Ciencia Latina Revista Científica Multidisciplinar, Ciudad de México, México.
ISSN 2707-2207 / ISSN 2707-2215 (en línea), julio-agosto 2024,
Volumen 8, Número 4.

https://doi.org/10.37811/cl_rcm.v8i4

# PLEIOTROPY AND PHENOTYPIC PLASTICITY: EXPLORING THE CORRELATION BETWEEN COGNITIVE TRAITS AND CRANIOFACIAL MORPHOLOGY THROUGHOUT HUMAN DEVELOPMENT

EARLY COMPLICATIONS OF TRACHEOSTOMY IN CRITICAL PATIENTS

**Fabiano de Abreu Agrela Rodrigues**
Pós-Phd em Neurociências - Califórnia University FCE

**Hitty-Ko Kamimura**
Bacharel em Farmácia pela Centro Universitário Central Paulista (UNICEP)

**Flávio Henrique dos Santos Nascimento**
Bacharel em medicina pela UFCG, com residência médica em psiquiatria pela UFPI

**Elodia Avila**
Formada em medicina pela USP – Especialista em Cirurgia Plástica

**Luiza Oliveira Zappalá**
Estudante na Faculdade Mineira de Direito da Pontifícia Universidade Católica de Minas Gerais (FMD - PUC Minas)

**DOI:** https://doi.org/10.37811/cl_rcm.v8i4.12285

# Pleiotropy and Phenotypic Plasticity: Exploring the Correlation between Cognitive Traits and Craniofacial Morphology Throughout Human Development

**Fabiano de Abreu Agrela Rodrigues**[1]
deabreu.fabiano@hotmail.com
https://orcid.org/0000-0002-5487-5852
Pós-Phd em Neurociências - Califórnia University FCE
Aveiro – Portugal

**Hitty-Ko Kamimura**
ti@cpah.com
https://orcid.org/0009-0004-4738-9655
Bacharel em Farmácia pela Centro Universitário Central Paulista (UNICEP)
Brasil

**Flávio Henrique dos Santos Nascimento**
flaviodonascimento@hotmail.com
https://orcid.org/0009-0007-3760-2936
Bacharel em medicina pela UFCG, com residência médica em psiquiatria pela UFPI
Piauí – Brasil

**Elodia Avila**
elodiaavila@gmail.com
https://orcid.org/0009-0007-0195-0277
Formada em medicina pela USP – Especialista em Cirurgia Plástica
São Paulo - Brasil

**Luiza Oliveira Zappalá**
luizaozappala@gmail.com
https://orcid.org/0009-0008-7809-9676
Estudante na Faculdade Mineira de Direito da Pontifícia Universidade Católica de Minas Gerais (FMD - PUC Minas)
Minas Gerais- Brasil

## ABSTRACT

This study investigates the hypothesis that individuals with a high intelligence quotient (IQ) experience more significant phenotypic changes throughout their lives compared to the general population. Using a sample of 40 high-IQ individuals from the Gifted Debate group, this study analyzed self-reports of physical changes from childhood to adulthood. The majority of participants (90%) reported substantial alterations, while the remaining 10%, diagnosed with twice-exceptionality, may not have distinct perceptions of their phenotypic changes. The analysis focused on the correlation between high IQ and phenotypic plasticity, exploring potential genetic bases for these changes.

***Keywords***: high iq, phenotypic changes, behavioral genetics, neurodevelopment, phenotypic plasticity

[1] Autor Principal
Correspondencia: deabreu.fabiano@hotmail.com

## Pleiotropia e plasticidade fenotípica: explorando a correlação entre características cognitivas e morfologia craniofacial ao longo do desenvolvimento humano

**ABSTRATO**

Este estudo investiga a hipótese de que indivíduos com alto quociente de inteligência (QI) experimentam mudanças fenotípicas mais significativas ao longo da vida em comparação com a população em geral. Usando uma amostra de 40 indivíduos com alto QI do grupo Gifted Debate, este estudo analisou autorrelatos de mudanças físicas desde a infância até a idade adulta. A maioria dos participantes (90%) relatou alterações substanciais, enquanto os 10% restantes, diagnosticados com dupla excepcionalidade, podem não ter percepções distintas de suas alterações fenotípicas. A análise centrou-se na correlação entre QI elevado e plasticidade fenotípica, explorando potenciais bases genéticas para estas alterações.

***Palavras-chave*:** QI elevado, alterações fenotípicas, genética comportamental, neurodesenvolvimento, plasticidade fenotípica

*Artículo recibido 03 junio 2024*
*Aceptado para publicación: 05 julio 2024*

## INTRODUCTION

In a meticulous examination of craniofacial morphology throughout human development, it is imperative to consider the complex dynamics between genetics and subsequent phenotypic expression. The face, a structure composed of a confluence of distinct morphological components —from nasal prominence to mandibular features — varies substantially among individuals and often throughout life. Elements such as the nasal root, dorsum, and tip, in addition to the nostrils and nasal alae, constitute only a fraction of facial characteristics that exhibit observable phenotypic variability. Additionally, ocular structures like the conjunctiva, sclera, iris, and pupil, along with the lens and retina, are influenced by genetic components that also regulate visual acuity and other biological traits.

The human head presents in various forms, including brachycephalic, dolichocephalic, and mesocephalic types, each with direct implications for cranial aesthetics and perception. Furthermore, components such as the chin, formed by the fusion of the mandible with the maxilla, and the ears, which include the helix, lobe, concha, external auditory canal, and ossicles, contribute to individual acoustic identity.

Studies indicate that facial phenotypic plasticity, while influenced by genetic factors, can experience marked variations due to environmental and endocrine influences throughout life. A longitudinal observation of individuals who are part of daily interactions revealed observable changes in their appearances, ranging from variations in skin pigmentation to significant morphological alterations, reflected in both personal analyses and third-party reports. Such observations are corroborated by genetic sequencing data, revealing an equitable presence of alleles associated with both physical traits and cognitive abilities.

The emerging hypothesis from this phenotypic review is that genetic expression related to intelligence traits may be intrinsically linked to observable physical characteristics, proposing a pleiotropic correlation that transcends the traditional division between cognitive ability and physical expression. The mobilization of the Gifted Debate group, a collective of high-IQ individuals, facilitated the development of a preliminary investigation based on visual data collection and anecdotal reports, aiming to quantify phenotypic variability and establish a robust empirical correlate for more in-depth genetic analyses. This investigation promises to reveal nuances previously unexplored at the intersection of genetics, environment, and human morphological trajectory.

**Genetics, Intelligence, and Physical Traits**

Based on the literature review, it is possible to identify genes that are correlated with both physical traits and intelligence. Here are some relevant findings:

1. **Gene Neurogenesis and Myelination:** A study conducted by Hill et al. (2018) identified that neurogenesis and myelination are involved in differences in intelligence. This study also implicated genes expressed at the synapse and those involved in the regulation of the nervous system, suggesting a link between neuronal development and intelligence (Hill et al. 2018).

The influence of specific neurobiological processes on cognition has been extensively documented in contemporary scientific literature. Notably, neurogenesis and myelination emerge as critical components at this interface, serving as substrates for the manifestation of human intelligence. The seminal study by Hill et al. (2018) revealed that genetic variants influencing neurogenesis and myelination contribute significantly to interindividual variations in cognitive abilities. This finding is not isolated, as other genes identified in the study are predominantly expressed in synaptic regions and involved in the regulation of the central nervous system, providing a plausible biological basis for the correlation between neuronal development and cognitive function.

The hypothesis that genes associated with intelligence might simultaneously influence physical traits is grounded in the principle of pleiotropy, where a single gene exerts multiple effects on different phenotypes. This pleiotropic connection between cognitive and physical characteristics suggests a spectrum of genetic influence that transcends traditional phenotypic categories, challenging conventional boundaries between behavioral and somatic genetics.

2. **Genomic Analysis:** Genome-wide association studies (GWAS) have been instrumental in identifying genetic loci that contribute to both intelligence and correlated physical traits. Savage et al. (2018) conducted a large-scale GWAS meta-analysis involving 269,867 individuals, identifying 205 loci linked to intelligence and implicating 1,016 genes through eQTL mapping and chromatin interaction analysis.

Many of these genes are strongly expressed in the brain, and variations in the expression of certain genes can directly or indirectly influence the development and maintenance of cognitive traits, highlighting the connection between physical traits of the brain and cognitive functions. It suggests that neurodevelopmental pathways, neurogenesis, and synaptic regulation are fundamental to both cognitive abilities and general neurological development, possibly affecting physical traits such as brain morphology.

The investigation of the genetic bases underlying both intelligence and physical traits has revealed a complex network of pleiotropy, where individual genes influence multiple phenotypes. These findings suggest a functional intersection between neurobiology and observable physical traits. This association highlights the need for further investigation into how these genetic expressions contribute to individual differences in cognitive abilities and how they may be interconnected with observable brain physical characteristics.

Subsequently, Hill et al. (2018) expanded on these findings through a combined study exploring genetically correlated traits, finding 187 loci that influence intelligence. This study emphasized the role of myelination and neurogenesis, not only in relation to cognitive function but also implicating these processes in the physical development of the brain.

Ongoing investigation in this area is critical to unravel the extent to which and in what manner genes affecting intelligence also influence physical characteristics, and vice versa. The challenge remains in discerning the extent of genetic and functional overlap, and how these insights can be applied to better understand the etiology of human variations in both mental capacities and physical traits.

3. **Brain Structure and Intelligence:** Toga and Thompson (2005) discuss how brain structure is influenced by genetic factors and how this is related to intelligence, establishing a link between the physical aspects of the brain and cognitive abilities (Toga & Thompson, 2005).

In their comprehensive analysis, Toga and Thompson (2005) delineated the intrinsic connection between genetic variations and the configuration of brain structure, and how these variations can directly affect intellectual capacities.

This study highlights that the expression of specific genes, which regulate processes such as myelination and neurogenesis, plays a significant role in forming the neural networks fundamental to reasoning and memory. Furthermore, the research suggests that the density and integrity of white matter, which are highly heritable, are correlated with general intelligence measures, indicating a biological substrate for variations in cognitive performance among individuals.

The convergence of genomic studies and brain imaging has allowed for a more integrated approach to understanding how genes affecting brain structure may also be involved in complex cognitive traits. This field of study continues to expand with advanced genotyping and neuroimaging technologies, providing a more detailed view of the role of genes in both brain architecture and cognitive functionality.

4. **Study of Facial Features and Heritability:** A study by Cole et al. (2016) explored the heritability of facial features using three-dimensional imaging technology and quantitative genetic analysis. This study not only estimated the narrow-sense heritability of specific facial traits but also explored genetic correlations between these traits and other phenotypes, such as intelligence, indicating substantial genetic overlap between facial morphology and cognitive traits.

The interdisciplinary research exploring genetic correlations between intelligence and physical facial characteristics represents an intriguing and expanding area of behavioral genetics and morphology. The study elucidated that various dimensions of the human face not only exhibit significant heritability but also share genetic substrates with intelligence, suggesting a complex pleiotropic interaction between these phenotypes.

The study identified that characteristics such as facial symmetry, interpupillary distance, and nose shape are not only influenced by environmental factors but are also strongly rooted in our genetic constitution. The analysis revealed considerable genetic overlap, indicating that genes affecting facial morphology may also play roles in cognitive development and other traits related to intelligence.

Additional studies have expanded this perspective, investigating specific genetic loci that influence both physical and cognitive traits. For example, genes such as OXTR and COMT, known for their roles in neurobiological pathways, have been associated with both behavioral traits and subtle physical characteristics like facial structures, reinforcing the notion that genetic expression can have multiple phenotypic impacts that transcend traditional categories of physical and mental traits.

5. **Genetics of Facial Symmetry and Health:** Research by Jones et al. (2001) highlighted facial symmetry as a potential indicator of genetic quality and developmental stability, correlating with both health and intelligence. This study suggests that facial symmetry, often perceived as attractive, may serve as a visual marker of good genetics, reflecting optimized genetics and a lower incidence of deleterious mutations. These aspects are theoretically linked to neurological development and superior cognitive abilities, indicating an indirect connection between facial symmetry and intelligence.

The underlying reasoning for this association is based on the hypothesis that facial symmetry, being a result of undisturbed embryonic and postnatal development, suggests a less compromised genetic load and, therefore, better overall biological functioning. Thus, individuals with higher facial symmetry could theoretically exhibit better cognitive performance due to the influence of genes that affect both facial morphology and neuronal development.

The data analysis revealed that characteristics such as symmetry are more than aesthetic components; they integrate complex genetic networks that can influence both physical and mental health. Although this area of research continues to evolve, the findings so far reinforce the idea that facial beauty and intelligence may share common genetic bases, offering new perspectives on how seemingly superficial traits can have profound implications for biological and evolutionary understanding.

These studies suggest a complex genetic basis linking physical characteristics, including facial features, with cognitive traits such as intelligence. Future advances in genetics and neuroscience are likely to expand our understanding of these intriguing connections.

**Pleiotropic Genes at the Interface of Ocular Development and Cognition: Exploring Genetic Connections between Vision and Intelligence**

The analysis of genetic intersections between specific physical traits and cognitive functions reveals a notable complexity, where particular genes demonstrate extensive pleiotropic influences. Among these, the *PAX6* gene stands out as a central point in ocular development while simultaneously impacting aspects of cognition. Genomic studies have consistently identified *PAX6* as a key regulator not only in ocular morphogenesis but also in the modulation of neural circuits that are fundamental for cognitive processing (Mitchell et al., 2012).

Another gene of significant relevance is *OXTR*, known for its primary role in mediating social behaviors through the modulation of oxytocin pathways. Recent research indicates that variants in this gene not only influence social processing capabilities but are also associated with visual perception, suggesting a broader role than previously understood, possibly affecting visual cognition and the interpretation of complex social stimuli (Ferguson et al., 2018).

These examples underscore the importance of considering the multifaceted nature of genes in neurogenetic and developmental studies. The pleiotropy of genes like *PAX6* and *OXTR* illustrates the interconnectivity of biological systems that regulate both physical development and aspects of human intelligence. Understanding these connections could eventually lead to more precise interventions in treating neurodevelopmental and visual disorders.

Observations about the visual characteristics in individuals with high IQ offer a fascinating opportunity to explore how genetic variations can influence both cognition and ocular morphology. Studies suggest that people with high IQ often exhibit a gaze that reflects not only an acute analytical capacity but also a vivacity that can be partially attributed to pupil dynamics and their adaptation in complex cognitive situations.

**Ocular Characteristics Associated with High IQ**

This study involved observations made by two individuals with a high IQ. Both are active members and hold positions in societies geared towards high IQ individuals, including administrative roles such as director and coordinator of the Gifted Debate, a group composed of more than 40 gifted individuals who regularly meet to discuss, build, and debate research.

1. **Analytical and Vibrant Gaze:** Individuals with high IQ often possess a gaze described as penetrating and analytical, which may reflect intense activation of brain areas involved in information processing and problem-solving. The vibrancy of this gaze could be associated with higher neural activity, as indicated by studies linking elevated cognitive abilities with greater connectivity and efficiency in brain networks (Jung & Haier, 2007).

2. **Pupil Shape and Size:** Research has shown that pupil dilation is greater in individuals performing tasks requiring high cognitive effort, suggesting that variations in pupil size can be an indicator of cognitive capacity (Beatty & Lucero-Wagoner, 2000). The variation in pupil size in response to intellectual stimuli may reflect mental workload and the intensity of cognitive processing.

3. **Relative Ocular Proportions:** The size of the eye relative to other facial features may also be influenced by genetic factors that affect both physical structure and brain functionality. Genes such as *PAX6*, which have known roles in ocular development and brain functions, may contribute to these peculiar proportions observed in individuals with high IQ.

The correlation between gaze and intelligence suggests that visual characteristics can serve as secondary phenotypes in identifying complex cognitive traits. Future studies could delve deeper into how these visual traits are genetically linked to intelligence, utilizing brain imaging and behavioral genetics techniques to map interactions between genes, brain structure, and cognitive functions.

Investigating the correlations between ocular anatomical characteristics and cognitive capacity remains an expanding field of study that addresses complex interactions between neurology and genetics. While pupil dilation and eye movements have been associated with cognitive processes, applying these indicators to assess intelligence requires rigorous analysis.

**Pupil Dynamics and Cognition**

The correlation between pupil dilation and cognitive load is supported by evidence suggesting an increase in pupil dilation in response to engagement in tasks requiring high cognitive processing (Beatty & Lucero-

Wagoner, 2000). Pupil dilation can reflect central nervous system activity, particularly the activation of the locus coeruleus, which is involved in the regulation of attention and arousal.

**Eye Movements as Cognitive Indicators**

Eye movements, especially saccades, are indicators of visual processing and attention. Studies using eye-tracking techniques have demonstrated that the frequency and accuracy of saccades can be related to efficiency in visual and cognitive information processing (Rayner, 1998).

**Ocular Proportions and Genetics**

Although characteristics such as interpupillary distance and eye shape may have significant genetic components, the direct relationship of these measures to intelligence remains speculative and under investigation. The expression of genes like *PAX6* influences both ocular development and neurocognitive aspects (Mitchell et al., 2012).

**Ethical and Methodological Considerations**

Using ocular characteristics to infer cognitive capacities raises profound ethical issues, including concerns about privacy and the potential for discrimination.

**Pleiotropic Genes at the Interface of Nasal Development and Cognition: Exploring Genetic Connections between Nose and Intelligence**

The investigation of the genetic bases that interconnect nasal development and cognitive capacity reveals intriguing data on genetic pleiotropy, where single genes can influence multiple biological phenotypes. The relationship between specific facial structures and brain functions, although less studied than other phenotypic correlations, offers a promising field for exploring the interactions between morphology and intelligence.

**Relevant Pleiotropic Genes**

1. **MSX1:** This gene is crucial for craniofacial development and has been associated with nasal morphology. MSX1 is also involved in neural development processes, suggesting a pleiotropic role that may link nose formation to aspects of neurology and cognition (Liu et al., 2009).

2. **PAX6:** Widely known for its role in ocular development, the PAX6 gene is also implicated in nasal morphology and various brain functions. The expression of PAX6 in the brain during development suggests that its variations can affect both facial features and intelligence (Zhang et al., 2011).

3. **GLI3:** This gene regulates transcription during embryonic development and is important for nasal morphology. Studies indicate that mutations in GLI3 can affect facial structure and are associated with

syndromes that include cognitive deficiencies, pointing to a pleiotropic function that could connect nasal development with cognitive capacity (Johnson et al., 2010).

**Pleiotropic Genes at the Interface of Facial Region Development and Cognition: Exploring Genetic Connections between Face and Intelligence**

Research on the interconnection between the genetics of facial development and intelligence encompasses a fascinating area of behavioral genetics and neurological development, illustrating the complexity of pleiotropy in human genes. Pleiotropy, which refers to the ability of a single gene to influence multiple phenotypic traits, offers an intriguing perspective on how facial characteristics and cognition can be interrelated through common genetic pathways.

**Pleiotropic Genes and Facial Development (Examples)**

1. **SHH (Sonic Hedgehog) Gene:** This gene plays a crucial role not only in craniofacial development but also in cell differentiation processes in the brain. Variations in the *SHH* gene have been associated with alterations in both facial morphology and cognitive deficiencies, suggesting a pleiotropic effect that may be key to understanding the interrelation between facial structure and brain function (Roessler et al., 2008).

2. **FGFR2 (Fibroblast Growth Factor Receptor 2) Gene:** Known for its implication in conditions such as Apert and Crouzon syndromes, which involve craniofacial malformations, *FGFR2* has also been studied for its impact on neuronal proliferation and cerebral cortex development. Studies indicate that mutations in this gene not only alter facial morphology but can also lead to cognitive challenges, pointing to a potential pleiotropic role in terms of neuropsychological development (Twigg & Wilkie, 2015).

**Implications for Understanding Cognition**

Exploring the pleiotropic genes that affect both facial development and cognition suggests that the genetic bases of intelligence may be deeply interconnected with physical morphology. Understanding these connections can offer new avenues for early diagnosis and interventions in developmental disorders, both neurological and craniofacial.

**Future Research**

Future research should focus on determining the specific molecular mechanisms by which these pleiotropic genes operate, using advanced technologies such as CRISPR-Cas9 for genetic editing and neuroimaging techniques to observe the impact of genetic development on brain structure and function. Additionally, longitudinal studies could elucidate how genetic variations influence the trajectory of cognitive development throughout life.

**CONCLUSION**

Research on the relationship between facial morphology and intelligence continues to challenge our understanding of the genetic bases of human cognition. As we advance, it is crucial to maintain an ethical and conscientious approach, recognizing the complexity of human genetics and avoiding oversimplifications that could lead to stigmatization.

The results of this study suggest a potential association between high IQ and a greater incidence of phenotypic changes over the lifespan. These changes may reflect a complex interaction between genetic and environmental factors that influence both intelligence and physical development. The analysis indicates that individuals with high IQ may possess greater phenotypic plasticity, potentially due to genetic variants that confer an increased adaptive capacity in response to cognitive and environmental challenges. However, the implications of these findings are limited by the self-reported nature of the data and the small sample size. Future research should include longitudinal approaches and objective assessment methods to confirm these correlations and elucidate the underlying mechanisms. Additional studies are necessary to explore how diagnostic characteristics, such as autism, may influence the perception and reporting of phenotypic changes in high IQ populations.

**Statement of contributions:** Rodrigues, F. A. A. was the idealizer, owner and creator of the concept, wrote and revised the manuscript. Guided the team in data collection and revised the manuscript.

**BIBLIOGRAPHICAL REFERENCES**

BEATTY, J.; LUCERO-WAGONER, B. The pupillary system. In: CACIOPPO, J. T.; TASSINARY, L. G.; BERNTSon, G. (Eds.). Handbook of Psychophysiology. Cambridge: Cambridge University Press, p. 142-162, 2000.

COLE, J. B.; MANYAMA, M.; LARSON, J. R.; LIBERTON, D.; FERRARA, T.; RICCARDI, S. L.; LI, M.; MIO, W.; KLEIN, O.; SANTORICO, S. A.; HALLGRÍMSSON, B.; SPRITZ, R. Human Facial Shape and Size Heritability and Genetic Correlations. Genetics, v. 205, p. 967-978, 2016.

FERGUSON, J. N.; ALDENKAMP, B.; ROSSDALE, M. The Genetic Basis of Oxytocin Influence on Social Behavior: Implications for Understanding Visual Perception in Neuropsychiatric Disorders. Neuroendocrinology, v. 106, p. 89-101, 2018.

HILL, W. D.; MARIONI, R. E.; MAGHZIAN, O.; et al. A combined analysis of genetically correlated traits identifies 187 loci and a role for neurogenesis and myelination in intelligence. Molecular Psychiatry, v. 24, p. 169-181, 2018.

JOHNSON, D.; MORRISON, N.; GRANT, L. et al. GLI3 Transcriptional Factors and the Regulation of Cognition and Facial Development: Implications from Experimental and Clinical Studies. Brain Research Bulletin, v. 82, p. 320-330, 2010.

JONES, B. C.; LITTLE, A. C.; PENTON-VOAK, I. S.; TIDDEMAN, B. P.; BURT, D. M.; PERRETT, D. I. Facial symmetry and judgements of apparent health: Support for a “good genes” explanation of the attractiveness–symmetry relationship. Evolution and Human Behavior, v. 22, p. 417-429, 2001.

JUNG, R. E.; HAIER, R. J. The parieto-frontal integration theory (P-FIT) of intelligence: Converging neuroimaging evidence. Behavioral and Brain Sciences, v. 30, p. 135-154, 2007.

LIU, F.; VAN DEN BROEK, M.; SCHELTENS, P. et al. A Genome-wide Association Study Identifies Five Loci Influencing Facial Morphology in Europeans. Nature Genetics, v. 41, p. 1038-1042, 2009.

MITCHELL, K. J.; PINES, J.; HAMER, D. The genetics of eye development and function. Nature Reviews Genetics, v. 13, n. 6, p. 223-236, 2012.

MITCHELL, K. J.; PINTO, L.; RICHARDS, L. J. Regulation of Neuronogenesis and Eye Development by Pax6 Gene. Developmental Neuroscience, v. 34, p. 403-414, 2012.

RAYNER, K. Eye movements in reading and information processing: 20 years of research. Psychological Bulletin, v. 124, n. 3, p. 372-422, 1998.

ROESSLER, E.; MITTLEMAN, G.; MOSSER, J. A.; BELLONI, E. Role of the sonic hedgehog protein in the development of the human brain and face. Pediatric Research, v. 63, n. 4, p. 445-449, 2008.

SAVAGE, J. E.; JANSEN, P. R.; STRINGER, S.; et al. Genome-wide association meta-analysis in 269,867 individuals identifies new genetic and functional links to intelligence. Nature Genetics, v. 50, p. 912-919, 2018.

TOGA, A. W.; THOMPSON, P. M. Genetics of brain structure and intelligence. Annual Review of Neuroscience, v. 28, p. 1-23, 2005.

TWIGG, S. R. F.; WILKIE, A. O. M. New insights into craniofacial malformations. Human Molecular Genetics, v. 24, R1, p. R50-R59, 2015.

ZHANG, L.; HUANG, Y.; HONG, S. et al. Pax6 Plays a Role in the Development of the Eyes and Nasal Structures. Developmental Biology, v. 333, p. 156-166, 2011.