Writing Processing Deficits in Developmental Dyslexia and Their Neural Mechanisms

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Abstract

Developmental dyslexia constitutes one of the primary categories of learning disabilities, profoundly affecting the development of individuals' cognitive, emotional, and social adaptive functioning. Writing and reading are intimately related, and individuals with dyslexia frequently exhibit deficits in writing processing. At the behavioral level, writing deficits in dyslexic individuals manifest across multiple dimensions, including poor writing quality, reduced speed, and frequent pauses. At the neural mechanism level, neuroimaging research has revealed that writing processing deficits in dyslexia are associated with aberrant activation in orthographic processing brain regions, as well as anomalous functional and structural connectivity between orthographic and motor areas. Overall, evidence for orthographic access deficits during writing in dyslexia is relatively robust; however, whether difficulties exist in the interface between orthographic and motor coding or in motor execution itself remains underinvestigated. Compared to alphabetic languages, the relationship between writing and reading is more pronounced in Chinese, and research on writing in Chinese dyslexia will provide crucial guidance for developing Chinese-characteristic diagnostic and therapeutic protocols.

Full Text

Writing Deficit in Developmental Dyslexia and Its Neural Mechanisms

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Abstract

Developmental dyslexia represents a major category of learning disabilities that severely impedes the development of cognition, emotion, and social adaptability. Writing is intimately related to reading, and individuals with dyslexia frequently exhibit writing processing deficits. At the behavioral level, dyslexics demonstrate impaired writing quality, reduced speed, and increased pauses across multiple dimensions. At the neural level, neuroimaging studies have revealed that writing deficits in dyslexia are associated with abnormal activity in brain regions involved in orthographic processing, as well as atypical functional and structural connectivity between orthographic and motor areas. Overall, evidence for deficits in orthographic access during writing is relatively robust in dyslexia, yet whether difficulties exist in the interface between orthographic and motor encoding or in motor execution remains understudied. Compared to alphabetic languages, the relationship between writing and reading is even more tightly intertwined in Chinese, making research on writing in Chinese dyslexia crucial for developing diagnostically and therapeutically distinctive approaches for Chinese-speaking populations.

Keywords: developmental dyslexia, Chinese, writing, neural mechanisms

Introduction

Reading serves as a fundamental pathway for human information exchange and knowledge acquisition, playing a vital role in individual survival and development. However, a subset of individuals struggle with reading difficulties due to developmental dyslexia, which refers to a learning disability characterized by reading performance significantly below grade- or age-expected levels in individuals with normal intelligence, adequate educational opportunity, and no apparent neurological or organic abnormalities. As a neurobiologically based developmental disorder, dyslexia not only constrains knowledge acquisition and academic achievement but also exerts severe negative impacts on emotional, behavioral, and social development. Prevalence rates vary considerably across studies. In alphabetic languages, dyslexia affects approximately 5-17.5% of the population (Shaywitz, 1998). In Chinese, using the low-achievement definition (reading performance two standard deviations below grade average), the prevalence is 4.55%, whereas the discrepancy definition (reading score below the 10th percentile and two standard deviations below IQ-predicted reading level) yields a rate of 7.96% (张承芬, 张景焕, 殷荣生, 周静, & 常淑敏, 1996). A recent survey conducted in Jining, Beijing, and Guangzhou reported a substantially higher overall prevalence of 28.15% among Chinese children in grades 3-5 (Tan, Xu, Chang, & Siok, 2013), suggesting a rising trend. These discrepancies likely stem from three factors: first, different assessment tools may detect varying prevalence rates; second, different diagnostic criteria produce different estimates, as demonstrated by 张承芬 et al. (1996); and third, sample characteristics influence outcomes. For instance, Tan et al. (2013) attributed the sharp increase to digital era influences, particularly extensive use of pinyin input methods that may elevate reading difficulty rates. Consequently, research on the pathogenic mechanisms and remediation of dyslexia remains a focal point across psychology, education, and neuroscience.

Several theoretical perspectives explain dyslexia' s etiology. The phonological deficit theory posits that impaired phonological decoding and manipulation constitute the core factor underlying reading difficulties (Goswami, 2011). The general sensory deficit theory argues that linguistic deficits are merely surface manifestations, with more fundamental perceptual processing deficits as the true cause. For example, the visual magnocellular theory suggests that impaired magnocellular function in dyslexia affects oculomotor control and visual perception during reading, creating visual processing difficulties (Stein, Richardson, & Fowler, 2000). The cerebellar deficit theory directly addresses neural mechanisms, proposing that cerebellar dysfunction impacts motor skill development and automaticity, subsequently causing difficulties in articulatory skills, spelling, and ultimately reading (Nicolson, Fawcett, & Dean, 2001).

Critically, individuals with dyslexia exhibit not only reading difficulties but also pervasive writing or spelling problems (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008; Kalindi et al., 2015; Kandel, Lassus-Sangosse, Grosjacques, & Perret, 2017; Lam, Au, Leung, & Li-Tsang, 2011; Martlew, 1992; McBride-Chang, Chung, & Tong, 2011; Sumner, Connelly, & Barnett, 2013; E Sumner, V Connelly, & A. L. Barnett, 2014), with a substantial proportion meeting diagnostic criteria for dysgraphia (Nicolson & Fawcett, 2011). The cerebellar theory suggests that cerebellar deficits may cause writing impairments through compromised motor or automatic processing abilities. Meanwhile, the phonological mediation theory of writing proposes that phonology serves as an intermediary connecting semantics to orthography during writing production (Bonin, Peereman, & Fayol, 2001), implying that writing problems in dyslexia may also relate to phonological deficits. Therefore, investigating writing deficits in dyslexia can illuminate pathogenic mechanisms and inform remediation strategies, warranting substantial attention (Berninger et al., 2008).

The Influence of Writing on Reading

Writing involves a complex series of linguistic, cognitive, and motor processing activities. Broadly, writing can be divided into central and peripheral processes (Purcell, Turkeltaub, Eden, & Rapp, 2011). Central processes primarily retrieve orthographic information, involving lexical selection and extraction of orthographic and imagistic representations. Orthographic access in central processing includes lexical and sublexical routes. The lexical route retrieves whole words directly from long-term memory representations, operating on familiar words, whereas the sublexical route extracts phonemes based on grapheme-phoneme correspondence rules before activating corresponding orthographic information, functioning in pseudo-word or low-frequency word processing (Afonso, Suárez-Coalla, & Cuetos, 2015). Peripheral processes handle writing motor execution, involving orthographic-motor encoding and implementation. Neuroimaging studies reveal that writing engages multiple brain regions, including premotor cortex, posterior parietal lobe, posterior inferior temporal gyrus (fusiform gyrus), and cerebellum. Specifically, the left posterior inferior temporal gyrus, superior frontal gyrus, and inferior frontal gyrus/sulcus manage central orthographic retrieval (Planton, Jucla, Roux, & Démonet, 2013; Purcell et al., 2011), while the left middle frontal gyrus, intraparietal sulcus/superior parietal lobule, and cerebellum handle peripheral motor processing (Planton et al., 2013).

Writing and reading share an intimate relationship. Process-wise, they represent inverse operations involving multiple common components: reading transforms visual word form input into linguistic comprehension, while writing converts semantic information into visual word form output (王成, 尤文平, 张清芳, 2012). Empirical studies demonstrate significant correlations between writing accuracy and performance on lexical decision (Burt & Tate, 2002) and orthographic judgment tasks (Holmes & Carruthers, 1998), with writing-reading correlations persisting across elementary grades (Abbott, Berninger, & Fayol, 2010). Training studies further reveal that writing practice yields superior reading gains compared to typing or visual presentation (Cao et al., 2013; Longcamp, Zerbato-Poudou, & Velay, 2005). One possibility is that writing and reading share similar orthographic processing mechanisms, with writing practice helping establish high-quality orthographic representations that facilitate orthographic recognition during reading. Neuroimaging research in typical adults supports this view (Rapp & Lipka, 2011). For instance, fMRI studies show substantial co-activation in the Visual Word Form Area (VWFA) when the same participants perform writing and reading tasks (Purcell, Jiang, & Eden, 2017; Rapp & Lipka, 2011). However, brain lesion studies reveal distinct VWFA subregions corresponding to reading versus writing, suggesting possible segregation of orthographic processing areas (Baldo et al., 2018; Purcell, Shea, & Rapp, 2014). Thus, the overlap and dissociation of orthographic representations in writing and reading require further investigation. An alternative perspective posits that writing practice forms motor memory and representations of characters, thereby facilitating visual character recognition. Neuroimaging findings support this hypothesis, showing significant activation in writing-related motor functional areas during letter recognition (Nakamura et al., 2012). A recent transcranial magnetic stimulation study demonstrated that disrupting premotor cortex increased response times for printed and handwritten word judgments, establishing a causal role for motor area activation in visual word recognition (Pattamadilok, Ponz, Planton, & Bonnard, 2016).

Based on these intrinsic connections between writing and reading, researchers have investigated writing processing deficits in dyslexia across different writing systems to understand etiology from an orthographic output perspective and develop corresponding remediation approaches.

2. Writing Research in Dyslexia

2.1.1 Studies on Children with Dyslexia

An early study of English-speaking children with dyslexia found that, compared to age-matched controls, dyslexic children showed higher spelling error rates and poorer writing quality in both word dictation and sentence copying tasks. When compared to spelling-level-matched controls, dyslexic children copied complex words more slowly, indicating that writing difficulties in dyslexia represent a deficit associated with dyslexia itself rather than merely a developmental lag in writing ability (Martlew, 1992). A subsequent study using tasks at different processing levels—letter naming, word dictation, and essay composition—revealed significant underdevelopment of writing abilities in dyslexic children, with letter writing fluency 1.1 standard deviations below age level, word dictation 1.03 standard deviations below, and essay composition 1 standard deviation below. Regression analyses further identified verbal fluency and inhibitory control as independent predictors of letter naming performance, whereas general sequential motor processing did not independently predict essay composition scores. This suggests that writing deficits in dyslexia do not stem from basic finger motor processing deficits (Berninger et al., 2008). Although this study ruled out low-level motor factors, its dictation and copying tasks involved multiple components including orthographic access, orthographic-motor conversion, and motor execution, leaving unclear which specific stage is impaired.

The introduction of digital writing tablets has enabled deeper investigation of writing processes in dyslexia, allowing examination of latency, movement velocity, duration, and pause intervals beyond conventional measures of writing time and quality. Sumner et al. (2013) compared English dyslexic children to age- and spelling-level-matched controls on letter writing and essay composition tasks. The letter writing task required sequential alphabet writing within one minute, while the essay task required composing a short text on a prompted topic within 15 minutes, with fine motor ability also assessed. Results showed that dyslexic children paused more frequently and for longer durations than age-matched controls during both tasks, but did not differ from spelling-level controls. No significant group differences emerged in single-letter writing speed or finger fine motor skills, suggesting that writing deficits in dyslexia likely occur during rapid orthographic access rather than motor execution (Sumner et al., 2013). To control for confounding cognitive factors in essay composition (e.g., idea generation, discourse organization, semantic processing), Sumner et al. (2014) employed sentence copying tasks and found that dyslexic children wrote fewer words and made more within-word pauses than age-matched controls, but outperformed spelling-ability controls in words written and pause frequency. Regression analyses revealed that spelling ability and pause frequency during writing explained 76% of variance in dyslexic children' s writing performance (Sumner, Connelly, & Barnett, 2014). Additionally, Kandel et al. (2017)

used movement duration, latency, and regression count measures to examine French dyslexic, dysgraphic, and typical children during real and pseudo-word copying. Dyslexic and dysgraphic children showed stronger orthographic regularity effects than controls, performing worse on irregular than regular words, with this difference more pronounced than in typical children. They also exhibited stronger word frequency effects in latency and regression counts, with larger low- versus high-frequency differences than controls. The authors attributed writing motor processing deficits in dyslexia to cognitive load during orthographic-motor integration (Kandel et al., 2017).

A developmental study of Italian dyslexic children investigated whether writing difficulties change with language and motor development. Compared to age-matched controls, third-grade dyslexic children showed slow speed and high error rates when dictating various word types (regular/irregular, consistent/inconsistent), whereas fifth-grade dyslexic children exhibited deficits only when writing inconsistent words and phonologically similar words. This suggests different forms of orthographic access deficits at different ages: younger dyslexic children experience difficulties in both lexical and sublexical routes, while older children may show deficits primarily in the lexical route (Angelelli, Notarnicola, Judica, Zoccolotti, & Luzzatti, 2010). These findings indicate that writing difficulties in dyslexic children primarily stem from central processing deficits in rapid, accurate orthographic retrieval.

Some research has also examined peripheral motor deficits in dyslexic writing. One study compared Italian dyslexic children (with and without dysgraphia) to age-matched controls on word copying tasks under different speed (natural vs. fast) and size (large vs. small) conditions. Dyslexic children wrote slower than controls under fast and large conditions but showed no differences during natural writing. Single-letter analysis revealed that dyslexic children lacked stability in maintaining letter writing speed across conditions and failed to appropriately adjust speed according to size demands. Notably, dyslexic children with and without dysgraphia showed no differences in finger motor performance (Pagliarini et al., 2015). Since orthographic access demands were equivalent across conditions, these findings suggest that despite intact general finger fine motor skills, dyslexia may involve specific motor processing deficits in the peripheral writing process. The motor instability in dyslexic children may reflect abnormal motor rhythm associated with cerebellar dysfunction (Nicolson et al., 2001). However, this remains the sole study of its kind, necessitating further investigation of peripheral processing deficits in dyslexic writing.

2.1.2 Studies on Adults with Dyslexia

Do writing processing deficits persist in adults with dyslexia as cognitive and motor abilities mature? Research indicates that adults with dyslexia still cannot complete essay tasks within time limits, produce numerous spelling errors, and write fewer words than typical readers. These deficits do not result from high-level linguistic organization processes such as writing intention formation or discourse composition (Connelly, Campbell, MacLean, & Barnes, 2006; Gregg, Coleman, Davis, & Chalk, 2007). One study found that adults with dyslexia produced more spontaneous spelling errors in essay composition than spelling-level controls (Connelly et al., 2006). Because discourse-level tasks cannot fully exclude confounding syntactic and semantic factors, a recent study systematically investigated word-level writing in adult dyslexia using dictation and copying tasks that manipulated central processing factors including consistency, word frequency, and length. Results showed that dyslexic adults performed worse than controls on latency, inter-letter intervals, and duration measures, indicating persistent orthographic access deficits in writing (Afonso et al., 2015). These findings demonstrate that writing deficits in dyslexia do not remit spontaneously with maturation, underscoring the necessity of early diagnosis and intervention.

2.1.3 Summary of Behavioral Research

Behavioral studies reveal that dyslexics across alphabetic writing systems exhibit writing processing difficulties at multiple levels—from letters to vocabulary to discourse—manifesting in both process measures (speed, pauses) and quality. While both children and adults with dyslexia show writing deficits, age-related differences exist. In older children and adults, lexical route deficits may be more prominent (Afonso et al., 2015; Angelelli et al., 2010). Previous research has primarily focused on orthographic access, establishing it as a key contributor to writing deficits in dyslexia. In contrast, evidence for peripheral processing deficits remains scarce, making it difficult to determine whether such deficits exist. Two factors contribute to this gap: First, discourse and sentence writing tasks cannot easily exclude syntactic and semantic influences to isolate peripheral motor components, potentially masking motor abnormalities under high cognitive load (Kandel, Lassus-Sangosse, Grosjacques, & Perret, 2017). Second, previous studies typically used independent motor tests (Connelly et al., 2006; Sumner et al., 2013), whereas writing-specific motor components may constitute a specialized motor process not captured by general motor assessments. One solution involves factorial designs that manipulate motor demands, as demonstrated by Pagliarini et al. (2015) who specifically varied writing speed and amplitude. Importantly, behavioral studies using reaction time or accuracy measures cannot fully separate orthographic retrieval from motor processes in this continuous activity. Recent findings indicate that central and peripheral processes interact during writing (Kandel & Perret, 2015; Roux, Mckeeff, Grosjacques, Afonso, & Kandel, 2013), meaning motor indices may also reflect central processing components. Future research should employ more sensitive methods, such as neuroimaging techniques, to dissociate orthographic and motor components at the neural level and clarify the respective roles of central and peripheral processes in dyslexic writing deficits.

2.2 Neural Mechanisms of Writing in Dyslexia

Writing is a complex process involving multiple components, with dyslexic writing deficits potentially occurring at one or several stages. While behavioral research reveals multiple manifestations of writing difficulties, it cannot fully elucidate underlying mechanisms. Neuroimaging studies can uncover the neural basis of dyslexic writing deficits through functional localization and connectivity analyses.

One neuroimaging study examined brain function and structure related to writing in English dyslexic children, dysgraphic children, and typical controls (Richards et al., 2015). Functional connectivity results showed that during letter writing and spelling tasks, dyslexic children exhibited stronger functional connectivity between left temporo-occipital regions and cerebellum than age-matched controls, suggesting that writing deficits in dyslexia may relate to abnormal connectivity between visual-language and motor areas. During essay composition, no functional connectivity differences emerged between dyslexic and control children, but dysgraphic children showed stronger connectivity networks than controls, including: (1) connections between left temporo-occipital cortex and left Broca' s area, left visual cortex, and bilateral cerebellum; (2) connections between left precuneus and right cerebellum; and (3) connections between left Broca' s area and left inferior parietal lobule, left visual cortex, and bilateral cerebellum. Additionally, diffusion tensor imaging revealed distinct white matter structural abnormality patterns between dyslexic and dysgraphic children. These findings indicate that despite similar behavioral manifestations, dyslexic writing deficits involve specific neural mechanisms distinct from other writing-related disorders (Richards et al., 2015). However, due to technical limitations, this remains the only study directly examining neural mechanisms of writing in dyslexia.

No study has specifically investigated the neural mechanisms underlying central versus peripheral processing deficits in dyslexic writing. However, previous research suggests that writing and reading may share orthographic processing mechanisms (Purcell, Jiang, & Eden, 2017). Therefore, abnormal brain activation and connectivity patterns during orthographic judgment tasks may indirectly reveal neural mechanisms of orthographic access deficits in dyslexic writing (van der Mark et al., 2009; van der Mark et al., 2011). For example, van der Mark et al. (2009) found that dyslexic children lack the anterior-to-posterior sensitivity gradient in the visual word form area (VWFA), suggesting deficits in orthographic representation specificity. The study also found reduced connectivity between VWFA and left inferior frontal and inferior parietal language areas in dyslexic children, potentially constituting an important neural basis for orthographic retrieval deficits (van der Mark et al., 2011). Another study found that dyslexic children showed greater connectivity in left temporo-occipital regions during spelling judgment tasks than controls, reflecting an inability to establish specialized orthographic functional connectivity pathways (Berninger, Richards, & Abbott, 2015). Notably, although spelling judgment tasks involve orthographic retrieval, they lack motor output, and the cognitive processes may differ substantially from actual writing. Therefore, clarifying the specific processes underlying dyslexic writing difficulties requires further investigation of neural mechanisms during authentic writing tasks to obtain more direct evidence.

In summary, neural mechanism research has revealed abnormal functional connectivity between the cerebellum and other cortical regions (inferior frontal gyrus, temporo-occipital areas) during writing in dyslexia (Richards et al., 2015), supporting the cerebellar deficit hypothesis. By linking cerebellar abnormalities to writing deficits, these findings provide experimental evidence for how cerebellar dysfunction may cause reading and writing difficulties. However, research on neural mechanisms of dyslexic writing remains in its infancy, with unclear correspondences between writing components and functional abnormalities. Future studies must more deeply explore the functional and structural basis of dyslexic writing deficits from perspectives of brain localization and connectivity, revealing the stages and characteristics of these deficits as an important research direction. Advancing neuroimaging techniques for writing research, such as MRI-compatible writing tablets (Planton, Longcamp, Péran, Démonet, & Jucla, 2017; Tam, Churchill, Strother, & Graham, 2011), provide powerful technical support for investigating neural mechanisms of dyslexic writing.

3. Writing Research in Chinese Dyslexia

3.1 Characteristics of Chinese Character Writing

Chinese characters differ substantially from alphabetic scripts. First, Chinese characters possess unique visual features. Structural units include strokes and radicals (components). Strokes constitute the smallest structural units, while radicals and components comprise strokes. Characters include single-component and compound structures: single-component characters consist directly of strokes, whereas compound characters combine different radicals. This creates highly complex visual configurations. Second, Chinese has complex orthography-phonology correspondence. Unlike alphabetic systems where phonemes map to graphemes, Chinese uses syllables as phonological units, with each character corresponding to one syllable. Approximately 1,300 syllables exist, but about 5,000 morphemes serve as semantic units (尹斌庸, 1984), resulting in numerous homophones with varying orthographic similarity. These characteristics create specificity in Chinese writing processing. For instance, writing units are radicals (or components) whose visual orthographic and motor processing complexity far exceeds alphabetic letters (Damian & Qu, 2017; Han, Zhang, Shu, & Bi, 2007; Zhang & Feng, 2017). Research shows that, unlike alphabetic scripts, phonetic consistency does not affect Chinese dictation performance (张大成, 张厚粲, 周晓林, & 舒华等, 1999). Neuroimaging studies reveal that Chinese writing involves both shared brain regions with alphabetic scripts (left premotor cortex, left intraparietal sulcus/superior parietal sulcus, left posterior inferior temporal gyrus/fusiform gyrus, right cerebellum) and script-specific regions such as right occipital lobe, related to Chinese characters' complex visual features (Cao & Perfetti, 2016; Cao et al., 2013; Yang et al., 2018; Yang et al., 2019). Direct comparisons further show stronger left middle frontal gyrus activation during Chinese writing (Cao & Perfetti, 2016).

3.2 Relationship Between Chinese Writing and Reading

Due to Chinese characters' complex visual features and orthography-phonology correspondence, writing serves as a core pathway for Chinese character acquisition and is crucial for reading ability development (Cao et al., 2013; Tan, Spinks, Eden, Perfetti, & Siok, 2005; Wang, McBride-Chang, & Chan, 2014). Through writing, children learn to parse characters into specific units (strokes and components) and integrate these units into complete square configurations. This decoding process occurs at the visual-orthographic level, promoting orthographic awareness development and helping children establish form-sound-meaning connections to build high-quality lexical long-term memory representations. Studies of Chinese-speaking children show that Chinese copying speed significantly correlates with reading ability after controlling for other factors (Tan et al., 2005; Ying, Mcbride-Chang, & Chan, 2014). Research on Chinese second-language learners confirms that character copying instruction better facilitates Chinese character learning than pure phonological or orthographic instruction (Cao et al., 2013; Guan, Perfetti, & Meng, 2015). Additionally, reduced writing frequency in the digital era may contribute to increased reading difficulty rates (Tan, Xu, Chang, & Siok, 2013). Given this close writing-reading relationship, investigating writing processing deficits and their relationship to reading difficulties in Chinese dyslexia provides crucial guidance for diagnosis and remediation.

3.3.1 Behavioral Research

No consensus exists regarding the primary cognitive deficits in Chinese dyslexia. Phonological processing deficits (Cao et al., 2017; Su et al., 2018), orthographic processing deficits (Ho, Chan, Lee, Tsang, & Luan, 2004; Liu et al., 2012), and morphological awareness deficits (Liu et al., 2013; Shu, McBride-Chang, Wu, & Liu, 2006) all represent important behavioral manifestations. Some researchers suggest that writing/spelling difficulties may be more severe than reading difficulties themselves (Leong, Cheng, & Lam, 2000), with writing difficulties included in Hong Kong' s diagnostic criteria for dyslexia (Education Department of HKSAR, 2002).

A large-scale Hong Kong study (N=1,235) found that Chinese dyslexic children scored significantly lower than normative standards on dictation tasks (Chan, Ho, Tsang, Lee, & Chung, 2006). Another study comparing Hong Kong dyslexic children in grades 2-6 to age-matched controls on Chinese character copying revealed that dyslexic children across all grades exhibited slower speed, poorer accuracy, larger characters, greater variability, and more stroke errors. Writing speed and accuracy discriminated dyslexic readers from controls with 70% accuracy, with the authors attributing these difficulties to fine motor and visual-perceptual memory deficits (Lam et al., 2011). However, McBride-Chang et al. (2011) argued that using familiar characters or graphics as materials introduces experience-related confounds. To control this factor, they employed non-meaningful characters and found that copying performance for three types of non-meaningful characters (Korean, Vietnamese, and Hebrew) effectively distinguished dyslexic from typical children, indicating that copying ability (visual-motor integration) itself constitutes an important factor in Chinese dyslexia (McBride-Chang et al., 2011). A recent study supported this finding, showing that non-meaningful character copying effectively discriminated Chinese but not English dyslexic children from controls (Kalindi et al., 2015), highlighting the special significance of character writing in Chinese dyslexia. While these studies focused on Hong Kong children, a recent mainland China (Beijing) study similarly found that Chinese dyslexic children copied Chinese characters and symbols more slowly than age-matched controls (Meng, Wydell, & Bi, 2018). Thus, writing processing deficits are widespread in Chinese dyslexic children, manifesting in both linguistic (character copying) and non-linguistic (symbol copying) domains. Unlike alphabetic research, Chinese dyslexia shows deficits in non-verbal symbol writing that more directly reflect basic visual-motor integration deficits (Meng, Wydell, & Bi, 2018), though the internal relationship between these general integration deficits and Chinese dyslexia remains unclear.

3.3.2 Neural Mechanism Research

No neuroimaging studies have specifically investigated writing processing deficits in Chinese dyslexia. However, previous neuroimaging research reveals functional and structural abnormalities in Chinese dyslexic children in left middle frontal gyrus (Siok, Niu, Jin, Perfetti, & Tan, 2008), bilateral temporo-occipital regions (Liu et al., 2012; Qi et al., 2016), and cerebellum (Feng et al., 2017; Yang, Yang, Chen, Zhang, & Bi, 2016; Yang, Bi, Long, & Tao, 2013; Yang & Bi, 2011)—all regions closely associated with writing processing (Planton et al., 2013). Therefore, the neural basis of Chinese dyslexic writing deficits, particularly the relationship between abnormalities in middle frontal gyrus, bilateral temporo-occipital regions, and cerebellum and writing deficits, warrants intensive investigation and presents an important opportunity to reveal Chinese dyslexia-specific neural mechanisms.

4. Summary and Future Directions

Writing processing deficits are widespread in both alphabetic and Chinese dyslexia. Alphabetic research indicates that dyslexic writing deficits primarily manifest in orthographic access—the central process of writing. Compared to alphabetic scripts, Chinese writing processing is more complex and more closely related to reading ability. Behavioral studies report that Chinese dyslexics exhibit significant writing difficulties at both linguistic (character) and non-linguistic (symbol) levels, suggesting deficits in both central and peripheral processes. However, systematic research, particularly neuroimaging studies, is lacking, leaving our understanding of Chinese dyslexic writing deficits at a phenomenological level with numerous scientific questions unresolved. Future research should address the following:

1) Systematically investigate central (orthographic access) and peripheral (motor execution) processing deficits in Chinese dyslexic writing by simultaneously manipulating central and peripheral factors to clarify the internal mechanisms of writing deficits and their relationship to reading difficulties.

2) Orthographic working memory plays a crucial role in writing orthographic retrieval, temporarily maintaining orthographic information for motor encoding and output, serving as an intermediary between central and peripheral processes (Rapp, Purcell, Hillis, Capasso, & Miceli, 2015). Neuroimaging studies reveal language differences in orthographic working memory neural representation: alphabetic languages localize it to superior frontal sulcus and superior parietal lobule (Rapp & Dufor, 2011), whereas Chinese localizes it to left middle frontal gyrus and angular gyrus (Chen, Chang, Chen, Lin, & Wu, 2016). Previous dyslexia writing research has not examined this factor; future studies should investigate Chinese dyslexia-specific neural mechanisms from an orthographic working memory perspective.

3) Employ neuroimaging techniques to examine brain activation and functional connectivity during dyslexic writing. Given writing' s complexity involving both linguistic and motor processing, functional connectivity studies will be essential for investigating dyslexic writing deficit mechanisms. Introducing MRI-compatible digital writing tablets to record behavioral responses during scanning can establish brain-behavior relationships and enhance ecological validity by examining neural mechanisms in more authentic writing contexts.

4) Although adult and child dyslexia writing deficits show some differences, no studies have directly examined developmental changes and their neural mechanisms. Longitudinal research is critically needed.

5) Effective remediation of writing difficulties in dyslexic children and whether writing training can improve reading abilities remain important questions. For instance, what unique role does writing training play in Chinese dyslexia remediation compared to other reading interventions, and what are the underlying cognitive-neural mechanisms? Answering these questions is essential for incorporating writing into Chinese dyslexia diagnosis and treatment protocols.

Systematic investigation of Chinese dyslexic writing processing from these perspectives will enrich and advance Chinese dyslexia-specific theory while providing guidance for clinical diagnosis and remediation.

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