focus excessive resources on the secondary task and their performance in the primary task is consequently impaired. This aspect was considered in the present study by examining WM performance too, seeking evidence either of such a trade-off effect or of children who did better in the WM task (due to a higher WM capacity) also having a better performance in the spelling task.

The children were involved in writing the dictated words by hand, so the present study also gave us the opportunity to examine the quality of the children's handwriting, and several associated issues. Children with ADHD reportedly (e.g. Borella, Chicherio, Re, Sensini, & Cornoldi, 2011) write less well than TD 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, I could also examine whether a visuospatial WM load typically affecting performance in concurrent visuospatial tasks (Logie, 2014) would also impair handwriting quality due to its visuomotor characteristics.

Finally, to investigate the implications of handwriting skills more in general, I also conducted 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 (Ross, Poidevant, & Miner, 1995; Re, 2006; Adi-Japha et al., 2007; Shen et al., 2012), and to analyze whether a relationship exists between writing speed and spelling accuracy.

So, the aims of the study were to examine:

- whether children with ADHD symptoms made more spelling mistakes than control children;
- whether their spelling difficulties were specifically exacerbated by high WM loads, and especially whether there were more PEs under verbal WM loading, and more NPEs under visuospatial WM loading;

- whether there was a compensatory mechanism at work (i.e. children who did better in the WM task had dedicated fewer resources to the primary task, and consequently made more spelling mistakes), or whether children with a better WM had a better spelling performance too;
- whether children with ADHD symptoms had a handwriting quality and speed comparable with those of children in the control group;
- whether there was a relationship between handwriting quality under dictation, WM and spelling difficulties.

## 2.2. Study 1: The role of working memory in orthographic abilities

### 2.2.1. Method

#### Participants

A group of 26 primary-school children (22 males, 4 females) with ADHD symptoms in 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 ( $M= 18.75 [2.91]$ ), as measured with the Reasoning subtest of the Primary Mental Abilities battery (Thurstone & Thurstone, 1981), and no other serious psychological or neurological problems, as assessed with the COM scale (Comorbidity questionnaire for teachers; Marzocchi, Re, & Cornoldi, 2010; Capodieci, in press), or diagnosed learning disabilities. Table 1 shows the two groups' mean age, mean scores in the SDAI (Scala per i Disturbi di Attenzione/Iperattività per Insegnanti [ADHD scale for teachers]; Marzocchi et al., 2010) subscales, and mean family environment, which was obtained with a specific COM item (Marzocchi et al., 2010) item, and ranged from 0 (*high*) to 3 (*low*).

Table 1. Means and standard deviations (SD) for the two groups.

	ADHD group (N=26)	Control group (N=26)	F (1,50)	<i>p</i>
Age (months)	116.00 (14.41)	115.31 (12.1)	0.04	.853
Family environment (COM)	1.95 (1.07)	1.53 (.96)	0.98	.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

*Note.* COM= Comorbidity questionnaire for teachers; SDAI= ADHD scale for teachers;

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 (Marzocchi et al., 2010; see also Capodieci, in press; Marzocchi & Cornoldi, 2000), based on the DSM, (APA, 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). Written consent was obtained from the children's parents before 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

In the first phase of the project, information about the pupils was collected through the ADHD Scale for teachers (SDAI) and COM questionnaires, filled out by the teachers after a sufficiently long period of observation, and through a test that examines the general cognitive abilities (PMA,



Thurstone & Thurstone, 1981) carried out for the students in the classroom. In addition, the parents who wanted it could fill a parallel questionnaire, the ADHD Scale for parents (SDAG).

After collecting and computing the scores obtained from the questionnaires and the PMA test to form the groups, the second phase provided to administer to the students some tests of dictated sentences, in order to investigate the performance of subjects in three different conditions: simple dictation, dictation with a concomitant verbal WM task and dictation with a concomitant visuospatial WM task.

The pupils also performed a writing speed test, which consisted of writing numbers in letters starting from 'one' for a period of 20 seconds: this test allowed the evaluation of the graph-motor skills. Finally, in the third and last phase, the tests were corrected: spelling mistakes and handwriting ability were taken into account.

**SDAI Scale.** The scales for detecting typical ADHD traits most commonly used in Italy, born and standardized in Italy, are the SDAs, the scales for the detection of inattention and hyperactivity at the school age, existing in 3 versions: for teachers - SDAI, for parents - SDAG and for children - SDAB. These scales have been elaborated and standardized by Marzocchi and Cornoldi in 2000. The SDAI scale, which must be filled by teachers after a sufficient period of observation, allows us to evaluate the presence of characteristics of ADHD symptoms in children, with reference to the indications provided in DSM-5 (APA, 2013). In fact, the scale contains 18 items in total, 9 for inattention, and 9 for impulsiveness/hyperactivity, expressing typical behaviors corresponding to the 18 symptoms included in the Manual. Equal items describe impulsive/hyperactive behaviors, while odd ones list behaviors that belong to the sphere of inattention.

The score for the different items is assigned based on the frequency with which the described behavior is shown: a score can be assigned ranging from 0 (*never presents*) to 3 (*very often presents*). Let's see some examples of items:

- item 4: 'the child cannot stay seated' (hyperactivity);

- item 16: 'the child finds it difficult to wait for his turn' (impulsiveness);
- item 15: 'the child is easily distracted by external stimuli' (inattention).

The scores given to all odd items to get the inattentive score and those assigned to all even items to get the hyperactivity/impulsiveness score had to be considered separately.

The maximum score that can be reached for each of the two subscales is 27, but the cut-off value of reference for this scale is 14 (Marzocchi et al., 2010): this means that higher scores correspond to typical ADHD symptoms. It is important to clarify that achieving the cut-off is not enough to formulate ADHD diagnosis: this only indicates the presence of some aspects that are typically problematic in subjects with the disorder and may give suspicion of the presence of the disorder. Additional and more detailed insights are needed to make the diagnosis.

**COM Scale.** SDAI scales are quick to administer and concise, but it is important to associate them with other questionnaires, since a child may have symptoms of the disorder but also severe other problems. In this regard, it may be useful to use the COM scale (Marzocchi et al., 2010) available in two versions, one for parents and one for teachers. This scale allows you to check for the presence of symptoms frequently associated with ADHD, so it is important to detect the presence of problematic behaviors. When specific symptoms of two or more disorders occur simultaneously in the same subject, the association between the disorders is called comorbidity, while is defined longitudinally when the disorders appear in succession. Comorbidity is particularly noticeable in subjects with ADHD. The questionnaire consists of 30 items, the first 5 of the control and the remaining 25 divided into 6 areas that define the disorders most associated with ADHD:

- items 1-5: Control items - investigate the school and social learning of the child;
- item 6: Tourette syndrome - evaluates the presence of motor or vocal tics;
- items 7-15: Conduct Disorder (CD) and Opposition Defiant Disorder (ODD) - Check for aggressive and/or hostile behavior towards peers and/or challenging attitudes, especially for adults;
- items 16-20: Autism - detect stereotyped behaviors and communicative problems;
- items 21-24: Depression - evaluate aspects such as fatigability, fatigue, sadness;

- items 25-30: Anxiety - consider worry states, irritability and similar ones.

Below are some examples of the items:

- item 2 (control): 'presents low cognitive abilities';
- item 6 (Tourette syndrome): 'presents daily motor or vocal tics that create great disturbance';
- item 10 (DC): 'tries to get what she/he wants by force';
- item 14 (DOP): 'deliberately misleads peers and adults';
- item 18 (autism): 'is completely absorbed by one or more types of narrow, repetitive and / or stereotyped interests';
- item 23 (depression): 'shows an increased fatigue or lack of energy';
- item 25 (anxiety): 'is worried without a specific reason'.

Teachers had to fill in the questionnaire after having carefully observed for a certain period of time the pupils in the different school situations. The frequency or intensity with which the behaviors described by the item appeared had to be evaluated through a 4-point Likert scale from 0 (*behavior never presents*) to 3 (*always/very presents*).

The cut-off for each subscale corresponds to the 95th percentile. Scoring is very simple: the values of the items relative to the different subscales are added to obtain a complete picture of the disorders in comorbidity.

**PMA.** The students, in the classroom, performed the PMA test, a battery exploring the general cognitive abilities. At the base of the battery there is the idea that certain specific intelligence factors form the basic elements of mental processes. The 5 factors measured are:

- verbal meaning (V);
- perceptual speed (P);
- numerical ability (N);
- reasoning (R);
- spatial skills (S).

There are 4 versions of the test, each adapted to the school level of the examined subjects. For the purpose of research, the version 4-6 was used, which was adapted for children from the third grade of the primary school to the third grade of the secondary school of first degree. It should be noticed that the pupils did not perform the entire battery, but only the reasoning test (R), examining the ability to solve logical problems through a test of grouping of figures and a test of grouping of words. For each item 4 figures are presented and the task of the subject is to indicate one that has no characteristics in common with the other 3 (e.g. three figures consisting of two parallel lines, but with different inclinations, and a figure with three parallel lines: this last figure is the one that has to be indicated being unlike the other three figures). In the examination of words the principle is the same: four words are presented in each series, in the series one is not relevant to the other 3 (for example, the words 'cow', 'dog', 'cat' and 'hat': this last word has to be indicated as it does not belong to the category of 'animals').

The time available to complete the grouping of figures (25 in total) is 6 minutes, for the grouping of words (also 25) is 8 minutes. The correction is very simple: it is assigned the score 0 if the answer is wrong and the score 1 if the answer is correct.

**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 to 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): "L'uomo/ con il cappotto rosso/ che è sulla porta/ di casa tua/ ha suonato/ più volte/ il campanello" (*The man/ with the red coat/ who is at the door/ to your house/ has rung/ the bell/ several times*). A pilot study in

which the sets of sentences were administered without any concurrent task had shown that the 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 seconds, 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 minutes. The sentences were dictated aloud, at a constant pace, adapted to the children in the classroom, i.e. it is waited for almost all the children to finish writing a sentence 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 when they finished writing they had to draw a box around the sentence they had written. Children received the following instructions: *This test consists of a dictation of sentences. Listen carefully and write the sentences that I will now dictate to you as accurately as possible. Remember that, during the dictation, I will only say each word once. If you don't understand or can't write some of the words in time, don't ask me to repeat them. You will have to skip them and carry on with the next sentence. When you've finished writing the sentence, you have to draw a box around it.*

***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. The instructions were as follows: *This test consists of a particular dictation of sentences. Now I will ask you to keep in mind a set of digits that will be required at the end of each*

*dictated sentence. Listen carefully to the digits that I will pronounce, keep them in mind, and then write the sentence that I will dictate to you as correctly as possible. As soon as you have finished writing the sentence I dictated, write the digits that I pronounced before. Then I will tell you some other digits to keep in mind while I dictate the next sentence, and you will have to write them on the sheet at the end of this second dictated sentence, and so on for the subsequent sentences. Remember that, during the dictation, I will only say each word once. If you don't understand or can't write some of the words, don't ask me to repeat them. You will have to skip them and carry on. Likewise, if you don't remember some of the digits, just write down the ones you could keep in mind, and if you don't remember any of them, just carry on and pay attention to the next set.*

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 at a 3x3 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 3x3 grid on their answer sheet. The instructions were: *This test consists of a particular dictation of sentences. I will also ask you to remember the position of some dots placed inside a grid. You will have to keep these positions in mind and draw them in the grid that you have on your sheet of paper after you have written each sentence I dictate. Try to write the sentence that I dictate as correctly as possible. As soon as you've finished writing the sentence, draw the dots in the grid that you have in front of you. Then I will show you another set of dots that you will need to keep in mind while I dictate the second sentence, and draw them on the sheet after you've finished writing the sentence, and so on for the next sentences. As soon as I say 'full stop', that means that the sentence is finished and you can put the dots you remember inside the grid.*

*Remember that, during the dictation, I will only say each word once. If you don't understand or can't write some of the words, don't ask me to repeat them. You will have to skip them and carry on. Likewise, if you don't remember some of the positions of the dots in the grid, mark the ones you were able to keep in your mind, and if you don't remember any of them, just carry on and pay attention to the next set.*

Here again, a trial run was conducted after providing the instructions to make sure that everyone had understood the task.

As it was not allowed to test the children individually, the tests were administered to whole classes included in the experimental sample and it was balanced in the order in which the different conditions were administered but not the materials between subjects. This procedure 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 from the whole sample.

**Writing speed test.** To assess their handwriting speed, the children performed 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 seconds). The instructions were: *"Now I will ask you to write the numbers in letters as fast as possible for twenty seconds, starting from one. You can use whatever character you like"*. This procedure was drawn from a battery of tests for assessing handwriting and spelling competence, the BVSCO-2 (Tressoldi et al., 2013), with a high reliability and validity.

## 2.2.2. Results

### **Scoring**

Spelling mistakes were assessed according to the BVSCO-2 criteria (Tressoldi et al., 2013), considering PEs, NPEs, and a third category comprising errors involving the addition or omission of accents and double letters (AD). The NPEs included incorrect separations and fusions, additions

or omissions of apostrophes, omissions or additions of the letter ‘h’, and the swapping of homophonic graphemes (e.g. ‘squola’ for ‘scuola’).

For dictations in the simple condition the only aspect to consider was the number of spelling mistakes. For the dictations with concurrent WM tasks the recall of digits (in the verbal WM loading condition) and dot positions (in the visuospatial WM loading condition) were considered. For the sets of digits, based on the procedure adopted in previous works (Re et al., 2014; Lanfranchi, Cornoldi, & Vianello, 2004), 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; children who wrote “632” scored 2 points because they recalled the 6 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’. Some examples are provided that may be helpful for scoring purposes. 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 writing speed measure, it was 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, Maechler, Bolker, & Walker, 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.

Generally speaking, ADHD children made more than twice as many mistakes as controls, with a mean number per condition of 10.66 (as opposed to 3.69 for controls). 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).

Concerning the total number of spelling mistakes, it has been 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,  $B=0.99, p < .001$  (where B represents the estimated variation of the value from one group to the other). It has also been 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 ( $B=0.20, p = .006$ ; and  $B=0.16, p = .034$ ; 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.

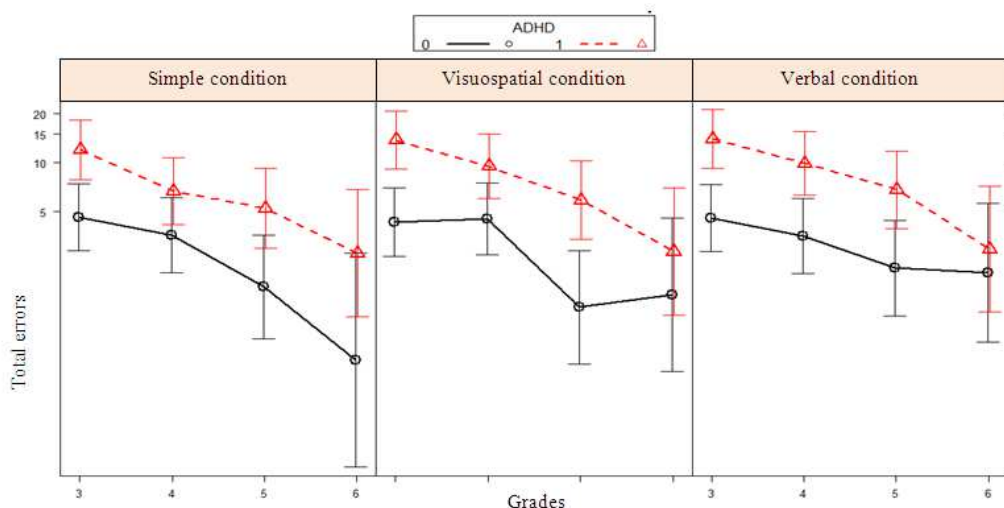


Figure 3. Estimated total number of spelling mistakes in the two Groups (ADHD vs control), the different Grades (third, fourth, fifth, sixth grade), under the different dictation Conditions (simple vs spatial vs verbal).

In a second step the children's WM performance was analyzed. For the whole sample of children, the correlation between their performance in the two WM loading tasks was low,  $r(52)=.24$ , 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]), and visuospatial WM (ADHD:  $M=88.02$  [12.22]; control:  $M=93.39$  [9.08]), 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, it has been 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 ( $\chi^2(1) = 0.12$ ,  $p=.732$ ). 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.

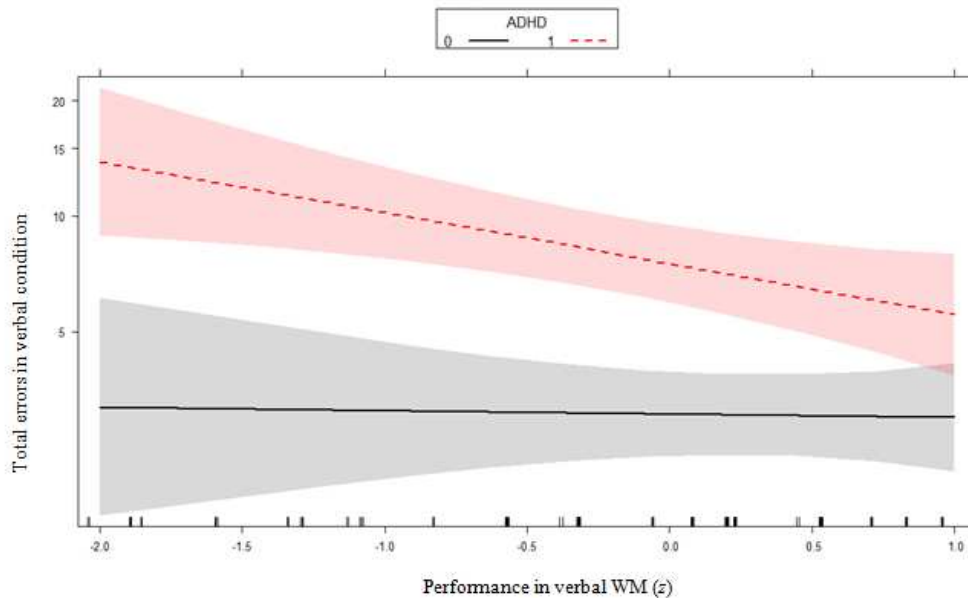


Figure 4 – Estimated average of total spelling mistakes under dictation with a concurrent verbal WM task as a function of performance in the concurrent verbal WM task.

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, it has been 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 ( $B=0.67$ ,  $p<.001$ ;  $B=0.36$ ,  $p=.045$ ,  $B=0.55$ ,  $p<.001$ ). 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 ( $B=0.60$ ,  $p=.001$ ; see Fig. 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.

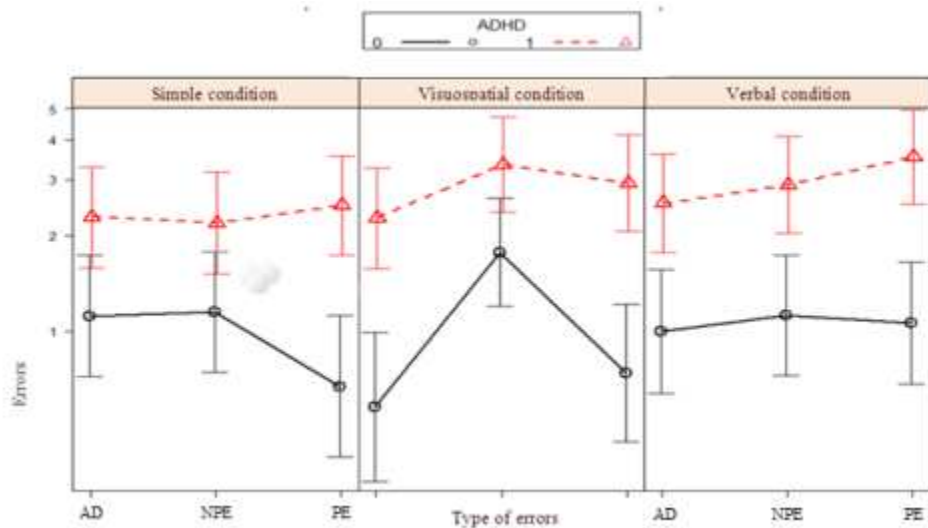


Figure 5. Estimated average number of the different types of error (PE vs NPE vs AD) for the two Groups (ADHD vs control) in the different Conditions (simple vs verbal vs spatial).

In considering the types of error (with the two-way interactions), it has been 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. It has been found that the two-way interaction Type of error  $\times$  verbal WM was significant,  $\chi^2(4) = 63.81, p < .001$ , and so was the two-way interaction Type of error  $\times$  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 children with a good performance in the verbal WM task made fewer PEs ( $B = -0.06, p = .048$ ). It has also been found a three-way interaction for Type of error  $\times$  Group  $\times$  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 ( $B = -0.54, p = .008$ ).

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 measure, 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). It has been 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). The two groups have been compared, 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,  $F=7.34$ ,  $p=.007$ ,  $\eta^2=.35$ , with the ADHD group obtaining lower scores for handwriting quality than the control group (ADHD:  $M=48.78$  [18.84]; control:  $M=57.50$  [18.39]). So was the main effect of Grade,  $F=11.18$ ,  $p<.001$ ,  $\eta^2=.41$ , with children in third and fourth grade ( $M=47.89$  [18.86]) obtaining lower scores for handwriting quality than children in fifth and sixth grade ( $M=64.54$  [16.43]). 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 writing speed, the task did not depend on the WM loading condition because the children had no concurrent task, so it has only been 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 seconds, 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 ( $M = 94.74$  [19.95]) than those in fifth and sixth grade ( $M = 126.67$  [19.80]). No interactions emerged. It has also been considered the correlations between writing 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,  $r(52) = -.41$ ,  $r(52) = -.33$ , and  $r(52) = -.36$ , respectively).

### 2.2.3. 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 used. The study confirmed, moreover, that WM is crucially involved in spelling (Kellogg, 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, 2015). It also clarified some of the mechanisms behind writing

abilities, highlighting the role of verbal and visuospatial WM in the writing process. It has been compared children with ADHD symptoms and a group of TD 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 made more spelling mistakes than controls in all dictation conditions.

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, it has been found that children made more NPE than PE or AD in the visuospatial WM loading condition - an effect not seen in the case of a verbal WM load. The phonological representation of the word seem to not be enough to write it correctly, so maybe only considering also the visual representation together with the phonological one can allow children to write it correctly. 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 impression needs to be tested in future research by obtaining an independent measure of verbal WM. In the TD children, and in the case of visuospatial WM loading, it has been 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 is known from the principal writing models, i.e. that WM is crucial during the writing process for two main reasons: first, because it enables all the conceptual information needed to produce a sentence (such as linguistic strings, ideas, and grammatical rules, stored in long-term memory) to be maintained; and second, because it enables ongoing monitoring, which is fundamental during writing (Cornoldi et al., 2010; Kellogg, 1996; McCutchen, 1996; Swanson & Berninger, 1996). An efficient WM 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 (Kellogg, 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 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, it has been found that children with ADHD symptoms had a worse spelling performance than their TD 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 Cornoldi (2015), 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, it has been found no specific effects in the ADHD group, even though verbal WM loading influenced their spelling more than in their TD 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). There have been 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 (Coltheart et al., 2001) in spelling.

As for handwriting, it has been 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 et al., 2014; Luisotto et al., 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 et al., 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. It has already been suggested (Berninger & Abbott, 1994) that handwriting skills influence other aspects of writing.

Our findings offer a new, coherent description of certain facets of the writing skills of TD 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 seemed to reflect the characteristics of the populations at the schools involved in the study). In addition, if the children had been tested on other measures, it might have been possible to examine the role of other aspects potentially involved in spelling accuracy, such as motor skills, reading decoding ability, and 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, with the possibility of a verbal recall. A broader array of written materials should be used in future research as well, because the fact that some of our results did not replicate previous findings (i.e., the higher frequency of accents and geminates; Re & Cornoldi, 2015) may be due to the specific material used in this study, which focused on distinguishing between phonological and non-phonological errors in a relatively small number of words that might elicit such errors. Including another primary task with the same concurrent task effects would also offer 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, simultaneous tasks, for example, instead of preloading

manipulations. 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 writing 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 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.

### **3. STUDY 2: HANDWRITING ABILITIES AND THE ROLE OF WORKING MEMORY IN CHILDREN WITH SYMPTOMS ATTENTION DEFICIT AND HYPERACTIVITY DISORDER**

#### **3.1. Introduction**

Handwriting is an important and complex skill that combines different components, and involves integrating cognitive, psychomotor and biophysical processes acquired over an extended period of time (Adi-Japha et al., 2007) and also interacts with the linguistic processes involved in maintaining and processing the verbal to-be-written material (Berninger & Abbott, 1994). Handwriting skills are needed to cope with many tasks at school. Despite the introduction of computerized writing systems, handwriting is still a prerequisite for most classroom activities. If handwriting is considered *per se*, excluding the expressive and orthographic components, there are many aspects to consider when examining children's handwriting, including the legibility of the productions, the speed and rate variability of its production. Legibility is obviously crucial to meet the main functions of writing concerning maintenance and transmission of knowledge. However speed is also very important because it not only affects efficiency in performing classroom activities, but also enables children to keep up with classwork (by copying from the blackboard, for instance, taking notes, or writing under dictation). Thus, the ability to keep abreast with their peers when writing by hand becomes crucial for children who tend to go off-task, such as those with attentional problems. Writing speed develops in a rather linear manner during primary school, and the overall development of graphic skills continues during secondary school (Feder and Majnemer, 2007). In this respect, it is particularly important for children to acquire automatized processes in writing graphic signs that can be written quickly and accurately without the need for conscious attention. A low level of automaticity when writing by hand generates a poor performance, in qualitative and quantitative terms (Connelly & Hurst, 2001).

Children with ADHD have a diagnostic profile mainly featuring inattention, hyperactivity and impulsivity (APA, 2013). They may also have a number of associated problems with a potential

bearing on their writing activity. These include difficulties in executive functions, including working memory (WM; Kuntsi, Oosterlaan, & Stevenson, 2001; Willcutt et al., 2005), and inconsistency in cognitive responses, leading to a high intra-individual variability (IIV) due to marked fluctuations in their performance. In particular, IIV appears to be among the best predictors of ADHD (Castellanos & Tannock, 2002), has been studied in relation to various cognitive tasks and may be relevant also in the case of children's with ADHD handwriting (Borella et al., 2011).

In front of substantial evidence concerning spelling and expressive writing difficulties associated with ADHD (e.g. Cornoldi et al., 2010; Luisotto et al., 2011; Re et al., 2007), handwriting has been scarcely studied.

The studies on handwriting in ADHD (e.g. Brossard-Racine et al., 2011; Fliers et al., 2009; Shen et al., 2012) have suggested that children with ADHD have not only poor spelling skills but also weak handwriting skills. These results were confirmed by a recent meta-analysis (Graham et al., 2016) that compared the writing performance of grade 1 to 12 students with ADHD to their normally achieving peers. The average weighted effect sizes showed that students with ADHD obtained lower scores than their normally achieving peers for a number of writing dimensions also interesting handwriting. It should be noticed that some studies specifically considered the effect of stimulant medication on handwriting performance of children with ADHD (Brossard-Racine et al., 2015; Rosenblum, Epsztein, & Josman, 2008) finding that handwriting difficulties are common in children with ADHD, and medication alone is not sufficient to resolve these difficulties.

Writing difficulties of children with ADHD may prompt teachers' negative opinions and be a cause of stress and frustration for the children concerned (Whalen, Henker, & Granger, 1990), negatively affecting their self-esteem and self-acceptance (Brossard-Racine et al., 2008). The relevance of handwriting for children with ADHD is also confirmed by recent research, which showed that their writing expression skills were an important predictor of their academic results 18 months on (Molitor et al., 2016).

However the observations concerning the difficulties of children with ADHD in handwriting offer partly unclear results and mainly consider the order and legibility of their written productions with qualitative observations of teachers (Cornoldi et al., 1996), further supported by research showing the poor legibility of handwriting of children with ADHD (e.g. Langmaid et al., 2014). However, in the case of ADHD handwriting, also speed appears particularly relevant as writing slowly can be a crucial issue for children with ADHD because they find it difficult to comply with the time constraints on school work (Amundson & Weil, 1996), but evidence on differences in handwriting speed between children with ADHD and matched controls is unclear and even contradictory. For example, Ross, Poidevant, and Miner (1995) assessed writing speed in children with ADHD from first to fifth grade, comparing them with a TD control group matched for gender and schooling. The children were asked to write the numbers from zero to nine (in letters) and their own name repeatedly as quickly as possible for 1 minute. The results showed no difference between the two groups. Similarly, Re (2006) investigated whether ADHD affected the writing skills of secondary school students, finding that those at risk of ADHD had more difficulty in dictation (especially with double consonants and accents), but not in writing speed. Other authors did find differences in writing speed between children with ADHD and their TD peers, but with results even pointing in opposite directions. For example, Adi-Japha and colleagues (2007) found that children with ADHD wrote more slowly, while other authors found they wrote more quickly and hurriedly (Brossard-Racine et al., 2008; Shen et al., 2012). Such inconsistent results concerning the writing speed of children with ADHD may be partly due to the type of task proposed, which varied in the different studies. In particular, it should be noted that writing by hand in a laboratory context may differ from writing during everyday school activities, when children's WM may be loaded with other demands while they are writing (such as holding in mind complex instructions, committing information to memory, organizing the space on the paper, etc.), and there may be several contextual distractions: these aspects were not considered in previous studies. Examining handwriting performance in contexts where the cognitive system is overloaded may be therefore important.

In a typical classroom situation, children need to write quickly, and the task in hand is likely to be quite complex, generating a WM overload that may be accentuated by the presence of numerous distractors that also affect WM. In such activities, the importance of WM is clear: it is needed to keep in mind all the conceptual and linguistic information required to produce a sentence, while also monitoring what is being written (Molitor et al., 2016). Until now, no studies had systematically examined handwriting in a context involving a WM overload. The present study aimed to examining the influence of cognitive loading on handwriting legibility, speed and its variability. To test the impact of cognitive loading, the same handwriting task was administered to children with and without ADHD symptoms in three conditions, one without and two with cognitive loading. One cognitive load consisted in a concurrent request that involved the verbal component of WM (Baddeley, 2001), as this represents a typical school situation and has been shown to interfere directly with the spelling processes involved in writing verbal material (Re et al., 2011). The concurrent memory request consisted of a series of orally presented syllables that the children would hear just before the handwriting task and were subsequently asked to recall. This manipulation had already been used successfully (Re et al., 2014) to show that a verbal WM load disrupted spelling accuracy, especially in children whose writing had yet to become well automatized. Our hypothesis was that children with ADHD would also have handwriting problems under verbal WM loading because writing by hand requires resources associated with verbal WM too, to maintain the material to be written and its orthographic representation, and to divide words into their phonological components, where necessary. Since it could be argued that the verbal WM task disruptive effect on handwriting speed could not be specific, as handwriting is an activity in which the visuomotor component is strongly involved, a spatial WM pre-loading condition was also included, using a manipulation that reflected the one adopted for the verbal WM pre-load condition. Individuals with sufficient handwriting skills in simple conditions, but still lacking in automaticity, were expected to be impaired when their WM is overloaded (Re et al., 2008) especially in the case of verbal WM. This should be especially evident in children with ADHD, also because they show



significant impairment in WM (Martinussen et al., 2005; Martinussen & Major, 2011; Martinussen & Tannock, 2006; Olive, 2004).

In short, the main aim of the present study was to examine handwriting in a simple situation (which involved rapid writing a simple series of words for a limited amount of time), and in two cognitive loading conditions, one with a verbal and the other with a spatial WM load. The assumption was that, under WM loading, handwriting would suffer more in children with symptoms of ADHD than in TD children. In particular, the concurrent maintenance of information in verbal WM was expected to reduce the former's writing speed more than the latter's. Furthermore, as suggested by previous research (Brossard-Racine et al., 2011; Langmaid et al., 2014; Shen et al., 2012) the handwritten productions of children with ADHD should be of poorer quality than those of TD children and the effect should be more evident under not only a verbal, but also –due to the visuomotor component involved in producing well shaped letters (Cornoldi, Mammarella, & Fine, 2016) - under a visuospatial WM load. As a quality measure it has been considered the legibility of the written productions, as often suggested (Tressoldi et al., 2013; Woodcock et al., 2001), and it has been examined whether it differed between the two groups and the three test conditions. Finally, the two groups were compared on IIV in relation to handwriting speed to support the hypothesis that IIV is particularly high in children with ADHD and is typically associated with the tasks where they fail (Castellanos & Tannock, 2002).

## 3.2. Study 2: The role of working memory in handwriting abilities

### 3.2.1. Method

#### Participants

Two groups of children attending the fourth and fifth grades of two primary schools located in Northern-Eastern Italy, in an urban village near Padova (Padua) took part in the study: one group consisted of 16 children (12 males and 4 females) who had symptoms of ADHD (the ADHD group); the other (control) group included 16 TD children matched for age, class, gender, cognitive

ability and rated family environment level, but without symptoms of ADHD. As in Italy cases with an explicit diagnosis of ADHD are very rare (Skounti et al., 2007), of the children in the ADHD group only one child had been previously diagnosed and the others were selected by the authors on the basis of a screening process that included interviews and a score of 14 or higher (a cutoff proposed by the authors; see Marzocchi et al., 2010) on one or both subscales of the SDAI (Scala per i Disturbi di Attenzione/ Iperattività per Insegnanti [ADHD Scale for Teachers]; see also Capodieci, 2017; Marzocchi & Cornoldi, 2000). Teachers were also asked to complete another questionnaire (COM, Capodieci, in press; Marzocchi et al., 2010) to identify any minor symptoms of other psychological and psychopathological issues, and to record relevant information on the children, including their socio-cultural characteristics. Socio-cultural level was individuated through an item included in the COM questionnaire. All the children were of average cognitive level, as measured with the verbal reasoning subtask of the PMA battery (PMA; Thurstone & Thurstone, 1981), which involves identifying in sets of words (e.g. red; blue; heavy; green) which word is the odd one out (heavy, in this example). Teachers and parents were interviewed informally from researchers to verify information collected through the questionnaires and to collect further evidence on the children's ADHD symptoms (not only at school, but also in other settings such as home, sport groups etc.) and in order to rule out children with other relevant difficulties. The children in the control group were comparable with the ADHD group in terms of age, class, cognitive ability and socioeconomic level, but scored below 5 (corresponding to the 70<sup>th</sup> percentile) on both subscales of the SDAI questionnaire. Table 1 shows the characteristics of the two groups involved in the study. In each group there were 10 fourth grade and 6 fifth grade children, in the ADHD group the age range was between 112 and 130 months and in the control group between 114 and 131 months. None of the children involved had a history of neurological, psychiatric or serious psychological problems. Furthermore no child had a diagnosis of learning disability (in Italy the diagnosis is based on shared criteria including a performance in learning tasks below -2 standard deviations or below 5<sup>th</sup> percentile). Children were not receiving any treatments of any kind,

including medication (in Italy very rare). Written consent was obtained from children's parents before they took part in the experiment. The study was conducted in accordance with the recommendations of the ethics committee of the University of Padua and approved by our institutional committee.

Table 2. Means and standard deviations (SD) for the characteristics of the two groups.

	ADHD group (N=16)	Control group (N=16)	F (1, 30)	<i>p</i>
Age (months)	120.50 (6.92)	122.19 (6.46)	0.51	.48
Disadvantaged family environment (COM)	2.15 (1.03)	1.70 (.98)	1.32	.22
Inattention (SDAI)	15.81 (2.43)	2.44 (3.79)	141.06	< .001
Hyperactivity (SDAI)	7.00 (6.66)	.63 (1.26)	14.14	.001
Reasoning (PMA)	18.19 (2.81)	19.31 (3.00)	1.19	.28

*Note.* COM= comorbidity questionnaire for teachers; SDAI= ADHD scale for teachers; PMA= Primary Mental Abilities.

#### Material and procedure

The questionnaire used to identify children with ADHD was the SDAI, that is widely used in Italy and has been validated for the Italian population, showing high inter-rater and test-retest reliabilities ( $r > .80$  in both cases), optimal discriminatory power and concurrent validity, obtained by correlating the scale with others ( $r > .95$ ; Marzocchi et al., 2010). The scale exactly reflects the 18 symptoms listed in the DSM 5 (APA, 2013) for the diagnosis of ADHD and therefore includes two subscales, one for inattention (9 items), and one for hyperactivity/impulsivity (9 items). Teachers were asked to closely monitor a child's behavior for about two weeks and then report the frequency of the types of symptomatic behavior described in each item. Scores for the items on the SDAI scale range from 0 (*problematic behavior never presents*) to 3 (*very often presents*). The other

questionnaire teachers filled was the COM scale (Marzocchi et al., 2010; Capodieci, in press). This scale allows checking 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 inter-rater and test-retest reliabilities ( $r > .90$  in both cases). Even in this case teachers were asked to closely monitor a child's behavior for about two weeks and then report the frequency of the types of symptomatic behavior described in each item with a scores range from 0 (*problematic behavior never present*) to 3 (*very often present*).

The experimental task was an individual handwriting task adapted from the BVSCO-2, (Batteria per la valutazione delle competenze ortografiche nella scuola dell'obbligo [Battery for the assessment of writing skills in children between 7 and 13 years]), a standardized complete writing battery available in Italy (Tressoldi et al., 2013). The task consisted in writing the numbers in cursive letters starting from one (in letters: uno-one, due-two, tre-three etc.) as fast as possible on a blank sheet of paper, in 18 successive trials, each lasting 20 s.

Three conditions were adopted in a counterbalanced order, with a brief interval (one minute) between conditions, and an interval of approximately ten seconds between trials:

- simple condition: the child was asked to write the numbers in letters as fast as possible, in six 20-second trials, starting each time from the number one;
- verbal condition: the task used in the simple condition was associated with a verbal WM load, i.e. immediately before each writing trial, the child was auditory presented four meaningless two-letter syllables drawn from the PRCR-2 (Prove di Prerequisito per la Diagnosi delle Difficoltà di Lettura e Scrittura [Prerequisite tests for the diagnosis of reading and writing difficulties]; Cornoldi, Miato, Molin, & Poli, 2009) at a rate of 1 syllable per second, that s/he was asked to remember; then s/he did the above-described writing task; and then s/he was asked to write down the previously-heard syllables;

- spatial condition: the procedure was the same as in the previous condition except that the load was spatial rather than verbal; for each trial, the child was shown a 3x3 matrix containing 4 dots for 4 seconds and, after completing the writing task, s/he was asked to add the previously-seen dots in an empty matrix.

Children were individually tested in a quiet room of their school.

For each condition, the numbers of graphemes written in each 20-second trial were counted, the total number of graphemes written in the six trials and the between-trials intra-individual variability. For the verbal and spatial conditions, the number of syllables and dot positions correctly remembered were also considered.

Three independent judges blinded to the children's groupings assessed the legibility of the children's handwriting in the three conditions on a scale from 0 (*illegible*) to 100 (*excellent*) in 10-point steps, as on the "Handwriting legibility scale" proposed by Woodcock-Johnson (Woodcock et al., 2001).

A preliminary analysis found that all the examined variables met the assumptions of normality: numbers of written graphemes had skewness of -0.16 ( $SE=0.41$ ), kurtosis of -1.70 ( $SE=0.81$ ), Kolmogorov-Smirnov test (K-S) of .12,  $p >.05$ , handwriting legibility had skewness of -0.13 ( $SE=0.41$ ), kurtosis of -0.43 ( $SE=0.81$ ), K-S of .09,  $p >.05$ , memory task had skewness of -0.12 ( $SE=0.41$ ), kurtosis of -0.81 ( $SE=0.81$ ), K-S of -.12,  $p >.05$ , and intra-individual coefficient of variation had skewness of -0.88 ( $SE=0.41$ ), kurtosis of -0.85 ( $SE=0.81$ ), K-S of .10,  $p >.05$ .

Children with ADHD and TD students were then compared on handwriting measures using a univariate analysis of covariance (ANCOVA) and Pearson correlations was calculated to examine the associations between handwriting speed and variability.

### 3.2.2 Results

All the children perfectly understood the tasks and were able to complete them, even when asked to write while keeping other verbal and spatial information in mind (see the last part of the present section for their performance in the WM tasks).

First it has been considered handwriting speed that, due to the previous contradictory results, represented the main study goal. Table 2 shows the mean numbers of graphemes written by the children (and the standard deviations) for each group, and in each condition. Children with ADHD were compared with controls using a Group (ADHD group vs control group) x Condition (simple vs verbal vs spatial) mixed-design ANCOVA controlling (having as covariates) for the percentages of syllables and dot positions correctly recalled. The two groups differed in spatial and verbal WM performance (see below), but there were no effects of the covariates (percentages of correctly recalled syllables or dot positions) on handwriting speed. There was a significant main effect of Group,  $F(1,30)= 15.39, p<.001, \eta^2_p=.34$ , the ADHD group producing fewer graphemes than the control group, with 25% of children in the ADHD group that performed under 1.5 SD with respect to the normative sample (BVSCO) and no child in the control group. It has also been found a significant main effect of Condition,  $F(1,30)= 122.44, p<.001, \eta^2_p=.80$ . With Bonferroni's post-hoc test it has been found that all three conditions differed: participants produced significantly more graphemes in the simple condition, followed by the spatial condition, and the fewest graphemes in the verbal condition. The Group x Condition interaction was also significant,  $F(1,30)= 3.70, p=.03, \eta^2_p=.11$ . As shown in Table 2, the fewest graphemes were written by children with symptoms of ADHD in the verbal condition. Using Student's *t* tests to compare the two groups in the different conditions (with Bonferroni's correction for  $\alpha=.05$  and  $p<.02$ ), it has been found that they only differed significantly in the verbal condition,  $t(30)= 5.24, p<.001$ , Cohen's  $d=1.91$  (Cohen, 1988), while the differences for the simple and spatial conditions only approached significance,  $t(30)=2.33, p=.028$ , Cohen's  $d=0.85$ , and  $t(30)=2.28, p=.030$ , Cohen's  $d=0.83$ , respectively.

Table 3. Mean numbers of graphemes (SD in brackets) written by the two groups in the simple, verbal and spatial conditions.

	ADHD group (N=16)	Control group (N=16)	<i>t</i> (30)
Simple condition	223.13 (31.22)	247.13 (27.01)	2.33
Verbal condition *	130.31 (24.84)	180.19 (28.82)	5.24
Spatial condition	187.95 (45.78)	227.38 (23.08)	2.28

*Note.* \* = the groups differ significantly from one another,  $p < .02$ .

To find further support for the observation that the legibility of the handwriting was poor in the ADHD group, and to see whether it related to speed of production, handwriting legibility was analyzed based on the three judges' assessments of handwriting legibility (Woodcock et al., 2001). The ratings given by the three judges, despite their subjective nature, substantially correlated (between .60 and .80), and the mean score of the three judgments was considered. Table 3 shows the mean scores obtained by the two groups in the three conditions. There were slight differences between conditions, and more evident differences between groups. The children with symptoms of ADHD were compared with the TD children using a Group (ADHD group vs control group) x Condition (simple vs verbal vs spatial) mixed-design ANCOVA controlling for the number of graphemes written in the different conditions. There were no effects of the covariate (number of graphemes written in each condition), and only a significant main effect of Group,  $F(1,30) = 8.48$ ,  $p = .007$ ,  $\eta^2_p = .24$ , as the ADHD group's handwriting was generally less legible than that of the control group. The effect of Condition did not reach significance, with  $F(1,30) = 2.97$ ,  $p = .060$ ,  $\eta^2_p = .10$ . Despite the fact that the Group x Condition interaction did not reach significance,  $F(1,30) = 2.38$ ,  $p = .102$ ,  $\eta^2_p = .08$ , an inspection of Table 3 shows that the group effect was mainly related with the conditions with WM load. Using Student's *t* tests to compare the two groups in the different conditions (with Bonferroni's correction for  $\alpha = .05$  and  $p < .02$ ), it has been found that they differed significantly in the verbal condition,  $t(30) = 3.39$ ,  $p = .002$ , Cohen's  $d = 1.24$ , and in the spatial

condition,  $t(30)= 3.15$ ,  $p=.004$ , Cohen's  $d=1.15$ , while the difference in the simple condition only approached significance,  $t(30)=2.33$ ,  $p=.027$ , Cohen's  $d=0.85$ .

Table 4. Mean (SD in brackets) scores for judgments of handwriting legibility in the two groups and the three conditions.

	ADHD group (N=16)	Control group (N=16)	$t(30)$
Simple condition	34.06 (11.47)	43.75 (12.07)	2.33
Verbal condition *	34.90 (10.72)	47.40 (10.11)	3.39
Spatial condition *	33.54 (9.29)	45.83 (12.55)	3.15

*Note.* \* = the groups differ significantly from one another,  $p<.02$ .

Finally, to examine the IIV in speed between trials in each condition, the intra-individual coefficient of variation (ICV) was computed, which corresponds to the individual standard deviation (ISD) divided by the individual mean performance. The ICV index was used because it takes into account individual differences in the mean scores, and may be more appropriate than ex-Gaussian analyses, in the context of procedures such as the one adopted in the present study (Borella et al., 2011; Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000; MacDonald, Nyberg, & Bäckman, 2006). Table 4 shows the mean ICV scores and standard deviations for each group in each condition. The children with symptoms of ADHD were compared with the TD children using a Group (ADHD group vs control group) x Condition (simple vs verbal vs spatial) mixed-design ANOVA. A significant main effect of Group was found,  $F(1,30)=5.79$ ,  $p=.02$ ,  $\eta^2_p=.14$ , the ADHD group showing a greater IIV than the control group, and a significant main effect of Condition,  $F(1,30)=35.88$ ,  $p<.001$ ,  $\eta^2_p=.55$ . With Bonferroni's post-hoc tests, it has been found that both groups had a greater IIV in the verbal condition than in the other two conditions. The Group x Condition interaction was also significant,  $F(1,30)= 4.91$ ,  $p=.01$ ,  $\eta^2_p=.16$ . As shown in Table 4, the ADHD group had a high IIV in the verbal condition. Using Student's  $t$  tests to compare the two



groups in the different conditions (with Bonferroni's correction for  $\alpha=.05$  and  $p<.02$ ), it has been found that they only differed significantly in the verbal condition,  $t(30)= 2.49$ ,  $p=.019$ , Cohen's  $d=0.91$ , while they were very similar in the simple and spatial conditions,  $t(30)=1.60$ ,  $p=.120$ , Cohen's  $d=0.58$ , and  $t(30)<1$ , respectively.

Table 5. Mean IIV scores (SD in brackets) for the two groups in the three conditions

	ADHD group (N=16)	Control group (N=16)	$t(30)$
Simple condition	.07 (.02)	.06 (.03)	1.60
Verbal condition *	.23 (.13)	.14 (.07)	2.49
Spatial condition	.07 (.04)	.08 (.04)	.87

Note. \* = the groups differ significantly from one another,  $p<.02$ .

To examine the relationship between handwriting speed and variability, it has been calculated their Pearson correlations, and found them significantly inversely correlated only for the verbal condition (simple condition  $r(32) = .11$ ; verbal condition  $r(32) = .60$ ,  $p<.001$ ; spatial condition  $r(32) = .29$ ). The fact that a high IIV could have influenced the reduced speed in the case of the verbal condition is also confirmed by the ANCOVA including IIV as a covariate in the group comparison on speed, that showed a significant effect of the covariate in the verbal condition,  $F(1,30)=8.60$ ,  $p=.007$ , but not in the simple  $F(1,30)<1$ , and spatial conditions  $F(1,30)=3.73$ ,  $p=.063$ .

The children's performance in the WM tasks was then examined and a group difference in both the verbal and the spatial condition was found. In fact, although the tasks were relatively easy for all the children, two  $t$  tests showed that the control group remembered significantly greater percentages of syllables and dot positions ( $p < .05$ ) than the ADHD group: control group M (SD)= 70.57 (20.78) vs ADHD group M (SD)= 48.18 (19.78) in the verbal condition; and control group M (SD)= 92.45 (8.77) vs ADHD group M (SD)= 82.03 (9.83) in the spatial condition.

### 3.2.3. Discussion and conclusions

Research has shown that children with ADHD may fare worse in spelling (Brossard-Racine et al., 2011; Luisotto et al., 2011; Re et al., 2007), and the literature and clinical reports also seem to agree that their handwriting is less legible, although evidence is still scarce. On the contrary, there are conflicting results regarding their performance in terms of writing speed (Adi-Japha et al., 2007; Brossard-Racine et al., 2008; Re, 2006; Ross et al., 1995; Shen et al., 2012), but researchers have yet to consider this issue in depth, in situations under time pressure and with concurrent requests to be maintained in WM (as in everyday life and at school, where the child's WM may be overloaded). The main objective of this research was to examine this particular issue and to compare the handwriting performance of children with ADHD symptoms with TD children in conditions with and without cognitive (verbal or spatial) WM loading. WM is a relevant variable for the writing process in these settings, as demonstrated by its inclusion in the main models of writing (Hayes, 2006; Kellogg, 1996), not only in the maintenance and mental segmentation of the verbal material to be written, but also in the maintenance of contents and instructions and in control of irrelevant information. It has been known from the literature that children with ADHD have difficulties in various executive functions, and verbal and spatial WM in particular (Martinussen & Major, 2011; Martinussen & Tannock, 2006), and these may also affect not only their spelling accuracy (Re et al., 2014) but also their writing speed and legibility.

The present study showed that our experimental manipulation to include a WM load proved crucial in shedding light on the handwriting of children with ADHD, in particular with reference to speed, offering some explanation for differences previously reported in literature. In terms of handwriting speed in the simple condition, the performance of children with ADHD symptoms was found not very different from that of TD children, as already reported elsewhere by Re (2006) and Ross and coauthors (1995) who administered a task similar to the one used in our research, differently from other studies (Adi-Japha et al., 2007; Shen et al., 2012) that found differences in the performance of the two groups probably due to the different procedures adopted, although the different results

could be also partly due to the different characteristics of the language of children (Hebrew language, Chinese). For example Adi-Japha and colleagues found that children with ADHD spent more time when writing, mainly due to long words and excessive corrections, two aspects not particularly relevant in our task.

In the condition without WM interference, the children with ADHD symptoms only produced about 10% fewer graphemes than their TD classmates and it must be noticed that also their legibility presented a lower difference with respect to controls than in the cases with WM interference. Then, on switching from the simple to the spatial and verbal load conditions, the children in both groups tended to write more slowly, but with more serious consequences in the case of ADHD. Concerning speed, in the spatial condition, the difference between the two groups was slightly greater than in the simple condition (with 20% fewer graphemes in the ADHD group), but this difference was not significant. In the verbal condition, however, the ADHD group wrote significantly more slowly (producing 38% fewer graphemes) than the control group and, despite the fact that they wrote fewer letters than the other group, their legibility was also particularly poor with respect to controls.

The result that overloading the verbal WM led to a more marked impairment in the speed and legibility of writing numbers in letters is presumably due to the facts that the same domain of WM was involved in both the writing task and the concurrent syllable recall task. The fact that children with ADHD were more susceptible to verbal WM interference than the other group can be attributed to their lower automaticity in writing (Re at al., 2011, Olive & Kellogg, 2002) in a situation in which automaticity was particularly necessary for coping with a concurrent task that relied on the same WM resources. In the spatial condition, keeping dot positions in mind interfered less with the demands of the writing task, showing that the impairment in writing performance, especially in the case of speed, under verbal WM loading was due not only to the addition of a concurrent secondary task, but also to the particular characteristics of the verbal WM task.

As for the handwriting legibility, it has been found further support for the observation (Brossard-Racine et al., 2011; Langmaid et al., 2014; Shen et al., 2012) that it is typically worse in children

with ADHD, and the difference with the control group was more evident in the two WM loaded conditions. In fact, in the case of legibility, also the spatial load produced a significant impairment of performance, probably due to the crucial role of visuomotor processes in making handwriting legible (Cornoldi et al., 2016). Our results revealed similar handwriting legibility in all three test conditions, however, and speed did not appear to greatly influence legibility, suggesting that there was no clear trade-off between the two. Based on these findings, it can be surmised that legibility does not affect handwriting speed in the three different conditions considered here, since the children's performance remained similar with and without any (verbal or spatial) cognitive loading.

A related goal of this study was to test the differences between the two groups in terms of IIV in writing performance, with and without any concomitant WM loading tasks, as inconsistency in responses and variability in test performance are among the best predictors of deficits in ADHD (Castellanos et al., 2005). Our results confirm previous evidence of a high IIV in children with ADHD in a variety of tasks, including handwriting (Borella et al., 2011). They also confirm the importance of a condition in which verbal WM is overloaded: IIV increased for both groups in the verbal condition, but significantly more in children with symptoms of ADHD. In situations perceived by the children as less effortful (because their WM is not overloaded with the information needed to perform two concomitant tasks), their consistency in performing the task seems to be better and their variability lower. Overloading their verbal WM with a secondary task prompted an increase in IIV in all the children, but significantly more so in the ADHD group. The significant correlation found between IIV and handwriting speed in the verbal condition suggests that children with ADHD may write more slowly partly because of their greater IIV.

To sum up, the present study seems to offer an important clarification on handwriting-related issues in children with ADHD. It confirms that the legibility and speed of their handwriting are weaker than in TD children, but the difference may be more evident when automaticity is required because a verbal cognitive load interferes with the children's writing activity. Despite its innovative aspects and potential applications, the present research has certain limitations that need to be mentioned.

The first concerns how the selection of the group of children with ADHD was done, which ensured homogeneity but did not include only cases with an explicit diagnosis of ADHD (a diagnosis that is still rare in Italy). Second, constraints imposed by the schools meant that the study could only collect some measures, disregarding several aspects that might be relevant and related to handwriting (e.g. participants' motor, visuomotor and spelling skills, or their executive functions). Further research is therefore needed on these issues. Research should also examine whether the interference of a WM loading condition changes in the case of a graphic speed task that does not involve verbal processes (e.g. drawing simple shapes instead of writing words) and match the difficulty of the WM loading tasks to see whether the lower disruptive effect of the spatial task seen in our study might also be due to the task itself being easier. It is worth noting, however, that handwriting speed was not affected directly by a trade-off with the concurrent task, i.e. it did not happen that children who devoted more resources to the pre-loaded material (and therefore remembered it better) were more impaired in handwriting speed. In our sample, all the children in both groups performed well in the WM tasks, and the ADHD group, despite having a poorer handwriting performance, remembered less syllables or dot positions, thus replicating other reports of WM difficulties in children with ADHD (Martinussen et al., 2005). Furthermore the group differences in handwriting remained significant also when WM performance (in the concomitant tasks) was included in our analyses as covariate.

Even with these limitations, this research offers new and meaningful information on an underinvestigated but relevant issue for children with symptoms of ADHD, who have to cope every day with classroom situations in which the speed and legibility of their handwriting are important. Our findings could also be useful for the purpose of intervention in the classroom and in the clinical setting. They confirm the importance of reducing the verbal WM overload when children with ADHD are involved in writing tasks (e.g. by providing them with support materials), and teaching these children strategies to cope with the negative implications of an excessive WM load (e.g.

looking for non-demanding contexts, using available writing facilitating structures [Re et al., 2008], or dividing the material to be written into separate parts).

## **4. CONCLUSIONS**

### **4.1. Summary of the findings and their implications**

One of the main difficulties that children with ADHD encounter in life relates to the academic sphere, but the literature has set little attention to the nature of their difficulties at school, especially in cases of ADHD unassociated with any learning disability.

In the first study writing skills were examined comparing children with ADHD symptoms and a group of TD 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. WM is a relevant variable for the writing process in these settings, as demonstrated by its inclusion in the main models of writing (Hayes, 2006; Kellogg, 1996), not only in the maintenance and mental segmentation of the verbal material to be written, but also in the maintenance of contents and instructions and in control of irrelevant information. It has been known from literature that children with ADHD have difficulties in various executive functions, and verbal and spatial WM in particular (Martinussen & Major, 2011; Martinussen & Tannock, 2006), and these may also affect not only their spelling accuracy (Re et al., 2014) but also their writing speed and legibility. Our results showed that children with ADHD symptoms in all school grades made more spelling mistakes than controls in all dictation conditions.

When the overall number of errors was considered, the concurrent WM task prompted much the same increase in the number of spelling mistakes. 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 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 et al., 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, it has been found that children made more NPE than PE or AD in the visuospatial WM loading condition - an effect not seen in the case of a verbal WM load. Suggesting that phonological representation of the word seem to not be enough to write it correctly, so maybe only considering also the visual representation together with the phonological one can allow children to write it correctly.

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 impression needs to be tested in future research by obtaining an independent measure of verbal WM. In the TD children, and in the case of visuospatial WM loading, no such relationship between performance in the primary and secondary tasks was found, i.e. there was apparently no explicit tendency to subtract resources from one task in order to complete the other.

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 (Kellogg, 1996).

In short, I found that children with ADHD symptoms had a worse spelling performance than their TD peers under all test conditions, in all school grades, and for all types of error, with no clear distinctions between the types of error, differently from previous results (Re & Cornoldi, 2015). The difference may be due to the difficulties posed by the text used in the earlier study. As concerns the role of WM loading, no specific effects in the ADHD group were found, even though verbal WM loading influenced their spelling more than in their TD 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). It has been 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 (Coltheart et al., 2001) in spelling.

Concerning handwriting quality, children's performance generally improved with aging, and the children with ADHD symptoms had a worse handwriting in all test conditions, confirming previous reports (Langmaid et al., 2014; Luisotto et al., 2011; Noda et al., 2013). In this study, differently from the second, it has been found 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). This difference between the two studies may be due to the material used: in study 2 the sheet was blank and not lined and the material was easier to compare because the writing product was the same in the three conditions (number in letters) instead in the present study sentences were different in the three conditions.

No difference emerged between our two groups in terms of writing speed, confirming previous evidence (Re, 2006; Ross et al., 1995). In this study, anyway, it has not been investigated writing speed in situation of WM loading, issue deepened in study 2.

In the second study, indeed, I focused on handwriting, trying to contribute in shedding light on the contradictory results presented in literature (Adi-Japha et al., 2007; Re, 2006.; Ross et al., 1995; Shen et al., 2012). I examined the handwriting performance in a simple condition but also under verbal and visuospatial WM load in children with symptoms of ADHD and control children.

The results showed that our experimental manipulation to include a WM load offered some explanation for differences previously reported in literature. In terms of handwriting speed in the simple condition, the performance of children with ADHD symptoms was similar to the one of TD children, as already reported by some authors (Re, 2006, Ross et al., 1995) but differently from other studies (Adi-Japha et al., 2007; Shen et al., 2012). These differences may be due to the

different procedures adopted, although the different results could be also partly due to the different characteristics of the language of children (Hebrew language, Chinese).

Switching from the simple to the spatial and verbal load conditions, the children in both groups tended to write more slowly, but with more serious consequences in the case of ADHD. Concerning speed, in the spatial condition, the difference between the two groups was slightly greater than in the simple condition, but this difference was not significant. In the verbal condition, however, the ADHD group wrote significantly more slowly than the control group and, despite the fact that they wrote fewer letters than the other group, their legibility was also particularly poor with respect to controls. The result that overloading the verbal WM led to a more marked impairment in the speed and legibility of writing numbers in letters is presumably due to the facts that the same domain of WM was involved in both the writing task and the concurrent syllable recall task. The fact that children with ADHD were more susceptible to verbal WM interference than the other group can be attributed to their lower automaticity in writing (Re at al., 2011, Olive & Kellogg, 2002) in a situation in which automaticity was particularly necessary for coping with a concurrent task that relied on the same WM resources. In the spatial condition, keeping dot positions in mind interfered less with the demands of the writing task, showing that the impairment in writing performance, especially in the case of speed, under verbal WM loading was due not only to the addition of a concurrent secondary task, but also to the particular characteristics of the verbal WM task.

Regarding the handwriting legibility, further support has been found for the observation (Brossard-Racine et al., 2011; Langmaid et al., 2014; Shen et al., 2012) that it is typically worse in children with ADHD, and the difference with the control group was more evident in the two WM loaded conditions. In fact, in the case of legibility, also the spatial load produced a significant impairment of performance, probably due to the crucial role of visuomotor processes in making handwriting legible (Cornoldi et al., 2016). Our results revealed similar handwriting legibility in all three test conditions, however, and speed did not appear to greatly influence legibility, suggesting that there was no clear trade-off between the two. Based on these findings, I surmise that legibility does not

affect handwriting speed in the three different conditions considered here, since the children's performance remained similar with and without any (verbal or spatial) cognitive loading.

A related goal of this study was to test the differences between the two groups in terms of IIV in writing performance, with and without any concomitant WM loading tasks, as inconsistency in responses and variability in test performance are among the best predictors of deficits in ADHD (Castellanos et al., 2005). Our results confirm previous evidence of a high IIV in children with ADHD in a variety of tasks, including handwriting (Borella et al., 2011). They also confirm the importance of a condition in which verbal WM is overloaded: IIV increased for both groups in the verbal condition, but significantly more in children with symptoms of ADHD. In situations perceived by the children as less effortful their consistency in performing the task seems to be better and their variability lower. Overloading their verbal WM with a secondary task prompted an increase in IIV in all the children, but significantly more so in the ADHD group. The significant correlation found between IIV and handwriting speed in the verbal condition suggests that children with ADHD may write more slowly partly because of their greater IIV.

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To conclude, the present thesis sheds light on the important role of WM in sustaining the writing process, and on the difficulties encountered by children with ADHD symptoms. The findings of these studies 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. Furthermore, the present findings confirmed what is known from the principal writing models, i.e. that WM is crucial during the writing process for two main reasons: first, because it enables all the conceptual information needed to produce a sentence (such as linguistic strings, ideas, and grammatical rules, stored in long-term memory) to be maintained; and second, because it enables ongoing monitoring, which is fundamental during writing (Cornoldi et al., 2010; Kellogg, 1996; McCutchen, 1996; Swanson & Berninger, 1996). An efficient WM enables all the information needed during the writing process to be managed adequately.

Our findings could also be useful for the purpose of intervention in the classroom and in the clinical setting. They confirm the importance of reducing the verbal WM overload when children with ADHD are involved in writing tasks (e.g. by providing them with support materials), and teaching these children strategies to cope with the negative implications of an excessive WM load (e.g. looking for non-demanding contexts, using available writing facilitating structures, or dividing the material to be written into separate parts). For instance, Re, Caeran and Cornoldi (2008) showed that giving children 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.

#### **4.2. Limitations and suggestions for future research**

Our findings offer a new, coherent description of certain facets of the writing skills of TD children and those with symptoms of ADHD, but the studies suffer 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), even if 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 to point out is the small number of females in the samples, which made it impossible to examine any gender-related effects (although the gender distribution seemed to reflect the characteristics of the populations at the schools involved in the study). In addition, if the children had been tested on other measures, it might have been possible to examine the role of other aspects potentially involved in spelling accuracy, such as motor skills, reading decoding ability, and 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. For example, we could ask for a verbal recall in the case of the verbal WM loading condition.

A broader array of written materials should be used in future research as well, because the fact that some of our results did not replicate previous findings (i.e., the higher frequency of accents and geminates; Re & Cornoldi, 2015) may be due to the specific material used in this study, which focused on distinguishing between phonological and non-phonological errors in a relatively small number of words that might elicit such errors. Including another primary task with the same concurrent task effects would also offer 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, simultaneous tasks, instead of preloading manipulations. Spatial sequential rather than spatial simultaneous material (Pazzaglia & Cornoldi, 1999) could be used to mirror the sequential presentation of the verbal material. Further research is therefore needed on these issues. Research should also examine whether the interference of a WM loading condition changes in the case of a graphic speed task that does not involve verbal processes (e.g. drawing simple shapes instead of writing words) and match the difficulty of the WM loading tasks to see whether the lower disruptive effect of the spatial task seen in our study might also be due to

the task itself being easier. It is worth noting, however, that handwriting speed was not affected directly by a trade-off with the concurrent task, i.e. it did not happen that children who devoted more resources to the pre-loaded material (and therefore remembered it better) were more impaired in handwriting speed.

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## **APPENDICES**

Appendix A – Questionnaire used for assessing symptoms of Attention Deficit and Hyperactivity Disorder (SDAI scale plus)

### **Questionario SDAI per la classe**

Gentilissima insegnante,

il presente questionario è volto all'individuazione di comportamenti di Disattenzione e Iperattività e di alcuni aspetti a essi associati.

La prego di compilare il questionario solo dopo aver osservato il bambino per un periodo (circa due settimane). Dovrà valutare, per ciascuno dei comportamenti elencati nella pagina seguente, la frequenza con cui compaiono nell'alunno. A ogni item attribuirà la valutazione di:

- 0 se mai o quasi mai o per nulla il bambino/a (o ragazzo/a) presenta il comportamento illustrata dall'item;
- 1 se la cosa accade qualche volta o il bambino presenta il tratto ma in misura modesta;
- 2 se avviene spesso o il bambino presenta il tratto in una certa misura (abbastanza)
- 3 se accade sempre o il bambino presenta il tratto in misura elevata (molto).

Solamente per quanto riguarda l'item numero 1, dovrà usare i seguenti valori:

- 1 se il bambino appartiene ad un ambiente socioculturale svantaggiato;
- 2 se il bambino non appartiene ad un ambiente socioculturale svantaggiato

Le valutazioni devono essere riferite alla classe di frequenza dell'alunno, in particolar modo tenendo conto di quello che tipicamente fanno i suoi coetanei. È importante che risponda a tutti gli item del questionario.

La ringrazio anticipatamente per la collaborazione e per la disponibilità.

SCUOLA _____ LOCALITÀ _____ SEZIONE _____ INSEGNANTE _____ DATA _____	Nome dell'alunno (o sigla)																	
	Data di nascita (mese-anno)																	
	Sesso (1=maschio; 2=femmina)																	
1) Presenta nell'insieme scarse capacità cognitive? (1=sì 2=no)																		
2) Presenta scarso apprendimento linguistico																		
3) Presenta un apprendimento matematico insufficiente																		
4) incontra difficoltà a dirigere l'attenzione sui dettagli o compie errori di negligenza																		
5) Spesso si agita con le mani o con i piedi o si dimena sulla seggiola																		
6) incontra difficoltà nel mantenere l'attenzione nei compiti o nei giochi in cui è impegnato																		
7) Non riesce a stare seduto																		
8) Quando gli si parla non sembra ascoltare																		
9) Sperimenta una irrequietudine interna, corre e si arrampica dappertutto																		
10) Pur avendo capito le istruzioni e non avendo intenzioni ostili, non segue le istruzioni o fa fatica a portarle a compimento																		
11) incontra difficoltà ad impegnarsi in giochi o in attività tranquille																		
12) incontra difficoltà ad organizzarsi nei compiti e nelle sue attività																		
13) È in movimento continuo come se avesse dentro un motorino che non si ferma																		
14) Evita o è poco disposto ad impegnarsi in attività che richiedono uno sforzo continuato																		

15) Parla eccessivamente																			
16) Perde oggetti necessari per l'attività che deve svolgere																			
17) Risponde precipitosamente prima ancora che la domanda sia formulata interamente																			
18) Viene distratto facilmente da stimoli esterni																			
19) Incontra difficoltà ad aspettare il suo turno																			
20) Tende a dimenticarsi di fare le cose																			
21) Spesso interrompe o si comporta in modo invadente con altri impegnati in un gioco o in una conversazione																			
22) Fa il prepotente, minaccia o aggredisce fisicamente persone, anche animali, danneggiando oggetti																			
23) Irrita deliberatamente compagni e adulti																			
24) Presenta scarso interesse o piacere per tutte le attività che gli vengono proposte																			
25) Quando è interrogato presenta evidenti segnali di disagio (tremori, sudori, ecc..) ed impaccio																			
26) Sembra non essere accettato dal gruppo																			
27) E' uno degli ultimi ad essere scelto per formare una squadra o per giocare																			
28) Non ha amici																			
29) Non sa come stringere amicizia																			
30) Ha scarse capacità di interazione sociale																			
31) Ha difficoltà di rapporto con i compagni																			

## Appendix B – Example of the stimuli used for assessing writing abilities

### Sentences dictated in simple condition

1. Se vuoi scendere/ dalla macchina/ devi togliere/ la cintura/ di sicurezza.
2. Il falegname/ sa intagliare/ il legno/ benissimo/ e con dei prezzi/ molto convenienti.
3. Mio nipote/ ieri/ ha portato/ a casa/ l'anatra/ che ha vinto/ alla festa/ del suo paesino.
4. Quest'abito/ ha /una caratteristica speciale,/ lo potranno vedere/ solo gli intelligenti.
5. Verrò/ con te/ in stazione/ domani pomeriggio,/ il tuo treno/ partirà/ alle dieci.
6. L'uomo/con il cappotto rosso/che è sulla porta/di casa tua/ ha suonato/più volte/ il campanello.
- 7 La mamma/era seduta / in giardino:/ stava/ cucendo/ i pantaloni rotti/ con l'ago.
8. Quando/ inizia/ l'anno/ le persone/ preparano/ delle festine/ per amici.

### Sentences dictated in verbal condition

1. Lo sciopero/ degli insegnanti/ spesso/ rende molto allegri/ i pigri alunni.
2. Ricordiamoci/ di bagnare/ il suo prato,/ tagliare/ i rami/ e spazzare/ le foglie secche.
3. Amava/ l'arte,/ era brava/ a suonare/ il flauto/ e ha organizzato/ concerti/ con amiche.
4. Quest'anno/ la mia mamma/mi ha insegnato/ad usare/ago e filo,/ aggiustare calzini/e ricamare.
5. Il palloncino/ è scoppiato/ e ora/ vado a comprarne/ uno bianco ancora/ più bello.
6. Il contadino/ ha detto:/ 'l'uva/ è ormai appassita,/ vuol dire/ che arriverà/ il freddo inverno'.
7. Vicino/ al letto/ di Maria/ c'erano/ le caramelle/ colorate/ al gusto di arance.
8. Il bambino/ ha mangiato/ tutta l'anguria/ prima/ di andare/ in spiaggia.

### Sentences dictated in spatial condition

1. La villa/ vale tanto:/ bisognerebbe avere/ il consiglio/ di un architetto.
2. In montagna/ tra le folte chiome/ degli alberi,/ potrai vedere/ coppie di scoiattoli.
3. Le piace/ andare a scuola/ ma non sopporta/ se l'insegnante/ la costringe/ a studiare.

4. A primavera/ la rondine/ ha fatto ritorno/ alla fattoria/ riconoscendo/ l'albero/ con il nido.
5. Lunedì prossimo/ il mio amico Marco/ festeggerà/ il suo ventesimo/ compleanno.
6. Sulla pista/ è atterrato/un grande elicottero/che ha portato/doni/dall'America/per tuo papà.
7. Era/ l'una / di notte/ e i bambini/ si alzarono/ per guardare/ il cielo e le stelle.
8. Hai comprato/ un vasetto/ a forma/ di farfalla/ decorato/ con l'argento.

Appendix C – Example of the stimuli used for assessing working memory capacity

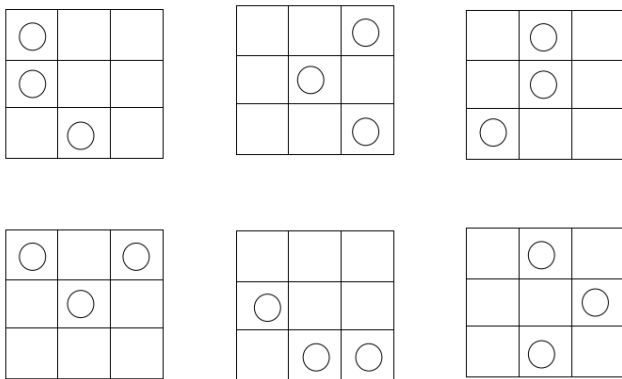
Numbers for children of third and fourth grade

• 729 • 613 • 472 • 851 • 374 • 596 • 185 • 937

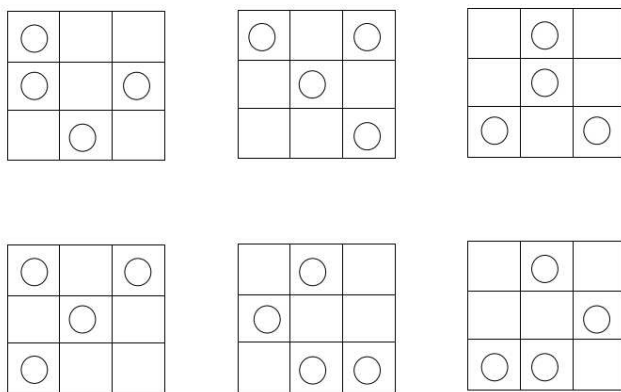
Numbers for children of fifth and sixth grade

• 7295 • 6138 • 4726 • 8519 • 3741 • 5962 • 1857 • 9374

Examples of matrix for children of third and fourth grade



Examples of matrix for children of fifth and sixth grade



Appendix D – Example of protocols of Study 1

4<sup>a</sup> cartella

3

15/10/2015

Se vuoi scendere dalla macchina devi togliere la cintura  
di sicurezza <sup>AD</sup>.

Il falegname sa intagliare il legno benissimo e con dei prezzi  
molto con <sup>ENF</sup> venienti.

Mio nipote ieri <sup>ENF</sup> a portabo a casa l'anatra che ha vinto alla  
festa del suo paesino.

Quest'abito ha una caratteristica speciale lo potranno vedere solo  
gli intelligenti.

Verrò con te in stazione domani pomeriggio, il tuo treno  
partirà <sup>AD</sup> alle dieci.

L'uomo con il cappotto rosso che è sulla porta di casa  
tua ha suonato più volte il campanello.

La mamma era seduta in giardino; stava cucendo i pantaloni  
rotti con l'ago.

Quando inizia l'anno le persone preparano delle festine  
per amici.

EF 0  
ENF 2  
AD 2

uno due tre quattro cinque sei sette otto nove dieci  
43

Ricordiamoci di <sup>EF</sup> ~~d~~agnare il suo prato, <sup>EF</sup> tagliare i <sup>EF</sup> rami e <sup>EF</sup> spazzare le foglie secche 229 ✓

Amava l'arte era brava a suonare il flauto e ha organizzato concerti con amici. 472 ✓

Quest'anno ~~4~~ mia mamma mia <sup>ENF</sup> a 581 x mancano 10 parole

Il ~~palla~~ palloncino è scoppiato e ora vado <sup>ENF</sup> a comprarne uno bianco ancora più bello 374 ✓

Il contadino <sup>ENF</sup> a detto: "l'uva è ormai appassita, <sup>AD</sup> <sup>EF</sup> voldine che <sup>AD</sup> <sup>ENF</sup> arriverà il freddo in <sup>ENF</sup> verno 546 ✓

<sup>ENF</sup> Vi cino al letto di Maria c'erano le caramelle colorate al gusto di arance. 285 ✓

Il bambino ha mangiato ~~la~~ tutta l'anguria prima di andare in spiaggia. 37 ✓

uno due tre quattro cinque sei sette otto nove

EF 5  
ENF 5  
AD 2

MU e arrow MANCANO 10 PAROLE

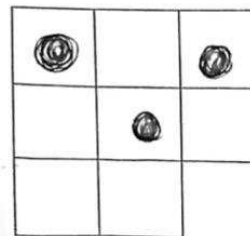
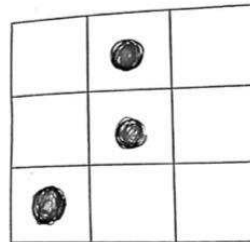
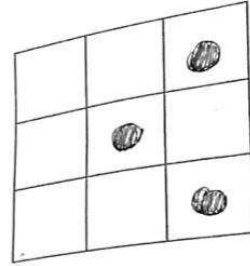
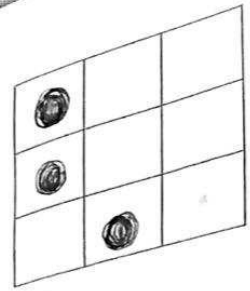


3 La villa vale tanto bisognerebbe avere il <sup>ENF</sup> consiglio  
di un'architetto

4 In montagna tra le folte chiome degli <sup>AD</sup> alberi, potrai  
<sup>EP</sup> vedere coppie di scialtoli

5 Le piace andare a scuola ma ~~non~~ non sopporta se  
l'insegnante <sup>EP</sup> la costringe <sup>ENF</sup> a studiare

<sup>ENF</sup> Ha primavera la rondine <sup>ENF</sup> a fatto ritorno alla fattoria ricorrendo  
sceso l'albero con il nido.



uno - due - tre - quattro - cinque - sei - sette - otto <sup>34</sup>

uno - due - tre - quattro - cinque - sei - sette - otto - nove <sup>37</sup>

uno due tre quattro cinque sei sette otto nove  
dieci <sup>40</sup>

uno due tre quattro cinque sei sette otto nove <sup>37</sup>

uno due tre quattro cinque sei sette otto nove  
dieci <sup>43</sup>

uno due tre quattro cinque sei sette otto  
nove dieci <sup>43</sup>

unó - due - tre - quattó - cinqúe - sei - sette 31

bi - bó - gó - dó 2

unó - due - tre - quattó - cinqúe - 22

pe - ti - ró - x - 2

unó - due - ~~tre~~ - quattó - 16

fe - lu - ró - dó 3

unó - due - tre - quattó - 16

ce - ró - bó - ma . 1

unó - due - tre - quattó - 16

su - bó - vi - ga 4

unó - due - tre - quattó - cinqúe - sei 25

pe - mi - fó - vi 2

1

Vinci

6-A

34 uno - due - tre quattro cinque  
sei sette otto

0		
0		0
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4

}  
}

43 uno due tre quattro cinque  
sei sette otto nove dieci

0		0
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		0

4

}  
}

34 uno due tre quattro cinque  
sei sette otto

0		0
	0	
0		

4

## SUMMARY IN ITALIAN / RIASSUNTO IN ITALIANO

Il deficit d'attenzione e iperattività (ADHD) è un disturbo evolutivo dell'autocontrollo di origine neurobiologica che interferisce con il normale sviluppo psicologico del bambino e ostacola lo svolgimento delle comuni attività quotidiane. Il bambino solitamente non riesce a orientare i propri comportamenti rispetto a quanto atteso dall'ambiente esterno. Il disturbo è prevalentemente dovuto all'interazione tra una predisposizione cerebrale congenita e gli effetti dell'ambiente. I sintomi sono caratterizzati da difficoltà di attenzione e concentrazione, iperattività e incapacità di controllare l'impulsività (American Psychiatric Association, 2013).

L'ADHD si trova spesso associato a disturbi e/o difficoltà negli apprendimenti (Re, Pedron, & Lucangeli, 2010), a deficit nelle funzioni esecutive (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), oltre ad altre comorbidità con i disturbi del comportamento e dell'umore che spesso possono insorgere con la crescita dell'individuo (Barkley, 2014).

Le funzioni esecutive sono processi mentali deputati al controllo e alla pianificazione dei pensieri e delle azioni finalizzate al raggiungimento di un obiettivo. Sono necessarie poiché garantiscono anche il monitoraggio e la modificazione dei pensieri e delle azioni in caso di necessità, adeguandoli alla nuova situazione (Miyake & Friedman, 2012). Le principali funzioni esecutive sono: attenzione, memoria di lavoro, flessibilità cognitiva, inibizione e pianificazione. Tra i deficit nelle funzioni esecutive dei bambini con ADHD, il più rilevante – secondo la letteratura – è quello presente nella memoria di lavoro (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), che è la capacità di mantenere in memoria delle informazioni ma, allo stesso tempo, manipolarle durante lo svolgimento di un'altra attività cognitiva (Siegel e Ryan, 1989). È dunque chiaro come quest'abilità sia fondamentale negli apprendimenti, oltre che in numerose attività quotidiane, e come sia maggiormente rilevante nelle abilità scolastiche dei bambini con ADHD (Biederman et al., 2004).

Per quanto riguarda le difficoltà negli apprendimenti degli alunni con questo disturbo, alcuni autori hanno recentemente riportato come la comorbidità tra ADHD e disturbi dell'apprendimento possa raggiungere il 45% (DuPaul, Gormley, & Laracy, 2013); anche nel caso in cui non sia presente un

disturbo dell'apprendimento, i bambini con ADHD incontrano comunque maggiori difficoltà nelle abilità accademiche (Mayes, Calhoun, & Crowell, 2000), perdono anni scolastici e abbandonano più frequentemente la scuola (Barkley, 2014) rispetto ai loro coetanei. Tra le difficoltà di apprendimento dei bambini con ADHD quella della scrittura è stata presa in esame solo in tempi recenti. La causa di questo ritardo è da ricercare in due principali motivi teorici: da un lato il linguaggio scritto è stato sempre subordinato a quello parlato, dall'altro – da un punto di vista psicopedagogico – imparare a leggere è stato considerato più importante e propedeutico all'imparare a scrivere; di conseguenza gli studi sulla lettura hanno preceduto quelli sulla scrittura (Re, 2006).

La scrittura è un'abilità complessa che richiede l'integrazione di processi cognitivi, motori e linguistici e i principali modelli dell'abilità di scrittura inseriscono la memoria di lavoro tra le funzioni cognitive più rilevanti (Hayes, 2006; Kellogg, 1996).

L'abilità di scrittura comprende principalmente tre diversi aspetti: la componente grafica, quella ortografica e l'espressione scritta. La scrittura manuale o grafismo riguarda la parte più strumentale della scrittura; non è indispensabile al processo di scrittura ma rappresenta per il momento la forma più comune di scrittura – quasi esclusiva nella scuola primaria e secondaria – e accompagna la maggior parte delle attività umane, dalle più alle meno formali (prove d'esame, appunti, ecc.). I due indici più importanti nell'analisi del grafismo sono la velocità di scrittura e la leggibilità, aspetti che permettono agli studenti di stare al passo durante le lezioni e che fanno in modo che gli insegnanti siano in grado di leggere ciò che producono. Affinché questo avvenga, è importante che l'alunno abbia acquisito una certa automaticità nella produzione così da potersi concentrare, oltre che sulla velocità e leggibilità, anche su altri aspetti, come l'ortografia, la produzione di idee, il monitoraggio, la gestione di distrattori. In letteratura si trova unanimità nell'evidenza che i bambini con ADHD mostrino una grafia poco leggibile e disordinata (Langmaid, Papadopoulos, Johnson, Philips, & Rinehart, 2014; Luisotto, Borella, & Cornoldi, 2011). I risultati sulla velocità di scrittura sono invece contrastanti: alcune ricerche non trovano differenze tra la velocità di bambini con

ADHD e alunni a sviluppo tipico (Re, 2006; Ross, Poidevant, & Miner, 1995) mentre altre riportano una differenza nella prestazione dei bambini con ADHD rispetto ai pari, sul versante della lentezza (Adi-Japha et al., 2007) o su quello della rapidità (Shen, Lee, & Chen, 2012).

La componente ortografica della scrittura riguarda quei processi che permettono di scrivere in modo corretto senza compiere errori. Gli errori che si possono compiere sono principalmente di tre tipi (Tressoldi, Cornoldi, & Re, 2013): errori fonologici, errori non fonologici ed errori di accenti e doppie. I primi (EF) comprendono tutti quegli errori in cui non è rispettato il rapporto tra fonema e grafema come, ad esempio, lo scambio di grafema, l'omissione o l'aggiunta di lettere o sillabe, l'inversione e il grafema inesatto. Gli errori non fonologici (ENF) sono errori nella rappresentazione ortografica delle parole senza errori nel rapporto tra fonemi e grafemi, comprendono le separazioni e fusioni illegali, lo scambio di grafema omografo (es. scuola per scuola) e l'omissione o aggiunta di "h" nel caso in cui si debba decidere tra verbo avere e preposizione. Gli errori di accenti e doppie (AD) comprendono l'omissione o l'aggiunta di consonante doppia e di accento. In letteratura è riportato che i bambini con ADHD tendono a compiere un numero maggiore di errori rispetto ai compagni a sviluppo tipico (Noda et al., 2013) e, in particolare, errori di accenti e doppie (Re & Cornoldi, 2015).

Infine, l'espressione scritta comprende, oltre agli aspetti della scrittura già citati, l'abilità di generazione di idee, pianificazione, revisione. La letteratura che ha indagato questo aspetto nei bambini con ADHD è più estesa rispetto ai due ambiti precedenti e riporta la presenza di una prestazione maggiormente compromessa nei bambini con ADHD (Rodriguez et al., 2015). La produzione scritta richiede infatti un elevato utilizzo di tutte le funzioni esecutive che è risaputo essere più deboli nella maggior parte dei bambini con ADHD (Biederman et al., 2004).

Nel presente lavoro di tesi ci si è focalizzati sui primi due aspetti della scrittura e in particolare sulla loro relazione con la memoria di lavoro nei bambini con sintomi di ADHD. Si è trovato in letteratura che i bambini con ADHD commettono un maggior numero di errori e hanno una grafia meno leggibile, sono però pochi gli studi che prendono in esame come questi aspetti siano legati a

un sovraccarico in memoria di lavoro e, in specifico, in che modo la memoria di lavoro verbale e quella spaziale influenzino questi aspetti. Nel contesto scolastico, l'attività di scrittura più quotidiana (prendere appunti, copiare dalla lavagna, scrivere i compiti nel diario) è sempre accompagnata contemporaneamente da altre richieste come quelle di prestare attenzione a ciò che dice l'insegnante, non farsi distrarre dai compagni, etc. Per questo motivo, nel presente lavoro di ricerca, si è voluto analizzare in che modo un secondo compito (verbale e spaziale) possa influenzare la scrittura, sia da un punto di vista grafico sia ortografico.

Nel primo studio le abilità di scrittura di 26 bambini con sintomi di ADHD e di 26 bambini di controllo dalla classe terza primaria alla prima secondaria di primo grado (appaiati per genere, età, livello socioeconomico) sono state esaminate in un compito di dettatura semplice e in due condizioni con sovraccarico in memoria di lavoro attraverso due compiti concomitanti, uno di memoria di lavoro verbale o uno di memoria di lavoro visuo-spaziale. Nel primo caso lo sperimentatore pronunciava a voce alta una sequenza di numeri e successivamente dettava una frase. I bambini dovevano tenere in mente la sequenza di numeri, mentre scrivevano la frase, e subito dopo riportarli sul foglio in cui stavano scrivendo. Nel caso del compito visuo-spaziale la procedura era la medesima ma, in questo caso, al posto dei numeri veniva mostrata una matrice con all'interno dei pallini in determinate posizioni: i bambini dovevano tenere a mente i pallini e riportarli in una matrice vuota dopo aver scritto la frase che era stata dettata. Venivano dettate otto frasi per ognuna delle tre condizioni. La produzione scritta è stata valutata dal punto di vista della leggibilità e del tratto grafico da due giudici indipendenti (Woodcock, McGrew, Mather, 2001). È stato, infine, proposto ai bambini un semplice compito di velocità di scrittura di numeri in lettere solo in condizione semplice (BVSCO; Tressoldi et al., 2013).

I risultati hanno mostrato che i bambini con sintomi ADHD compiono in generale un numero maggiore di errori di ortografia rispetto ai bambini del gruppo di controllo e che le condizioni con sovraccarico in memoria di lavoro compromettono in modo più significativo la loro *performance*. I due dettati con doppio compito hanno mostrato effetti parzialmente diversi. Nella condizione



verbale vi è stato un aumento degli EF, mentre nella condizione visuospaziale un aumento degli ENF. Nel gruppo di bambini con sintomi di ADHD, gli alunni che hanno mostrato una miglior prestazione nel compito di memoria di lavoro verbale hanno mostrato anche migliori prestazioni ortografiche. Dal punto di vista della grafia, i bambini con sintomi di ADHD e il gruppo di controllo avevano una velocità di scrittura simile, ma la qualità del prodotto scritto è risultata peggiore nei bambini con sintomi di ADHD. I nostri risultati suggeriscono che la memoria di lavoro supporta l'abilità scrittura e che i bambini con sintomi ADHD hanno difficoltà di scrittura generali. Si è trovato inoltre che probabilmente, rafforzando l'abilità di gestire informazioni verbali, si possono avere benefici sulle prestazioni ortografiche. In questo studio l'aspetto della grafia è stato considerato solo in condizione semplice, senza un sovraccarico in memoria di lavoro, ed è per questo motivo che si è voluto approfondire questo aspetto attraverso il secondo studio.

Nel secondo studio abbiamo esaminato la prestazione del grafismo in 16 bambini di quarta e quinta primaria con sintomi di ADHD e 16 bambini di controllo (appaiati per genere, età e livello socioeconomico) in condizione semplice e anche in due condizioni con sovraccarico in memoria di lavoro (verbale e spaziale). I bambini svolgevano un compito di velocità di scrittura di numeri in lettere (BVSCO; Tressoldi et al., 2013) per sei volte e in tre condizioni. Una condizione semplice, in cui veniva richiesto solo di svolgere il compito di velocità di scrittura, e due condizioni di sovraccarico di memoria di lavoro con le stesse modalità utilizzate nel primo studio, solo che nella condizione verbale invece dei numeri veniva chiesto di memorizzare delle sillabe (PRCR, Cornoldi, Miato, Molin, & Poli, 2009). Nel secondo studio, avendo la prestazione in uno stesso compito per più volte consecutive, si è potuta analizzare la variabilità intra-individuale dal momento che in letteratura si trova che la variabilità nella *performance* è uno dei migliori fattori predittivi di difficoltà nell'ADHD (Castellanos & Tannock, 2005). Si è analizzata, anche in questo caso, la qualità del grafismo tramite le valutazioni di tre giudici indipendenti (Woodcock et al., 2001) I risultati hanno mostrato che la velocità dei gruppi differiva significativamente solo nella condizione verbale, dove i bambini con sintomi di ADHD hanno scritto più lentamente e hanno mostrato una

maggior variabilità intra-individuale rispetto ai controlli. La leggibilità della grafia è stata influenzata dal carico in memoria di lavoro verbale.

Le ricerche presentate hanno mostrato interessanti risultati nell'ambito delle abilità di scrittura nei bambini con sintomi di ADHD ma vanno citati anche alcuni limiti dei presenti studi. Innanzitutto il fatto di non avere un campione più ampio e con bambini che avessero un'effettiva diagnosi di ADHD. Quest'ultima in Italia è infatti ancora rara (Skounti, Philalithis, & Galanakis, 2007) e quando viene effettuata si tratta solitamente di casi gravi e con numerose comorbidità. Sarebbe comunque interessante riuscire a indagare se i risultati si mantenessero simili nel caso di bambini con diagnosi di ADHD. Un campione più ampio permetterebbe di prendere in esame anche l'effetto del genere. Un altro limite riguarda il numero di prove proposte e il contesto di somministrazione. Sarebbe interessante in futuro poter proporre un maggior numero di prove che indaghino le funzioni esecutive e prove che valutino gli aspetti di abilità motorie e altri apprendimenti. Il contesto classe, in cui sono state proposte le attività, rappresenta un contesto ecologico che ci permette di analizzare le abilità dei bambini all'interno del loro ambiente. Dall'altro lato, però, fattori di distrazione o alunni che hanno copiato dal compagno potrebbero aver influito sui risultati; una somministrazione individuale avrebbe potuto ovviare queste problematiche. Un altro limite riguarda il compito spaziale che, a causa della presenza solo in alcune scuole della lavagna interattiva, non ha potuto essere sequenziale come nel caso del compito verbale e potrebbe essere risultato più semplice. Nonostante i limiti citati il presente lavoro di tesi permette di aggiungere un tassello al puzzle sulle abilità di scrittura nei bambini con sintomi di ADHD e di ricavarne importanti applicazioni pratiche sia per l'ambito clinico sia per quello scolastico. Infatti, risulta chiaro che una memoria di lavoro efficiente permette di svolgere il compito verbale o spaziale e, allo stesso tempo, richiamare in modo corretto dalla memoria la parola da scrivere. Il fatto che la memoria di lavoro visuo-spaziale oltre a quella verbale influisca sulla prestazione ortografica fa pensare che il *loop* fonologico non sia sufficiente a evitare gli errori, soprattutto quelli che richiedono la memoria a lungo termine (Kellogg, 1996). I bambini con ADHD hanno anche prestazioni inferiori nei compiti di memoria di

lavoro a riprova che la loro prestazione ortografica non è dovuta al fatto che tutte le risorse fossero adibite a svolgere i compiti di memoria di lavoro ma, al contrario, che la richiesta di svolgere i due compiti contemporaneamente sovraccarica la loro ML portandoli a delle prestazioni deficitarie in entrambi i compiti. Per quanto riguarda il grafismo emerge come la velocità e la qualità della grafia siano particolarmente deficitarie nel momento in cui la memoria di lavoro verbale è sovraccaricata con un compito che richiede le stesse risorse. Il fatto che i bambini con ADHD siano maggiormente sensibili all'interferenza del compito verbale rispetto al gruppo di controllo, si può attribuire a una mancanza di automaticità nella produzione scritta in una situazione in cui risulta particolarmente necessaria (doppio compito). L'aumento della variabilità intra-individuale nel caso della condizione con doppio compito verbale si trova soprattutto nei bambini con ADHD e la correlazione con la velocità di scrittura può far pensare a un rallentamento dovuto in parte alla maggiore variabilità.

Questi aspetti emersi dalla ricerca possono essere interessanti spunti per aiutare i bambini con sintomi o diagnosi di ADHD in classe nell'affrontare i compiti che richiedono la scrittura, dalle semplici attività quotidiane di copiatura dalla lavagna alle verifiche scritte. Possono inoltre essere utilizzati nella pratica clinica per aiutare i bambini con ADHD a trovare delle strategie per gestire le situazioni che richiedono di scrivere in condizioni di sovraccarico in memoria di lavoro. Fornire ai bambini delle linee guide per pianificare come produrre un testo (Re, Caeran, & Cornoldi, 2008) si è mostrato, infatti, di grande utilità per migliorare la qualità del testo prodotto e diminuire il numero di errori. Allo stesso modo, ipotizzare delle linee guida e dei passi da seguire che alleggeriscano la memoria di lavoro e permettano di migliorare la grafia e di controllare gli errori ortografici nella produzione scritta, potrebbe aiutare i bambini con ADHD a migliorare queste prestazioni.