DYX1C1 Gene on Chinese Children's Reading Achievements

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Contributor: Yingnan Niu , He Cai , Li Zhang

Reading comprehension refers to the capacity of an individual to comprehend and interpret the intended message of an author through written text in the most objective manner possible.

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1. Introduction

In the field of reading research, there are two important concepts, namely reading comprehension and reading competence. Reading comprehension refers to the capacity of an individual to comprehend and interpret the intended message of an author through written text in the most objective manner possible [1]. Meanwhile, reading competence involves the ability to understand, use, reflect, and write text. However, there is currently no consensus on the exact relationship between the concept of reading comprehension and reading competence. Jiménez-Pérez pointed out that reading comprehension is a subset of reading competence, suggesting that reading competence encompasses a broader set of skills beyond just understanding written texts [1]. From this perspective, reading competence pertains to an individual's ability to effectively apply their reading comprehension skills in various social contexts [1] and this ability can help individuals achieve their goals, develop their knowledge and potential, and eventually integrate into society [2]. Therefore, reading competence has been viewed as one of the most important abilities necessary for people to study and work successfully [3]. According to the research of Rogiers et al., reading performance not only has the potential to predict academic success but also plays a significant role in promoting social participation [4]. Numerous studies, including the work of Ding and Homer, have highlighted the importance of reading proficiency in facilitating the learning of various subjects [5]. Furthermore, international assessments such as the Progress in International Reading Literacy Study (PIRLS), the Programme for International Student Assessment (PISA), and the National Assessment of Educational Progress (NAEP) have all conducted evaluations specifically focused on reading competence. In the past decades, reading education has received an increasing amount of attention in school education [6] because acquiring reading skills is thought to be a prerequisite for all other school-related successes [7].

In contemporary China, traditional reading teaching methods, which were centered around the teacher, focused on knowledge acquisition, and relied heavily on tests, have gradually been phased out. Reading education in modern times, under the guidance of enhancing core competencies, prioritizes the establishment of a favorable curriculum implementation environment that fosters active learning, self-directed learning, cooperative communication, analysis, and problem-solving abilities among students [8]. The "Chinese Language Curriculum Standards for

Compulsory Education in China (2022 Edition)" clearly states that by the end of primary school, students' extracurricular reading should not be less than 4 million words [9]. These data reflect the importance that the education department attaches to students' extracurricular reading. Indeed, Chinese senior students in primary school are encouraged to engage in extensive reading, with a preference for extracurricular reading materials related to the subject matter. Solely relying on schools for enhancing students' reading skills through both in-class and extracurricular reading may be challenging, and it necessitates the active involvement of families. Therefore, the collaboration between families and schools plays an indispensable role in improving primary school students' reading competence.

However, currently in China, the family–school collaboration system in reading instruction for upper-grade primary school students is incomplete, mainly manifested in the following aspects [10]: First, the teaching evaluation is inefficient, and it cannot promote family–school collaboration through evaluation. Second, the school-based family–school collaboration curriculum is lacking, and it is difficult to improve the level of family–school collaboration based on reading using only textbooks and extracurricular reading materials prepared by parents. Third, family–school collaboration lacks comprehensiveness, and students fail to develop comprehensively in reading activities, thus reducing the quality of family–school collaboration in reading instruction. In summary, it can be seen that in the construction of the family–school collaboration system in upper-grade primary school reading instruction, almost all evaluations emphasize the dominant position of schools. In other words, all evaluations focus on the school side in the construction of the family–school collaboration system, while the family side is relatively neglected. Therefore, it becomes very important to explore and strengthen the family factors that influence children's reading competence. Meanwhile, compared to other subject areas, such as mathematics, reading achievement has been proven to be more strongly influenced by family factors [11][12], such as parental home supervision. Therefore, exploring the relationship between family factors and children's reading performance is of great practical significance. Some studies showed that home supervision, which is a widely used rearing strategy, especially in China, was significantly correlated with children's academic achievement [13][14]. However, some G × E (Gene × Environment interaction) research suggested that the relationship between family factors and children's behavioral outcomes may be affected by some individual characteristics; specifically, the relationship may be moderated by genes [15][16][17][18].

2. Home Supervision and Children's Reading Achievements

The school work of Chinese students is usually conducted under external supervision [19] because the Chinese generally value the virtues of filial piety and the importance of education [19][20]. Therefore, home supervision is a widely used rearing strategy in China [13][14]. Home supervision or home monitoring is a set of correlated parenting behaviors involving attention to and tracking of a child's whereabouts, activities, and adaptations [21]. Indeed, home supervision has been widely proven to be associated with children's academic achievements [13][14]; however, the results were mixed. Specifically, on the one hand, some studies have found that home supervision could positively predict children's academic achievements. A meta-analysis showed that home supervision had a significant but weak relationship with children's academic achievements compared to other dimensions of parental involvement

[22]. Similarly, a longitudinal study analyzed 763 parents and children from the fifth to eighth grade and it showed that, when controlling for demographics, there was a significant positive effect of parental monitoring on GPA (Grade Point Average) [23]. In addition to general home supervision, a meta-analysis was used to examine the relationship between homework checking (one specific home supervision activity) and academic achievement and revealed that it was positively associated with students' learning [24].

However, on the other hand, there were also some inconsistent findings. In some research, a negative relationship was obtained. For example, Guo et al. explored the relationship between family SES (family socioeconomic status) and reading achievement, and the results showed that home monitoring played a critical mediating role between family SES and reading achievement; that is, home monitoring could negatively predict children's reading achievement, but this effect was only true for girls [25]. Similarly, McNeal's study revealed that home monitoring was negatively correlated with children's science achievements and that this effect was moderated by family SES [26]. However, there have been other different findings. Graves et al. found that parental control of children's TV time may have both positive and negative effects on children's reading achievements [27]. While Jeynes's meta-analysis revealed that, although it was positively related to student academic achievements, enforcing household rules did not have significant impacts [28]. Similar to Jeynes's meta-analysis, the meta-analysis of Tan et al. found that there was no significant relationship between parental supervision of their children and children's academic achievements ($M = 0.01$, $p > 0.05$) [29]. However, there are significant variations (Q (df) = 697.78(29), $I^2 = 95.84$) in this relationship among different populations, suggesting that there may be potential moderators for this relationship.

Therefore, the previous findings did not show agreement in the relationship between parental home supervision and children's reading achievements. These inconsistent findings show that different people may have different susceptibilities to the home supervision rearing strategy and thus demonstrate different relationships between home supervision and children's reading outcomes.

3. The DYX1C1 Gene and Children's Reading Achievements

In fact, a number of studies have shown that reading skills have a genetic basis. A twin study showed that reading achievements have a genetic basis of approximately 50 percent or more [30]. Another study also found a high degree of familial clustering of dyslexia, with nine loci identified as being associated with dyslexia in general [31]. Among these foci, the *DYX1C1* (dyslexia susceptibility 1 candidate gene 1) gene at the *DYX1C1* locus was the first identified and widely confirmed susceptibility gene to be associated with dyslexia [32]. Taipale et al. found that nucleotide polymorphisms of the *DYX1C1* gene (−3G > A and 1249G > T) were associated with dyslexia by mapping the breakpoint of a translocation precisely on the short arm of chromosome 15 (15q21DYX1) [33].

Recently, several *DYX1C1* loci have been shown to be associated with dyslexia, and among these studies, three polymorphisms were proven to be associated with reading achievements, namely, *rs3743205*, *rs11629841*, and *rs8040756* [34][35][36]. For instance, the *rs3743205* polymorphism of the *DYX1C1* gene affects reading and writing, rapid reading, phonological recall, and spelling abilities by affecting the migration of neurons [34]. The *rs11629841*

polymorphism was also found to be significantly associated with dyslexia [37] and the protein encoded by the *rs11629841* polymorphism of the *DYX1C1* gene may be involved in neuronal migration and the development of axons, and therefore, abnormal expression of related genes may lead to disordered neuronal migration and development of axons, further affecting cerebral cortex and thalamus function, resulting in phonological awareness and word-reading deficits [38]. Similarly, *rs8040756* was proven to be strongly related with reading competence in the general Australia population [35]. In this study, the *DYX1C1* gene *rs3743205*, *rs11629841*, and *rs8040756* polymorphisms were selected to investigate their moderating effects on the relationship between home supervision and children's reading achievements.

4. Studies on the Interaction of Genes and Environment

Notably, much of the previous research was merely focused on the unilateral effects of genetic or family factors on children's reading achievements; there were a few studies that have examined the effects of gene and environment interactions on children's reading achievements. However, the relationship between family factors and children's reading achievements may be moderated by genes [15][16][17][18]. Currently, there are three mainstream models for the interaction between genes and the environment, namely, the diathesis–stress model, the differential susceptibility model, and the vantage sensitivity model. The diathesis–stress model, originally proposed by Rosenthal [39] to explain the etiology of schizophrenia, uses the term "diathesis" as a synonym for vulnerability, which includes genetic, biological, physiological, cognitive, and personality factors [40]. The diathesis–stress model (see **Figure 1**a) suggests that individuals who carry risk alleles or susceptible genes are more susceptible to an adverse environment and consequently show problematic behaviors; but, in a supportive environment, whether the individual carries susceptible genes or not, their behavior will not show significant differences [41]. In 1997, Belsky expanded on the diathesis–stress model and proposed the differential susceptibility model based on evolutionary thinking to explain how individuals reproduce [42], that is, the different susceptibility of individuals is a product of evolution, and natural selection mechanisms allow parents to produce offspring with different susceptibilities to the environment, because in uncertain and unpredictable situations, this is the most advantageous way for offspring to reproduce. The differential susceptibility model (see **Figure 1**b) is based on the idea that individuals carrying susceptible genes will become better in a positive environment and show more behavioral problems in an adverse environment; that is, the individuals carrying susceptible genes will be affected by both favorable and adverse environments [43]. More recently, the vantage sensitivity model has been introduced by Sweitzer [44] to describe the different responses of individuals to positive environmental factors. The vantage sensitivity model (see **Figure 1**c) assumes that individuals carrying plastic/susceptible genes are more susceptible to positive environments but less susceptible to negative environments, regardless of whether they carry susceptibility genes [45]. All these three models are usually used to explain how different genetic susceptibilities respond to external environmental factors.

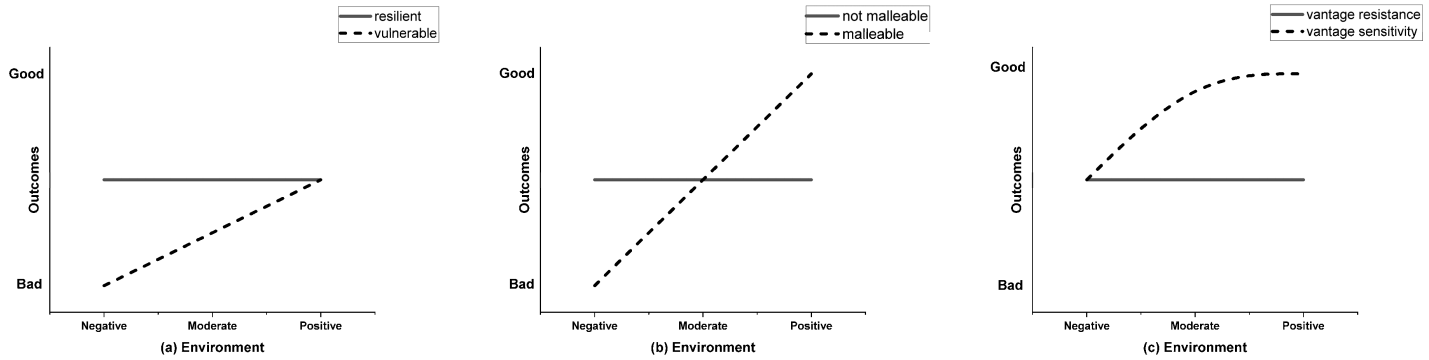

Figure 1. Three genes vs. environment models: (**a**) diathesis–stress model; (**b**) differential susceptibility model; (**c**) vantage sensitivity model. Note: The two lines in each graph represent individuals with different genetic bases. This figure is based on the literatures of Rosenthal [39], Belsky [42], and Sweitzer [44].

Some studies have supported the diathesis–stress model. For example, one study found that there was an interaction between *DYX1C1*–1259C/G and environmental factors (maternal smoking during pregnancy, birth weight, and family socioeconomic status) and this interaction was consistent with the diathesis–stress model, whereby a less supportive environment combined with a vulnerability gene may be associated with a greater risk of developing overt dyslexia, while the risk may remain relatively constant in a supportive environment [16]. Similarly, another study explored the reading achievement of Han children and found there was a significant interaction between the *rs57809907* polymorphism of the *DYX1C1* gene and the family's library size which indicated that this interaction was also in line with the diathesis–stress model [18]; that is, when the family's library size was small, the influence of genetic factors was greater.

However, in other cases, some studies supported the vantage sensitivity model. The study of Kegel et al. showed that when children with a *DRD4*–gene 7R (7-repeat) allele received positive feedback, they showed higher literacy skills [15]. However, among those who did not receive positive feedback, there were no significant differences in literacy skills among children with different genotypes. Additionally, there were some findings showing that children's reading performance may be affected by both positive and negative environments, which supports the differential susceptibility model. For instance, Zhao et al. found that there was a significant interaction between CGS of *KIAA0319* and parental education level on reading fluency in Chinese grade three to grade six primary school students and this interaction fit the differential susceptibility model well [46]. Specifically, in a positive environment, characterized by higher parental educational levels, children with a lower CGS of *KIAA0319* demonstrated superior reading fluency compared to children with a higher CGS. Similarly, Plak et al. conducted a randomized controlled trial and found that there was a significant three-way interaction among the CLT pretest, Living Books intervention, and the *DRD4*-gene 7R and that this interaction was consistent with the differential susceptibility model [17]. Specifically, children with delays who carry the *DRD4*-gene 7R benefited the most from the Living Books intervention.

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