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Neurodevelopmental Processes: Bisexuality

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Synonyms

Ambisexuality; Bisexual orientation; Non-monosexual orientation; Plural sexual attraction; Polysexual orientation; Sexual diversity; Sexual fluidity

Definitions

Bisexuality:	The quality or characteristic of being sexually, romantically, or emotionally attracted to individuals of more than one gender or sex. It is not merely a midpoint between heterosexuality and homosexuality but a distinct orientation with its own developmental pathways and variations in expression. Bisexuality can encompass fluidity and variability in attraction patterns across time and contexts.
Neurodevelopmental processes:	The biological and environmental factors that contribute to the maturation, growth, pruning, differentiation, and wiring of neural circuits in the brain. These processes are fundamental to cognition, social behavior, sexual identity, and emotional functioning. Neurodevelopmental processes encompass the role of genetics, hormones, and environmental influences in shaping brain structure, function, and behavior across the lifespan.
Sexual orientation:	An enduring pattern of emotional, romantic, and/or sexual attraction to individuals of a particular gender or multiple genders. Sexual orientation is influenced by genetic, hormonal,

T. K. Shackelford (ed.), *Encyclopedia of Sexual Psychology and Behavior*,
https://doi.org/10.1007/978-3-031-08956-5_1587-1

	neurobiological, and environmental factors and can emerge through complex developmental processes.
Prenatal development:	The period of development from conception to birth, during which the foundations of physical, neurological, and behavioral traits are established. Prenatal influences, such as exposure to hormones like androgens and estrogens, play a crucial role in shaping the sexual differentiation of the brain and the potential for later sexual orientation.
Puberty:	A developmental stage marked by hormonal changes, brain maturation, and the emergence of secondary sexual characteristics. Puberty is a critical period for the refinement and consolidation of sexual orientation, as biological and social factors interact to shape identity and attraction.
Epigenetics:	Heritable changes in gene expression that occur without alterations to the underlying DNA sequence. Epigenetic modifications, influenced by environmental factors like prenatal stress or maternal health, can impact the development of sexual orientation by altering gene expression patterns, including those related to hormone receptor sensitivity and neural wiring.
Neuroplasticity:	The brain's ability to reorganize itself by forming new neural connections in response to experiences, learning, or environmental changes. Neuroplasticity is crucial in shaping sexual identity and attraction during developmental stages like puberty, where the brain's responsiveness to social and hormonal cues can influence sexual preferences.
Reward system:	A network of brain structures, including the ventral striatum and prefrontal cortex, that processes and responds to rewarding stimuli, including social, emotional, and sexual cues. The reward system plays a significant role in attraction and motivation, influencing how individuals experience and express their sexual preferences.

Introduction

Throughout history, individuals have defied rigid categories of attraction, challenging the binary frameworks that have long dominated societal understanding of sexuality. Despite their resilience, those whose love and attraction transcend these boundaries often face misunderstanding, erasure, and systemic discrimination. Why do some people experience attraction to multiple

genders while others align with more traditional, binary patterns? The answers lie in the richness of lived experience and the intricate processes of brain development throughout the lifespan.

Bisexuality, defined as the capacity for emotional, romantic, and/or sexual attraction to more than one gender, represents a profound challenge to simplistic notions of sexual orientation. Rather than existing as a mere midpoint on a linear spectrum between heterosexuality and homosexuality, bisexuality emerges as a distinct orientation with unique developmental pathways. Nevertheless, despite comprising a significant proportion of the LGBTQ+ community, bisexual individuals are often sidelined, facing both societal and scientific neglect (Luoto & Rantala, 2020; Rosario et al., 2006). This dual erasure highlights the urgency of exploring the developmental origins of bisexuality, not only to dismantle stereotypes but also to fill critical gaps in our understanding of human diversity. As a lens into the complexities of identity, bisexuality offers fertile ground for examining the interplay of biological, environmental, and experiential factors (Mustanski et al., 2002). This review situates bisexuality as an integral component of sexual diversity, aiming to uncover its developmental underpinnings by synthesizing findings across multiple scientific disciplines (Andreazza et al., 2014; Safron et al., 2017). Historically, research on sexual orientation has been disproportionately focused on heterosexuality and homosexuality, leaving bisexuality underrepresented in the scientific narrative. However, recent advances in neurodevelopmental, endocrinological, and neuroimaging methodologies provide unprecedented opportunities to explore the biological processes that shape bisexuality (Mustanski et al., 2002).

This paper focuses on two pivotal stages in human development—prenatal development and puberty—to examine the emergence of bisexual orientations. Drawing upon interdisciplinary evidence, it explores how prenatal hormone exposure, neuroplastic changes during adolescence, and the interaction of genetic, epigenetic, and environmental factors contribute to the complexity of bisexuality. This review enriches scientific discourse by addressing these dynamics and underscores the need for a broader societal acceptance of sexual diversity (López-Rodríguez & Orozco-Calderón, 2016). Understanding the neurodevelopmental pathways that shape bisexuality is not merely an academic pursuit—it holds profound implications for public discourse, policy, and inclusion. By illuminating the biological and developmental mechanisms underpinning this orientation, we can challenge reductive stereotypes, advance inclusivity, and foster greater empathy for the nuanced spectrum of human identity. Bisexuality, with its inherent fluidity and complexity, is a powerful reminder of the diversity inherent in human experience. This exploration seeks to honor that complexity, emphasizing that bisexuality is not an anomaly but a natural variation within the vast tapestry of human sexuality.

Prenatal Development

Prenatal development lays the groundwork for numerous aspects of human identity, including sexual orientation. During this critical period, genetic, hormonal, and epigenetic factors shape the brain's structure and function, setting the stage for later emotional, romantic, and sexual attractions (Andreazza et al., 2014; Luoto & Rantala, 2020). The prenatal hormonal theory suggests that fluctuations in sex hormones—such as androgens and estrogens—during sensitive developmental windows have profound and lasting effects on the organization of neural circuits that govern sexual behaviors and attraction (Hutchison & Hutchison, 1990; Luoto & Rantala, 2020). These fluctuations can potentially result in a diverse range of sexual orientations, including bisexuality, by creating unique patterns of neural connections that mediate attraction to multiple genders.

Hormonal Influences and Brain Morphology

Research into prenatal androgen exposure has been instrumental in deepening our understanding of sexual differentiation in the brain. Studies in nonhuman animal models, including rats and primates, have shown that alterations in androgen levels during gestation affect both reproductive

anatomy and a wide range of behaviors, such as mating, aggression, and parenting (Andreazza et al., 2014; Hutchison & Hutchison, 1990). For example, in one seminal study, female rodents exposed to elevated testosterone levels exhibited male-typical mating behaviors such as mounting, revealing the organizational impact of prenatal hormones on neural circuits related to sexual behavior—male rodents with reduced androgen exposure displayed feminized behaviors, which further underscore the plasticity of brain development and its responsiveness to hormonal environments. Although direct experimental manipulation in humans is impossible, indirect evidence from clinical populations and neuroimaging studies suggests that similar principles apply (Andreazza et al., 2014). For instance, individuals with congenital adrenal hyperplasia (CAH), a condition characterized by excessive prenatal androgen exposure, are more likely to exhibit nonheterosexual orientations, including bisexuality (Luoto & Rantala, 2020). These findings align with the proposals of Luoto and Rantala (2020), who suggest that prenatal hormone levels can contribute to brain structural and functional differences associated with attraction and reward processing. In particular, bisexual individuals often exhibit unique patterns of brain connectivity, particularly in areas such as the prefrontal cortex (PFC) and ventral striatum (VS)—regions associated with decision-making, social behavior, and reward processing (Safron et al., 2017). Such findings suggest that bisexuality may not result from a binary process of neural masculinization or feminization but rather from the interplay between both pathways, producing a more complex and fluid brain network.

Epigenetics and Environmental Factors

Beyond genetic inheritance and hormonal influences, epigenetics—the study of heritable changes in gene expression without alterations to the DNA sequence—adds another layer of complexity to the prenatal development of sexual orientation. Even among individuals with identical genetic material, such as monozygotic twins, differences in prenatal environments can lead to divergent sexual orientations (Andreazza et al., 2014; Långström et al., 2010). A study by Andreazza et al. (2014) revealed that monozygotic male twins discordant for sexual orientation showed structural and functional differences in brain regions involved in sexuality, identity, and emotional processing, such as the amygdala and insula. These differences illustrate how subtle environmental variations during prenatal development can have lasting impacts on sexual orientation. Environmental factors, including maternal stress, diet, and exposure to toxins during pregnancy, also contribute to the variability of prenatal environments. Maternal stress, for example, has been shown to influence fetal hormone levels, potentially altering sexual differentiation processes. Stress-induced changes in cortisol, a glucocorticoid hormone, may disrupt typical androgen activity in male fetuses or elevate androgen activity in female fetuses, thereby skewing sexual differentiation and influencing later sexual preferences (Money, 1990). Furthermore, factors such as placental blood flow and nutrient delivery can create microenvironments that impact gene expression and neural organization, ultimately shaping sexual orientation. These findings underscore the profound impact of prenatal environments on sexual development and the complex interplay between biological and environmental factors.

Expanding the Role of Sex Hormones

In addition to their direct effects on brain structure, prenatal sex hormones also influence the development of neural circuits that govern attraction and sexual behavior through indirect mechanisms. For instance, sex hormones regulate the growth and connectivity of white matter tracts, facilitating communication between different brain regions. Variations in white matter organization could help explain the differences in how bisexual individuals process and respond to social and sexual stimuli compared to their heterosexual or homosexual counterparts. Safron et al. (2017) found evidence of differentiated incentive motivation in the ventral striatum (VS) among bisexual males, suggesting that prenatal hormone exposure may uniquely shape the integration of reward-related information.

Synthesis

The prenatal period represents a dynamic and multifactorial convergence of biological, environmental, and genetic forces that collectively shape sexual orientation. In particular, bisexuality appears to emerge from diverse and intricate developmental pathways, marked by unique interactions between hormonal fluctuations, brain structure, and environmental influences. These interactions reveal that the emergence of bisexuality is not a linear process but rather a nuanced and complex convergence of biological influences that highlight the diversity of human sexual identity. Continued research into these developmental mechanisms is essential to unravel the myriad contributions of prenatal development to sexual diversity and to understand bisexuality as a legitimate and integral part of human sexuality.

Puberal Development

Puberty represents a critical period of neurobiological reorganization, during which hormonal changes and brain maturation converge to shape sexual and social behaviors. During this time, the brain undergoes significant structural and functional changes that provide a foundation for the development of sexual orientation. For bisexual individuals, puberty offers a unique lens through which to explore how hormonal, social, and environmental factors interact to refine and expand patterns of attraction. This stage of development presents a key window for understanding the biological, social, and environmental influences that contribute to the complexity of bisexuality.

Hormonal Surges and Brain Plasticity

The hormonal fluctuations typical of puberty play a central role in the maturation of brain circuits that govern social and sexual behaviors. Estrogen and testosterone levels surge during adolescence, driving the development of secondary sexual characteristics and influencing neural pathways involved in attraction (Hutchison & Hutchison, 1990; Sisk & Foster, 2004). These hormonal surges are thought to refine connectivity and function in areas such as the PFC and VS. In bisexual individuals, the effects of pubertal hormones may reflect a balance between masculinizing and feminizing influences in the brain. This could result in a hormonal profile that supports a broader and more fluid range of attractions, diverging from the rigid patterns seen in heterosexual or homosexual individuals. Safron et al. (2017) demonstrated that bisexual males exhibit distinct patterns of incentive motivation in response to erotic stimuli, reflecting unique interactions between pubertal hormones and the brain's reward system. These findings suggest that bisexuality may involve a more flexible or fluctuating hormonal response during adolescence, which aligns with the fluidity often associated with bisexual orientations. Pubertal hormones might not only shape attraction in terms of sexual behavior but also enhance sensitivity to a wider range of stimuli, allowing for a broader spectrum of attractions across different genders (Hines, 2011).

Structural and Functional Brain Changes

During puberty, key brain regions undergo substantial reorganization, particularly in the PFC and limbic system, which play pivotal roles in social and emotional processing. The PFC, responsible for executive functions such as decision-making, self-regulation, and social reasoning, undergoes significant maturation during adolescence. Simultaneously, the limbic system—comprising areas like the amygdala and hippocampus—becomes increasingly responsive to environmental stimuli, including peer interactions and societal norms (Sisk & Foster, 2004). López-Rodríguez and Orozco-Calderón (2016) highlighted that bisexual individuals often exhibit unique patterns of brain connectivity, particularly in the frontal lobe (FL) and PFC. These areas are essential for regulating sexual and romantic behaviors. By comparing the neural activity of bisexual individuals with that of heterosexual and homosexual peers, it becomes evident that these brain regions play an integral role in the way bisexual individuals process and interpret sexual cues, allowing them to respond to male- and female-related stimuli in a more nuanced way (Dodge et al., 2007). These findings point to how neuroplasticity during puberty allows bisexual

individuals to navigate and integrate their attraction across diverse social contexts (Bao & Swaab, 2011; Ngun et al., 2011). The maturation of white matter tracts during this time also enhances communication between different brain regions, which may facilitate more complex processing of sexual attraction and desire.

Environmental and Social Influences

While biological factors such as hormonal changes and brain maturation are central to pubertal development, environmental and social factors also play a significant role in shaping sexual orientation. Adolescence is a period marked by heightened sensitivity to societal expectations, peer dynamics, and cultural influences, which can significantly modulate the development of bisexuality. The interaction between these social pressures and biological predispositions can either reinforce or suppress bisexual attraction. For instance, Andreazza et al. (2014) noted that epigenetic changes—such as DNA methylation influenced by stress or social experiences—can modify the effects of pubertal hormones. Cultural and social factors can, therefore, influence sexual orientation by either facilitating or constraining self-expression. A supportive and diverse social environment during adolescence may encourage the exploration of bisexuality, while societal pressure to conform to binary identities could suppress it. Luoto and Rantala (2020) further suggested that variations in pubertal hormone levels, when combined with social and cultural influences, may contribute to the expression of bisexual behaviors, particularly in women. As such, cultural norms often interact with biological processes during puberty, either amplifying or suppressing the development of bisexual orientations. This complex intersection of biology and culture further underscores the multifaceted nature of bisexual identity (Herek, 2002).

Integration of Earlier Developmental Influences

Puberty does not occur in isolation from earlier developmental influences; instead, it integrates and builds upon the foundations established during the prenatal period. Puberty serves as a critical juncture where the early hormonal, structural, and epigenetic influences of prenatal development are refined and expanded by adolescence's hormonal and social dynamics. For example, if an individual experiences atypical hormonal exposures during prenatal development, such as heightened or reduced androgen levels, these early influences may shape how the brain responds to the hormonal surges of puberty (Hutchison & Hutchison, 1990; Money, 1990). As a result, the integration of prenatal and pubertal experiences could result in a more fluid or complex sexual attraction profile, as seen in bisexual individuals (Ellis & Ames, 1987; Rahman & Wilson, 2003).

Puberty as a Period of Sexual Identity Exploration

Puberty is also a time of exploration and self-discovery regarding sexual identity. For many adolescents, the period of puberty serves as a key developmental stage for recognizing and experimenting with sexual orientation, including the potential for bisexual attraction. The increased sensitivity to social and emotional cues during this time can influence the exploration of romantic and sexual relationships. During this period, individuals may experiment with relationships or develop attraction to individuals of multiple genders, solidifying the understanding of bisexuality as a valid and authentic sexual orientation. Studies such as those by Rosario et al. (2006) have shown that adolescents who report fluid sexual preferences—attraction to individuals of different genders—during puberty are more likely to identify as bisexual in adulthood. This phase of exploration highlights the role of puberty as a critical time for recognizing the potential fluidity in sexual orientation, providing insight into the diversity of human sexual identities (Diamond, 2008).

Synthesis

Puberty serves as a critical phase in the development of sexual orientation, including bisexuality. During this period, hormonal surges, structural brain changes, and social influences intersect to refine the neural circuits that govern attraction and sexual behavior. The interplay between biological factors such as hormones, neural plasticity, and

environmental influences creates a developmental environment that can allow for the expression of bisexuality, often resulting from a complex and fluid interaction of multiple pathways. The dynamic nature of puberty also highlights the importance of both early biological influences and adolescent experiences in shaping sexual identity. For bisexual individuals, the period of puberty represents a juncture where early neurodevelopmental processes converge with the exploration of sexual and romantic attraction. This allows for a broader spectrum of sexual identities driven by the flexibility and adaptability of both the brain and the social environment.

Conclusion

The exploration of bisexuality through the lenses of prenatal and pubertal development reveals that sexual orientation is shaped by a complex interaction of genetic, hormonal, epigenetic, and environmental factors. By focusing on these critical developmental windows, we gain a deeper understanding of how bisexuality emerges—not as a deviation from a binary framework but as a natural, multifaceted variation of human sexuality. The evidence presented in this review suggests that bisexuality, far from being a fixed or easily categorized phenomenon, emerges from a dynamic and fluid interplay of biological and social influences.

Prenatal development lays the foundational groundwork for sexual orientation through hormonal exposure and neural organization. The prenatal hormonal theory suggests that fluctuations in sex hormones such as androgens and estrogens have lasting impacts on the brain's structure and function, influencing sexual attraction in ways that can result in a bisexual orientation. These early developmental processes, further shaped by genetic and environmental factors, establish the neural circuits that govern sexual and romantic attraction. As we have seen, individuals with conditions such as congenital adrenal hyperplasia (CAH) often exhibit nonheterosexual orientations, providing compelling evidence that prenatal hormone levels influence sexual attraction and behavior.

Puberty, as a period of profound neurobiological reorganization, acts as a critical juncture where the earlier hormonal influences of prenatal development converge with the hormonal surges of adolescence. The maturation of brain regions such as the prefrontal cortex and the ventral striatum during puberty refines the brain's ability to process sexual and social cues. For bisexual individuals, this process appears to be marked by a flexible, nuanced response to attraction, as evidenced by distinct patterns of brain connectivity. This development phase allows for the exploration and expression of a broader range of sexual orientations, reflecting a more fluid understanding of sexual identity. Additionally, the interaction of pubertal hormones with social and environmental influences further complicates the development of bisexuality, as societal norms and cultural expectations can either support or constrain this self-exploration. Together, the prenatal and pubertal stages highlight the complexity of bisexuality, suggesting that sexual orientation is not a simple, linear process but a dynamic, multifactorial phenomenon. It is shaped by a convergence of biological, environmental, and social factors that influence an individual's capacity for attraction to multiple genders. As society continues to evolve, so too must our understanding of sexual orientation, recognizing that bisexuality is not an anomaly or a transitional phase but a valid and integral part of human sexual diversity.

This review underscores the importance of expanding our research and discourse to include bisexuality as a legitimate and central aspect of human sexuality. The scientific community must continue to investigate the developmental pathways that contribute to bisexuality, integrating findings from neurodevelopmental, endocrinological, and psychological research. Moreover, societal acceptance and inclusivity must be prioritized to ensure that bisexual individuals are not marginalized or erased from the narrative. Research into the biological and developmental mechanisms of bisexuality has the potential to not only deepen our understanding of human sexuality but also to

challenge long-standing stereotypes and promote a culture of acceptance and empathy.

We call upon researchers, policymakers, and advocates to prioritize bisexuality in future studies and discussions surrounding sexual orientation. By embracing the complexity and fluidity of human sexuality, we can foster an environment that celebrates diversity, encourages self-exploration, and supports the well-being of individuals across the sexual orientation spectrum. It is only through continued research, open dialogue, and societal acceptance that we can ensure bisexuality is understood and respected as a valid, natural aspect of human identity.

Cross-References

- ▶ Androgens: Prenatal Influences on Bisexuality
- ▶ Bisexuality in Females: Prenatal Estrogen-Testosterone Hypothesis
- ▶ Bisexuality in Males: Postnatal and Prenatal Influences
- ▶ Callosal Theory, Prenatal Influences on Bisexuality
- ▶ Hypothalamus and Bisexuality
- ▶ Neurodevelopmental Processes: Bisexuality
- ▶ Neuroendocrine Correlates: Prenatal Influences on Bisexuality
- ▶ Sexual Arousal: Bisexual Orientation in Males

Competing Interest Declaration The author(s) has no competing interests to declare that are relevant to the content of this manuscript.

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