J Ment Health Disord. 2025;5(1):105–115.

Journal of Mental Health Disorders Review Article

ADHD, Dysgraphia, and Giftedness

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Received date: June 05, 2025, **Accepted date:** July 10, 2025

Citation: Hanna D. ADHD, Dysgraphia, and Giftedness. J Ment Health Disord. 2025;5(1):105–115.

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Abstract

The study of dysgraphia, which can be summarized as handwriting impairment, has developed in the last few decades concurrently with a deeper understanding of this neurodevelopmental disorder that affects many areas of life for everybody who suffers from it, but mainly children and adolescents. Though the rate of dysgraphia decreases when growing up, there is still a substantial number of children who suffer from it for the rest of their lives, many of whom are not diagnosed. Among gifted children, the problem of not being diagnosed at all or misdiagnosed is more common than among the non-gifted. One of the main reasons for diagnosing difficulties of dysgraphia is the co-occurrence of dysgraphia with attention deficit disorder, with or without Hyperactivity (AD[H]D). This work explains in detail the reasons for this phenomenon, as well as offers ways to overcome this difficulty. It also suggests ways to help gifted and non-gifted dysgraphia children and adolescents, based on new developments in understanding the phenomenon from a neuropsychological perspective and using this understanding to assist them in their academic, social, and emotional lives.

Keywords: Attention deficit hyperactivity disorder, Dysgraphia, Giftedness, Neuropsychology, Brain sciences

Introduction

Dysgraphia from linguistic and historical points of view

The Oxford Dictionary [1] notes that "dysgraphia" as a noun was first documented in 1934, with the adjective "dysgraphia" appearing about 30 years later. By the mid-20th century, researchers started to classify and study different forms of dysgraphia, recognizing that it can occur independently of dyslexia. The systematic study of giftedness began with Lewis Terman over 100 years ago. In 1916, Terman revised the Stanford–Binet Intelligence Scales (1905), which included 30 questions and was administered to only 50 examinees (e.g., [2]). Terman started a longitudinal study with about 1,000 children, later adding around 500 more; the first volume of his findings was published exactly 100 years ago [3].

Brody & Mills [4] note that in 1981, experts from the fields of learning disabilities and giftedness gathered at a Johns Hopkins University colloquium to discuss this issue. The early 1980s marked a shift from emphasizing gifted children's achievements for personal, national, or societal benefit to focusing on their well-being. The final two decades of the 20th century showed significant research on the "non-typical gifted," including identification by a single criterion (e.g., [5]), gifted underachievers (e.g., [6,7]), Afro-Americans (e.g., [8]), non-Europeans in developing countries (e.g., [9]), delinquent individuals (e.g., [10]), and females (e.g., [11]). It was also noted that in many cases, gifted individuals have different social and emotional needs than non-gifted individuals (e.g., [12]). In Israel, where all children are entitled to free giftedness assessment, there is no underrepresentation of ethnic or religious minorities. The country has 64 enrichment centers for gifted and high-achieving students [13]. Eighteen of these serve Arab children, with Arab principals and staff. There is also a Tel Aviv center in Jaffa for both Jewish and Arab children, led by an Arab director, and an Arab-led gifted center in Eilat, Israel's southernmost city, with many staff members and teachers being Arab. Often, Arab students find it easier to access enrichment opportunities, as the number of Arab centers exceeds their population proportion of about 20%, and these centers are generally closer to their homes.

The prevalence of dysgraphia

According to Overvelde and Hulstijn [14], the prevalence of dysgraphia ranges from 5% to 33%. Kushki *et al.* [15] and Mekyska *et al.* [16] reported that the variation ranges from 10%

to 30%. Smits-Engelsman *et al.* [17] found that 34% of a group of 125 children in grades 4 and 5 had handwriting problems. Overvelde and Hulstijn [14] observed that the prevalence of dysgraphia decreased significantly, from 37% among 4- to 5-year-olds to 17% in grade 2, reaching a stable rate of 6% in grade 3. Döhla and Heim [18], estimated that 7–15% of school-age children show some form of developmental writing deficit. According to Zolna [19], about 8.6% of the population in France is considered dysgraphia. Karlsdottir and Stefansson [20] found that 27% of children's handwriting was not functional at the end of grade 1; however, this decreased to 13% by the end of grade 5. Given these high occurrences, research on dysgraphia has historically been less extensive compared to other learning disabilities (e.g., [18,21]), and public awareness and research around it remain relatively low. The number of studies on dysgraphia and giftedness is minimal.

Definitions of Dysgraphia

There is no consensus on the definition of dysgraphia (e.g., [22]). The briefest definition, though not entirely accurate, is that of Sanders *et al.* [23]: handwriting impairment. Baggett et al. [24, p. 320] define it, combining the definitions of Cortiella & Horowitz [25] and Döhla & Heim [18], as "a neurodevelopmental disorder in which an individual has illegible or inefficient handwriting due to difficulty with hand movements used for writing and/or the ability to store and retrieve letter formations."

McCloskey & Rapp [21] divided dysgraphia into spelling and handwriting deficits, collectively called "dysgraphia's," offering a "framework for studying developmental dysgraphia's" (p. 65). They conclude that developmental writing deficits vary widely in their manifestations and causes. However, they exclude "Higher-level writing skills, such as those involved in composing sentences and combining them into coherent texts" (p.66) from the definition of "dysgraphia." Additionally, since "writing" encompasses many forms and shapes, they also discuss typing on a laptop or texting on a smartphone. Nevertheless, they include in "dysgraphia" both impaired spelling and deficits impacting the motor planning or production processes necessary for handwriting.

Connections between attention deficit [hyperactivity] disorder and dysgraphia have been extensively studied in existing research. Attention deficit hyperactivity disorder (ADHD) and attention deficit disorder (ADD) are strongly associated with dysgraphia. Children and teenagers with ADHD or ADD are much more likely to experience dysgraphia than those without these conditions. Mayes *et al.* [26], found that dysgraphia is common across all ages in children and adolescents with ADHD (p. 788). Adi-Japha *et al.* [27], explained the underlying mechanisms behind these connections. Racine *et al.* [28] observed that poor handwriting was widespread among children with ADHD, often marked by illegible text, with or without a slower writing pace compared to children without ADHD.

According to Racine *et al.* [28], "Existing evidence would suggest that children with ADHD have impaired handwriting performance, characterized by illegible written material and/or inappropriate speed of execution compared to children without ADHD".

According to Brossard-Racine *et al.* [29], children with ADHD are prone to handwriting difficulties; however, the specific characteristics of these difficulties and their connection to behavioral challenges remain unclear.

Dysgraphia and a learning disability in written expression are both linked to deficits in executive functions and other neurocognitive impairments [30,31]. These findings suggest an underlying neurological basis for dysgraphia. It is related to fine motor and visual-motor deficits [15,17,29,32], while motor-free visual perception shows little connection to handwriting [32]. Additionally, factors such as age, gender, overall intellectual ability (measured by IQ), and visuospatial skills did not predict handwriting performance in a study of children with autism [33]. Interestingly, children with ADHD and autism share similar neuropsychological profiles, including strengths in visual reasoning relative to IQ and weaknesses in graphomotor skills [34–40]. Research indicates that weaknesses in graphomotor skills, attention, and task speed frequently co-occur, with most students experiencing deficits in all three areas [31]. Furthermore, a study involving 886 children aged 6 to 16 years with ADHD or autism and typical intelligence found no differences between the two groups in tests of graphomotor ability, attention, working memory, and processing speed [26].

Detecting and diagnosing dysgraphia

Dysgraphia is hard to detect and often diagnosed too late. Accurate diagnosis is crucial and should happen as early as possible. Mekyska *et al.* [41] created a new scale for assessing Graphomotor and Handwriting Disabilities, enabling experts to perform objective and detailed computer-aided diagnosis and evaluation, with the possibility of adapting it for other languages.

According to some researchers, dysgraphia has a broad spectrum (e.g., [42]); others suggest it manifests in three levels (e.g., [43]). Chung *et al.* [22] mention that many theories exist about how dysgraphia works, as it is not well understood and often remains undiagnosed. Many scholars do not restrict dysgraphia to specific levels but instead say it shows many symptoms at different ages (e.g., [44]). There is a high overlap between dysgraphia and other disabilities (e.g., [22,45–49]); diagnosing it along with ADHD makes the process even more complicated and more likely to be misdiagnosed or

overlooked (e.g., [44]). Often, it goes undiagnosed [44]. There is often disagreement about what dysgraphia includes; in its broadest sense, it is "a disorder of writing ability at any stage, including problems with letter formation/legibility, letter spacing, spelling, fine motor coordination, rate of writing, grammar, and composition" [22, p. 46].

One of the main challenges in identifying dysgraphia, which is even more complicated among gifted individuals, is its high comorbidity with ADHD (e.g., [29,44]). Additionally, when a child is diagnosed with ADHD, their parents, educators and often the child themselves feel relieved to have "found the reason why I feel so asynchronous." While an ADHD child can overcome their disability through psychological treatment and medication, there is still no "medication" for dysgraphia. Identifying dysgraphia helps a child, adolescent, or adult understand their struggles and how to manage them, but it does not provide a cure. This realization can lead to frustration, lower self-confidence, and a diminished belief in their own abilities.

Approaches to identifying children with dysgraphia

Methods for identifying children with dysgraphia have been available to educators and teachers since the early 19th century. However, with the advent of personal computers and their widespread use, and especially due to the rapid development of AI in the 21st century, the study of dysgraphia has shifted in two main directions: first, towards substituting writing with a computer, and then with a program that converts spoken language into written text, and finally to AI (e.g., [50]), which can replace many of the steps previously necessary to turn initial thoughts into written work. Some of these key works include those of Devillaine *et al.* [51] and Deschamps *et al.* [44], which have provided a pre-diagnostic method for identifying dysgraphia using machine learning. Danna *et al.* [52] introduced a more accurate method for identifying dysgraphia by measuring Signal-to-Noise Velocity Peaks Difference, while Mekyska *et al.* [16] proposed an automated tool for diagnosing and rating developmental dysgraphia through handwriting analysis, as did Asselborn *et al.* [42,53] and Gargot *et al.* [43]. Although Amini *et al.* [54] identified developmental dysgraphia based on dynamic handwriting, Drotár and Dobeš [55] suggested detecting dysgraphia through machine learning, achieving an accuracy of 80%. Bublin *et al.* [56] developed a more advanced tool for diagnosing dysgraphia. Unlike earlier tools, which could only distinguish between students with or without dysgraphia, their new tool can perform fine-grained grading from 0 to 12 with 99% accuracy and a root mean square error of less than 1, utilizing automatic feature extraction and selection. Additionally, this study used a smart pen with sensors the Senso Grip that effectively simulates hand gripping, a feature missing in tablet use (see, for example, Gargot *et al.*, [43], regarding tablet use for identifying dysgraphia). Bishop and Erbeli [57] provide a summary of classroom accommodations for students with dysgraphia. Rosenberg-Adler and Weintraub [58] review error outcomes of test accommodations for dysgraphia students in higher education.

Lopez *et al.* [59] found that developmental dysgraphia is often linked to minor neurological dysfunction in children with developmental coordination disorder (DCD). Since gifted children with DCD are frequently misdiagnosed with autism, ADHD, due to their high energy, or specific learning disorders instead of DCD (e.g., [60,61]), their dysgraphia often goes undiagnosed for too long.

Gifted Children with Dysgraphia

Hamdioui and Vaivre-Douret [46)] examined handwriting difficulties in high-IQ children. They found no significant differences in handwriting issues. However, when a child or adolescent is gifted and shows these traits, the chances of identifying them as dysgraphia are even lower than when they do not.

I. Being Blamed for laziness: A dysgraphia child is often unfairly accused of being lazy (e.g., [26,62,63]). This happens even more frequently in gifted children (e.g., [64]).

II. Asynchrony: Asynchrony is common in every child with learning disabilities, but it occurs more frequently and is more noticeable among gifted children; in fact, it is one of the traits of giftedness [65–68]. It is not seen as a sign of a problem when a child has difficulty with writing. They often explain it as: "the child is not satisfied with their writing level," or "it is much more interesting to do other things than write boring tasks." Therefore, when a gifted child has writing problems (e.g., [47]), the "immediate suspect" is not dysgraphia.

III. In many cases, gifted children are not motivated in school and thus become disengaged from their schoolwork. As a result, they are often blamed for a lack of motivation (e.g., [62,64]), and their behavior is attributed to boredom [62,64]. Children who struggle with writing often have low motivation due to their difficulty in processing letters, but if they are gifted, their dysgraphia might be overlooked or go unnoticed.

IV. Brown [62] provides two additional reasons for poor handwriting in the classroom: a lack of work ethic and poor writing skills. Although there is no evidence to suggest that school ethic is weaker among the gifted, we can suggest that both gifted and non-gifted individuals may lack it, but there is no proof that this leads to unreadable writing for either group. Regarding writing ability, writing therapy often does not help, and the child remains dysgraphia (e.g., [69]). This is especially true for 9-year-olds and older; their handwriting seldom improves (e.g., [20]). However, when a child refuses to write, or their

writing is unclear or jumbled, parents and educators tend to blame the child too often.

V. When a child is verbally gifted and dysgraphia, they may choose not to write down their ideas or thoughts because translating spoken words into written form can seem too difficult or even impossible (e.g., [70]). While this transformation may be hard for non-gifted children, the gap between their written work and their mental or spoken ideas is even more frustrating for gifted children.

VI. The high comorbidity between ADHD and dysgraphia (e.g., [29]) makes it difficult to identify dysgraphia in typical children. When a gifted child underachieves, it is likely that their ADHD is contributing, and further investigation does not seem to be necessary, as many gifted children and youths do not meet expectations based on their high potential (e.g., [6,71]).

VII. The masking effect" of the gifted child (e.g., [70,72–76]) is common to all twice-exceptional children, who are often labeled as learning- or emotional- disabled, or simply as "regular" children, because they use their giftedness to hide their difficulties caused by their disability. However, when a child is both gifted and has dysgraphia, the masking effect is more likely to happen. Usually, a gifted child begins reading at a young age, sometimes as early as 3 or 4 years old. In these cases, the child's parents do not expect them to start writing that early.

The combination of the masking effect and the compensating strategy, which is common among the gifted, makes diagnosing dysgraphia more difficult or even suggests its presence. Often, the gifted child with dysgraphia performs well in school despite their writing difficulties. The compensation strategy, used by many gifted children with learning disabilities (e.g., [77,78]), frequently prevents parents, teachers, and mental health professionals from suspecting the child is dysgraphia.

VIII. A relatively weak working memory: Often found alongside ADHD, is also common in dysgraphia, along with other executive functions (e.g., [23]). Not only does the compensation mechanism help mask dysgraphia in gifted children with less effective working memory, but it also explains differences among the gifted regarding verbal and performance skills, as well as variations between sub-tests belonging to either the verbal or performance domain. Therefore, an average working memory score combined with a total verbal score two standard deviations (SD) above the norms is not considered a reliable indicator of learning disability (e.g., [71]).

IX. While both reading and spelling areas are often impaired in most cases of dysgraphia, this is not necessarily true for the gifted. According to Berninger & Richards [79], in many cases, spelling remains unaffected by dysgraphia among the gifted, due to their usually strong reading skills.

X. There is a tendency among educators and mental health professionals to attribute many inadequacies, irregularities, social problems, and even non-neurotypical behaviors to a "result" of giftedness, even though many studies have shown the opposite (e.g., [80–83]). The wide range of dysgraphia manifestations, such as those seen in handwriting (e.g., [14]), allows many gifted dysgraphia children and youth to go unnoticed for dysgraphia, especially when they are described as "just" mildly dysgraphia.

XI. Thinking speed: Fast thinking is a dual-edged trait of the gifted. According to Hamdioui & Vaivre-Douret [46], gifted children think faster than they write (p. 368). The reason, as explained by many researchers, is the asynchrony between their intellectual and motor performances. Poor handwriting results from this gap (e.g., [84]).

XII. Processing speed: During early development is known to influence general intelligence [85]. Individuals with high IQs tend to respond faster on simple reaction time tasks [86,87]. Usually, gifted children think more quickly than their peers. Processing speed is a component of intelligence (e.g., [86–88]. According to Park *et al.* [89], intelligence is characterized by information processing speed in both children with and without language impairments. Deary [86] also states that intelligence is positively correlated with visual and auditory inspection. However, when a gifted child shows signs of Cognitive Disengagement Syndrome (CDS) (or, as formerly called, Sluggish Cognitive Tempo [SCT]) (e.g., [90–92]), they often are not identified as gifted, and a suspicion of dysgraphia may not arise.

XIII. Like other disabilities, there is a common misconception that writing difficulties "will be reduced or go away over time" (e.g. [93]). With gifted children, people often believe that "a child cannot be good at everything." This belief is even more widespread when the child is gifted, which makes diagnosing dysgraphia in gifted children more challenging.

Neurocognitive Abilities and Dysgraphia/Dysgraphia and the Brain

Dysgraphia is a serious condition involving the central nervous system, affecting motor and neuro visual pathways [46]. It often co-occurs with Developmental Coordination Disorder (DCD): Neurological soft signs and electroretinogram abnormalities can serve as useful clinical markers of dysgraphia in children with DCD. Children with an FIQ >120 exhibit visual gnosis disorder as a specific clinical marker of dysgraphia [46].

We are just beginning to incorporate brain research into the study of children and adolescents with triple exceptionality. The earliest studies on comorbid ADHD and dysgraphia, as well as neurocognition, were conducted in the early 2000s. Notable among them are those by Berninger *et al.* [23,79,94,95]. Since both Cognitive Disengagement Syndrome (CDS) (formerly known as Sluggish Cognitive Tempo [SCT]) (e.g., [90–92]) and dysgraphia are among the most common issues that co-occur with ADHD (e.g., [26,96]), further research should explore the relationship between CDS and dysgraphia, as one or more of these variables could serve as mediators or moderators. Table 4 in Barkley [96] supports this hypothesis by showing that the prevalence of writing difficulties is significantly higher in children with ADHD (1.4% versus 7.8%) and even more so among children with SCT, at 12.7%.

Dysgraphia is a neurological disorder that affects written expression [97]. According to Dudley-Marling [98], dysgraphia impacts the ability to produce legible writing and proper sentence structure, making it very difficult for individuals to put their thoughts or ideas on paper, whether due to hereditary or developmental issues.

Dudley-Marling [98] proposes a new approach for linking brain research on dysgraphia to specific traits of the gifted. According to him, dysgraphia individuals have particular verbal strengths but face disadvantages in memory. Since their difficulties originate from poor grammar, existing programs that correct spelling, punctuation, and other errors can help compensate for these issues. These programs also improve sentence structure by suggesting at least one alternative. Gifted dysgraphia students may benefit from these tools, as they leverage the strengths of giftedness and encourage writing, knowing their work is not final until they apply the suggested corrections.

The process of writing requires the coordination of multiple neural networks. It involves attention, fine motor coordination, memory, visual processing, language, and higher-order thinking. The visual feedback mechanisms check the output, adjust fine motor skills, and monitor coordination. Simultaneously, kinesthetic monitoring systems track the fingers moving on the paper, paying attention to the grip of the pencil or pen, as well as the rhythm and pace of the writing [63]. Having difficulty with even one of these actions can lead to writing challenges. Since writing is not generally perceived—either by the public or teachers—as a vital skill [63], the situation of gifted children who think quickly but do not always write as fast, due to their inherent asynchrony (e.g., [46,84]), is seen as "natural" and not as dysgraphia, even when they experience it.

Breninger [99] summarizes how various brain systems—such as motor, sensory, cognitive, language subsystems, memory, attention, executive functions, and reading systems—contribute to handwriting, highlighting these as key areas for assessment.

The ongoing research by Berninger and her colleagues [23,64,69,70,79,94,95,100–103] has advanced the understanding of learning disabilities overall and contributed many valuable, insightful studies on dysgraphia in particular. However, only one of these studies [64] addressed gifted learners. Let us review the history of these studies.

The study by Richards *et al.* [103], which examines the relationship between the presence or absence of ADHD and fMRI connectivity during writing tasks in children with dysgraphia, demonstrates the potential of combining brain research on writing with clinical ADHD assessments to evaluate internal processing in writing tasks, which are often only assessed at the behavioral level. The internal processes offer clues as to why individuals with diagnosed dysgraphia and co-occurring ADHD may face significant challenges in transcription and translation tasks.

Until roughly the 21st century, it was widely believed that dysgraphia was closely associated with poor fine motor control (e.g., [104,105]). However, as Feder and Majnemer [106] pointed out, although children with developmental coordination disorder often show inferior motor performance, this issue has also been observed in children without a diagnosis of dysgraphia or writing difficulties. These findings led to the development of theories examining the causes of dysgraphia in the field of brain sciences.

Although the works of Berniner *et al.* [23,79,94,95] did not specifically focus on the gifted, they have made significant contributions to both the study of dysgraphia among the gifted and the teaching methods needed for gifted dysgraphia students based on neuropsychological knowledge. In the Breninger & Richards [79] study, students with and without dysgraphia were recruited from the longitudinal fMRI writing studies.

The study by Sanders *et al.* [23], although not specifically focused on gifted children, offers insights into various aspects related to learning-disabled gifted individuals in general, especially those with dysgraphia. By examining whether language-related working memory components predict reading and writing skills in grade 4–9 children with dyslexia and dysgraphia, they developed a five-level ladder that can predict the extent of language impairment. While cognitive-linguistic translation accounted for only about 15% of the variance in writing achievement—indicating a low influence of intelligence—and a modest advantage of giftedness, working memory components, which gifted children and adolescents have a significant advantage in, explained an additional 27% of the variance. Working memory is crucial for cognitive functioning [107]. A good working memory is typical of gifted children and adolescents (e.g. [108]). It is particularly essential for individuals with ADHD who often face challenges with attention, concentration, hyperactivity, and impulsivity. Therefore, gifted children with dysgraphia and ADHD are

frequently undiagnosed or untreated, or diagnosed later in their academic careers, if at all.

Sanders *et al.* [23, p. 153)]. offer a clearer clue that helps understand the challenge of identifying some gifted children with dysgraphia.

Cognitive-linguistic translation is not relevant for identifying dysgraphia (handwriting impairment), but components of working memory, such as orthographic coding and the orthographic loop, are. Additionally, if cognitive-linguistic translation is highly effective and writing skills are near average rather than below the typical range, it does not necessarily mean that a student does not have a specific learning disability (SLD) in written language. For twice-exceptional students—who are both verbally gifted and meet the criteria for dysgraphia—dysgraphia may conceal their talent in translating thoughts into oral language because of difficulties in converting oral language into written form (e.g., [70]).

Suppose cognitive-linguistic translation, which is common among the gifted, is not relevant for identifying dysgraphia. If so, it might even hinder the detection of dysgraphia in the gifted by acting as a tool to conceal this disability.

Teaching and Treating Children and Youths with Dysgraphia

According to Chung *et al.* [22], even after diagnosing and treating dysgraphia, school-based developmental dysgraphia should stay under the watch of pediatricians to offer guidance and support, as well as monitor for comorbidities with other disabilities, difficulties, and disorders.

Racine *et al.* [28] stated that ADHD is the most common neurobehavioral condition in childhood. Its consequences are diverse and include limitations in daily living skills, academic difficulties, reduced social skills, and motor challenges. Poor handwriting is an example of a life skill affected by ADHD, which educators and clinicians have anecdotally observed, and it can negatively influence academic success and self-esteem. To better understand the needs for health and educational services, the authors reviewed existing evidence on handwriting problems in children with ADHD.

Few studies explore practical techniques for gifted children and youths with dysgraphia. A recent example is Miranti and Ansoriyah [47], who studied gifted lower-grade students with written language challenges. Addressing their dysgraphia is essential to bridging the gap between their high intelligence and their subpar performance, motivation, and self-confidence. Children with dysgraphia often struggle with fine motor skills and logical organization, which can lead to frustration and emotional distress. Miranti & Ansoriyah [47] recommend occupational therapy, digital assistive tools like voice-to-text software, and adaptive learning strategies to help these children overcome their difficulties. Research further emphasizes the importance of collaboration between teachers, parents, and therapists to create an inclusive learning environment.

The publication of literature on teaching and treating children and adolescents with dysgraphia has increased since the early 21st century. However, almost all of these focus on "regular" children; very few address gifted children and adolescents or consider intelligence as a variable to consider when recommending teaching and treatment methods. For example, Berninger & Wolf [101], whose book concentrates on teaching students with dysgraphia, dyslexia, dyscalculia, and oral and written language learning disabilities (OWL LD), emphasize the importance of integrating research from multiple fields, including genetics, neuroscience, linguistics, and education. Nevertheless, in all these fields, new findings are relevant for typical children but not necessarily for gifted ones. The book suggests using differentiated instruction to organize classrooms. However, this approach does not always benefit gifted children, who often need higher-level challenges rather than just support, as they can rely on their compensation mechanisms up to a point. They often require encouragement to push beyond. In most cases, gifted students do not need extra effort just to "meet Common Core Standards" [101], but to achieve standards much higher than the minimum requirements.

Silverman [78] discusses the dual challenge faced by dysgraphia boys. Besides their struggles with handwriting, many of them are also not athletic. This is likely related, in many cases, to their self-confidence as well as biases against them. According to Bonneton-Botté *et al.* [50], Feder and Majnemer [106], and Gavenciak *et al.* [109], difficulties with handwriting can lead to negative learning experiences, which may cause low self-esteem.

If these issues are not identified and addressed early, they often lead to difficulties with athletic performance and handwriting (e.g., Biotteau et al., [110]). These problems are more common in boys than in girls (e.g., [22]). Gifted adolescents who engage in sports have higher physical abilities, usually as a result of being engaged in sports, have higher self-concepts than those who do not [111]. Untreated sensory processing disorder can cause boys to face social rejection and underachievement because they avoid written assignments. Here are the signs that a child has what special educators call "dysgraphia," what psychologists refer to as "developmental coordination disorder," or what occupational therapists' term "sensory processing disorder." For educators, I call this syndrome a "writing disability." Apologies for using the generic "he," but poor handwriting remains a bigger issue for boys than for girls.

Educational Implications for Gifted Children

For many years, children struggling with writing received various forms of help but did not overcome their writing issues (e.g., [23,109]). Linking brain science to education has opened the door to solving the dysgraphia puzzle, specifically, why the "traditional" aids did not improve children's writing beyond a certain point, and what steps are needed to overcome it.

Sanders *et al.* [23] conducted a long-term, interdisciplinary study over more than 20 years on learning disabilities, including family genetics, brain imaging, diagnostic assessments, and instructional interventions. Brain imaging studies show neurological differences between children with and without dysgraphia [79,102,103]. Dysgraphia can result from acquired neurological damage [112,113], but this research focuses on developmental dysgraphia rather than acquired neurological injury. These studies collectively support the conclusion that genetic factors partially explain developmental dysgraphia (e.g., [23,69]).

Puyjarinet *et al.* [114] have shown that handwriting activates the left dorsal premotor cortex, the inferior parietal cortex, the fusiform gyrus, the bilateral inferior frontal gyrus, the right cerebellum, and the primary motor cortex, all of which are involved in manual motor output. Children also engage the prefrontal cortex to perform writing tasks. Handwriting additionally involves gestural and kinematic components. To understand the nature of dysgraphia, it is essential to examine all these areas.

Hamdioui & Vaivre-Douret [46] found that dysgraphia was significantly related to pyramidal-tract dysfunction (p=0.01) and electroretinogram abnormalities (p=0.03) in both groups of children with average and high IQ. In high-IQ children, a visual gnosis impairment was found to be associated with a deficit in visual-spatial memory. These researchers concluded that dysgraphia affects the motor and neuro visual pathways and often co-occurs with developmental coordination disorder (DCD). They suggested that neurological soft signs and electroretinogram abnormalities can be considered interesting clinical markers of dysgraphia in children with DCD. Children with an FIQ >120 display visual gnosis disorder as a specific clinical marker of dysgraphia.

Richards *et al.* [102], found that four brain region seed points (left occipital temporal gyrus, supramarginal gyrus, precuneus, and inferior frontal gyrus) were used in these analyses, which were shown in a meta-analysis to be related to written word production on four indicators of white matter integrity and fMRI functional connectivity for four tasks (self-guided mind wandering during resting state, writing a letter that follows a visually displayed letter in the alphabet, writing a missing letter to create a correctly spelled real word, and planning for composing after scanning on a researcher-specified topic). A new, promising research direction for studying dysgraphia among the gifted was identified in this study through differences in white matter integrity, fMRI functional connectivity, and white matter–gray matter correlations. The studies by Abbott *et al.* [69] and Berninger *et al.* [95] expanded the understanding of brain connectivity by utilizing neuroimaging and other methods to gain more insight into dysgraphia generally and dysgraphia among the gifted specifically.

Conclusion

Dysgraphia is a common learning disability affecting far more than the academic life of children and adolescents. Several techniques are used to assist children with dysgraphia in completing schoolwork. Most of these focus on technology, such as using computers not only for writing but also for converting speech into text or reducing the amount of writing needed. However, some proven programs motivate dysgraphia individuals and encourage them to write willingly. One effective program encourages dysgraphia high school students to write creatively.

The support provided to individuals with dysgraphia varies, and there is often no consensus on the best method. Common suggestions include using computer-assisted tools, which can help or even replace the need to write (e.g., [115–117]; all are technology-based). Hopcan & Tokel [118] and Obatta *et al.* [97] also present a mobile writing app to help students with dysgraphia improve their handwriting.

However, as the study of dysgraphia progresses alongside advancements in brain sciences, the primary role of educational and mental health experts currently focuses on improving early diagnosis and utilizing available language aids. All teachers, pediatricians, and other healthcare professionals should be educated about new tools, methods, and technologies. The short-term prognosis for helping children with dysgraphia is very positive. However, the main goal is to help dysgraphia children build their self-confidence and self-esteem and become aware of their specific challenges.

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