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***Review***

# The Role of COMT (Val158Met) Polymorphism in Variation of Children's Cognition and Learning Character

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**Abstract.** This study exakines the role of the COMT Val158Met genetic polymorphism in variations of children's cognition and learning character through a systematic literature review. This approach aims to understand how internal biological factors influence differences in children's learning styles and academic performance, as well as to highlight the importance of the interaction between genetic factors and the learning environment (gene x environment interaction). Through the search and analysis of relevant scientific articles from various international and national databases, this study found that genetic variations in COMT affect dopamine activity and neurotransmitter mechanisms, impacting executive function, emotion regulation, and responses to academic stress. The research findings conclude that understanding molecular genetics in the context of education can support the development of more personalized and adaptive learning approaches and support the implementation of neurodiversity-based educational strategies. This study also indicates the need for further research on the direct relationship between COMT polymorphism and learning characteristics in Indonesia, which is still limited at present.

**Keywords:** Cognitive Ariation; COMT Val158Met; Molecular Genetics



## INTRODUCTION

Differences in children's cognitive abilities and learning characteristics are a universal phenomenon often encountered in everyday educational practices (Zagoto et al., 2019). In the same class, teachers often encounter student heterogeneity, both in terms of the speed of understanding the material, interest in the subject, and consistency in completing academic tasks (Ainayya et al., 2025). This variation is often explained through environmental approaches such as the quality of teaching, parental involvement, or socio-cultural factors that shape students' learning experiences (Turhusna & Solatun, 2020). This approach focuses on external influences on children's learning performance, without considering the potential internal roles such as biological and genetic factors.

In the last two decades, biological approaches, particularly genetic approaches, have increasingly gained prominence in explaining individual mechanisms behind differences in cognitive functions and learning behaviors (Amin et al., 2024). Several studies in the fields of neuropsychology and behavioral genetics have shown that, in addition to being influenced by the environment, variations in cognitive abilities can also be traced to the molecular level, specifically genetic variations in certain genes that affect the functioning of the central nervous system (Chen et al., 2023). The Catechol-O-Methyltransferase (COMT) gene is one of the genes that has received significant attention in cognitive neurobiology studies, given its essential role in regulating neurotransmitter homeostasis in the brain, particularly dopamine, through methylation mechanisms (Lee & Prescott, 2014).

The COMT gene encodes an enzyme responsible for the breakdown of neurotransmitters such as dopamine, norepinephrine, and epinephrine (Lee & Prescott, 2014). Dopamine specifically plays a central role in regulating

the brain's executive functions, including attention, decision-making, working memory, and impulse control (Febyan et al., 2020). The efficiency of the COMT enzyme affects the levels of dopamine available in the prefrontal cortex, a brain region involved in high-level cognitive processing (Roomaney et al., 2022). Small changes in the structure of the COMT gene can trigger significant differences in an individual's neurocognitive function.

The Val158Met (rs4680) polymorphism in the Catechol-O-Methyltransferase (COMT) gene is a single nucleotide substitution that results in the change of the amino acid valine (Val) to methionine (Met) at position 158 of the membrane-bound COMT (MB-COMT) enzyme isoform (Gerra et al., 2024). This variation contributes to differences in COMT enzymatic activity, which in turn affects dopamine degradation in the prefrontal cortex of the brain. This polymorphism directly implicates the activity of the COMT enzyme in the brain: individuals with the Met/Met allele have lower enzyme activity, thereby maintaining higher dopamine levels in the prefrontal cortex, whereas individuals with the Val/Val allele have higher enzyme activity, resulting in lower dopamine levels. Higher dopamine levels can provide advantages in situations that require concentration and working memory, although they can also increase sensitivity to stress (Dobewall et al., 2021).

Various neurogenetic studies have linked the COMT Val158Met polymorphism to differences in cognitive performance, emotional regulation, and responses to academic and social stress. Children with the Met/Met allele tend to perform better in working memory and focused attention tasks, but are also more susceptible to anxiety. On the other hand, children with the Val/Val allele tend to be more resilient to stress but may have lower cognitive performance in challenging task conditions (Koyama et al., 2024). This indicates that the genetic role in learning ability is dynamic and influenced by the environmental conditions in which the child develops.

The interaction between genetic and environmental factors (gene × environment interaction) is an important paradigm in explaining the heterogeneity of cognitive abilities and learning characteristics in children (Sultan & Syafiuddin, 2025). The polymorphism of the COMT gene, particularly the Val158Met variant, does not deterministically determine an individual's cognitive profile, but rather serves as a biological framework that is plastic in response to environmental variations. The phenotypic expression of the same genotype can undergo substantial modifications in response to the quality of social interactions, affective support, and the learning strategies received (Cahill et al., 2022). Therefore, a child's learning characteristics are not solely determined by genetic structure, but rather are the result of a dynamic interaction between biological predispositions and contextual experiences throughout development.

The study of the relationship between COMT Val158Met and cognitive variation has significant relevance in the field of education. Understanding how biological factors shape children's learning preferences and abilities can serve as the foundation for developing more personalized and adaptive learning approaches. In the long term, this approach supports the implementation of neurodiversity-based education, where biological differences are not seen as obstacles, but as part of the normal spectrum of human potential that needs to be wisely facilitated.

Research on the role of the COMT gene polymorphism, particularly the Val158Met variant, has rapidly advanced in various countries, especially those with a strong tradition in neuropsychology and molecular genetics. However, in Indonesia, research on this topic is still limited and has not been widely linked to the field of education, particularly in understanding children's different learning characteristics. Therefore, this literature review is prepared to summarize the latest findings on the COMT Val158Met polymorphism, its influence on dopamine activity, and its impact on cognitive differences and children's learning styles. It is hoped that the results of this study can provide useful insights for the development of research in the fields of educational psychology, neurogenetics, and more adaptive learning in accordance with students' biological differences.

## MATERIALS AND METHODS

The research method used in this study is a systematic literature review, which aims to summarize, analyze, and integrate relevant research findings on the COMT (Val158Met) polymorphism and its role in cognitive variation and children's learning characteristics. This literature review focuses on studies that discuss the relationship between genetic variations in COMT, the biochemical mechanisms involved, and their impact on cognitive aspects and learning behaviors in children. The articles used in this review were selected based on predetermined inclusion and exclusion criteria, specifically only research articles published in indexed and peer-reviewed scientific journals, focusing on studies conducted within the last ten years. The literature search was conducted through searches in various leading scientific databases, such as Google Scholar, PubMed, ScienceDirect, Scopus, and JSTOR, using keywords such as "COMT Val158Met," "Catechol-O-Methyltransferase," "COMT polymorphism," "dopamine," "cognitive performance," "learning behavior," and "gene-environment interaction."

After the initial search, the found articles were filtered based on the relevance of the title and abstract, then read thoroughly to ensure their suitability for the research topic. Articles that meet the inclusion criteria will be categorized based on the main themes discussed, such as the relationship between COMT polymorphism and cognition, the influence of dopamine on learning character, and the interaction between genetic and environmental factors. After the relevant articles are categorized, an analysis is conducted to identify similarities, differences, and gaps in the existing research findings. This analysis aims to further understand the role of COMT polymorphism in cognitive variation and children's learning behavior. The results of this data analysis are then synthesized to formulate conclusions that can provide insights into how COMT polymorphism affects differences in cognitive abilities and learning characteristics, as well as how these findings can be applied in a more adaptive and personalized educational context.

Nevertheless, there are several limitations in this study, including the limited number of studies directly examining the COMT Val158Met polymorphism in the context of children's education, as this topic is still relatively new and more extensively researched in the field of neurogenetics. Additionally, the literature search was limited to articles published in the last ten years, which may affect the scope of the available findings. The results of this study are expected to make a significant contribution to the further development of research in the fields of educational psychology, neurogenetics, and neurodiversity-based education.

## RESULTS AND DISCUSSION

As an effort to further understand the relationship between the COMT Val158Met gene polymorphism and variations in children's cognition and learning character, a systematic review of several relevant previous studies was conducted. This review includes studies that focus on the molecular mechanisms of COMT, its relationship with dopamine neurotransmitter activity, and its implications for cognitive phenomena, emotion regulation, and responses to academic stress. The synthesis of this review aims to summarize the main findings, methodologies used, and implications of each study, thereby providing a strong conceptual foundation in explaining the dynamics of the interaction between genetic and environmental factors on children's learning character. The following is a table synthesizing the results of the analyzed literature review.

**Table 1.** synthesis of the results of the literature review that has been analyzed.

| Author and Year | Research Topic | Research Result |
|---|---|---|
| (Zagoto et al., 2019) | Variations in children's learning styles | Differences in learning styles are individual and cannot be generalized; they support the cognitive heterogeneity of students. |
| (Ainayya et al., 2025) | Differentiated learning (TaRL) | Learning strategies need to be adjusted to the child's actual abilities, not their age; relevant in the context of genetic plasticity. |
| (Turhusna & Solatun, 2020) | The influence of the environment in the learning process | The environment plays a significant role in shaping learning attitudes and motivation; genetic factors are not the only determinants. |
| (Amin et al., 2024) | Genetics and learning behavior | Internal factors (including genetics) play an important role in character education, honesty, and learning consistency. |
| (Chen et al., 2023) | COMT and executive function | Alel Met increases working memory capacity but is vulnerable to anxiety under high cognitive load. |
| (Lee & Prescott, 2014) | Regulation of dopamine by COMT | COMT plays a role in dopamine homeostasis; the Val158Met genotype affects prefrontal cortex function. |
| (Febyan et al., 2020) | The function of dopamine on behavior | Dopamine is closely related to attention, emotional control, and children's learning focus. |
| (Roomaney et al., 2022) | Dopamine and executive cognition | The prefrontal cortex is sensitive to dopamine levels influenced by COMT activity. |
| (Gerra et al., 2024) | Val158Met and academic stress | Met/Met children are more prone to anxiety during exams; Val/Val children are more stress-resistant but have low executive performance. |

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|---|---|---|
| (Dobewall et al., 2021) | COMT polymorphism and affective balance | The activity of the COMT enzyme is associated with vulnerability to long-term emotional stress. |
| (Koyama et al., 2024) | Genetics and regulation of aggression/cognition | COMT is one of the main candidate genes for variations in learning behavior and emotional control. |
| (Sultan & Syafiuddin, 2025) | Gene × environment interaction in education | The interaction of biological and contextual factors is important in understanding a child's learning profile holistically. |
| (Cahill et al., 2022) | Epigenetics in the context of learning | The COMT gene can be influenced by the environment through epigenetic mechanisms that modulate its expression in the learning process. |
| (Weidler et al., 2024) | The influence of the COMT Val158Met polymorphism on aggressive behavior and brain function | Genetic variations (such as COMT Val158Met) influence individual responses to interventions (both brain stimulation and learning and cognition processes) |
| (Koyama et al., 2024) | Genetic variability such as COMT Val158Met affects brain function and behavior | COMT Val158Met is known to affect dopamine levels in the prefrontal cortex, which plays a crucial role in executive functions, attention, and learning abilities |

Based on the synthesis of the literature, it is clear that the COMT Val158Met genetic polymorphism plays a central role in shaping cognitive diversity and children's learning character. The Catechol-O-methyltransferase (COMT) gene plays a crucial role in regulating dopamine levels, particularly in the prefrontal cortex, which is the control center for executive functions such as attention, planning, decision-making, and working memory. The Val158Met polymorphism refers to the substitution of the amino acid valine (Val) with methionine (Met) at position 158, which causes variations in the efficiency of the COMT enzyme in metabolizing dopamine. Individuals with the Met/Met genotype have less efficient COMT enzymes, resulting in higher dopamine levels in the prefrontal cortex, which in certain situations benefits cognitive functions such as working memory and attention (Chen et al., 2023; Gerra et al., 2024).

However, this advantage is contextual. High levels of dopamine in the prefrontal cortex in Met/Met individuals can indeed support performance on complex cognitive tasks, but it also makes them more vulnerable to academic stress or emotional pressure. This is in line with the concept of the inverted-U theory of dopamine, which states that optimal cognitive performance occurs at moderate levels of dopamine; too low or too high actually decreases performance. Therefore, Met/Met children require a stable, structured, and low-stress learning environment to demonstrate their maximum cognitive potential.

On the other hand, individuals with the Val/Val genotype have more active COMT enzymes, causing dopamine to be metabolized more quickly, resulting in lower levels in the prefrontal cortex. This makes them more resilient to emotional stress, but they may have difficulty maintaining attention or working memory in the context of academically demanding tasks that require high concentration. Therefore, they can develop more optimally in learning approaches that are active, contextual, and exploratory, such as project-based learning or challenges that trigger intrinsic motivation and positive emotional engagement.

Local studies such as those by Zagoto & Yarni (2019) and Ainayya et al. (2025) reinforce that the expression of this polymorphism is truly felt in the field of education. Children show differences in learning styles, task preferences, and varying needs for learning approaches, even in the same environment. This emphasizes that the interaction between biological factors and the learning environment greatly determines educational outcomes. Cahill et al. (2022) add that genetic expressions such as COMT are plastic; meaning, the environment can enhance or suppress the potential possessed by these genetic variations. Two children with the same genotype can show very different learning performance depending on the quality of teaching, teacher-student relationships, and the socio-emotional conditions of the classroom.

Interestingly, Koyama et al. (2024) expand the understanding by linking the COMT gene not only with academic performance but also with self-control regulation, aggression tendencies, and other executive function abilities. These findings imply that teaching strategies that consider the neurogenetic profiles of students not only impact academic outcomes but also the development of character and mental health. For example, students with the Met/Met genotype may require stronger social support and stress management, while Val/Val students may need cognitive stimulation to maintain learning engagement.

Based on that evidence, it can be concluded that a pedagogical approach that is differentiated and personalized is very much needed in the education system. The education of the future ideally should be able to

facilitate diverse learning needs based on the biological and psychosocial profiles of students. This is where inclusive and data-driven education plays an important role not only looking at students from an academic perspective but also understanding the genetic, emotional, and social dimensions as a whole.

In the context of educational policy, the results of this research provide an impetus to adjust the curriculum and teaching methods to be more responsive to individual inherent diversity. Additionally, teacher training is needed to enable them to recognize indicators of learning needs based on students' cognitive and affective characteristics, even without conducting genetic testing. This can be achieved through observing learning behaviors, openness to dialogue, and creating a supportive classroom climate.

## CONCLUSION

This literature review shows that the COMT Val158Met genetic polymorphism plays an important role in influencing cognitive variation and children's learning character. This variation not only determines an individual's response to academic pressure and the learning environment but also relates to neuropsychological profiles such as executive function and emotional regulation. By understanding the role of genetics, the development of more personalized learning models that can facilitate the diversity of students' biological potential can be achieved more effectively. This approach supports the neurodiversity-based education paradigm that values differences as part of the spectrum of human potential. In Indonesia, research on this relationship is still limited, so more in-depth studies are needed to integrate biological aspects into educational practices to create a more inclusive and adaptive learning environment.

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