

**Dose-Dependent Effects of Neonatal Alcohol Exposure on Neuron Number in the
Cerebellum Using a Rat Model of Fetal Alcohol Spectrum Disorder**

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Abstract

Fetal Alcohol Spectrum Disorder (FASD) refers to a range of physical, cognitive, behavioral, and developmental abnormalities that result from prenatal exposure to alcohol. This paper examined the current scientific understanding of FASD by reviewing its causes, biological effects, diagnosis, treatments, and future directions for research while also investigating the effects of neonatal alcohol exposure on cerebellar neuron number using a Long-Evans rat model. Eight rats were assigned to sham, low-dose alcohol (E9.06), or high-dose alcohol (E11.9) treatment groups. Following perfusion, cerebellar tissue was carefully extracted and sectioned into thin slices, stained with cresyl violet, and analyzed using the optical fractionator stereological method to estimate the number of neurons in the Purkinje cell layer and interpositus nucleus (IPN). The experimental findings demonstrated how increasing levels of alcohol exposure were associated with the dose-dependent reduction in neuron number in both cerebellar regions, with the high-dose alcohol group exhibiting the greatest neuronal loss. These findings are consistent with previous research showing that alcohol exposure during critical periods of brain development disrupts normal neuronal development and contributes to lifelong neurological impairments. Continued research is needed to further understand the underlying biological processes involved in FASD and support the development of better diagnostic methods, treatments, and prevention strategies.

1. Introduction

Fetal Alcohol Spectrum Disorder (FASD) is an umbrella term that describes a group of lifelong developmental conditions caused by prenatal alcohol exposure (Centers for Disease Control and Prevention). FASD develops when alcohol consumed by the pregnant individual crosses the placenta, exposing the developing fetus to alcohol and disrupting normal brain and organ development. Because alcohol can interfere with normal fetal growth throughout pregnancy, individuals with FASD often experience a wide range of physical, cognitive, and behavioral impairments (Bradley et al.). These impairments can affect learning, memory, attention, and daily functioning (Centers for Disease Control and Prevention). As a result, prenatal alcohol exposure is known to be a major preventable cause of birth defects and long-term neurodevelopmental impairments, making FASD an important public health concern (Roozen et al.). Research on prenatal alcohol exposure has helped shape public health recommendations by providing scientific evidence to inform guidelines that encourage avoiding alcohol consumption during pregnancy.

FASD is a global public health concern that affects children worldwide. Lange et al. estimated that FASD affects approximately 7.7 per 1000 children and youth globally, with prevalence varying by region. According to the Centers for Disease Control and Prevention, about 1% to 5% of first graders in the United States have FASD.

Understanding how alcohol affects fetal development helps explain why FASD remains a significant public health concern. Alcohol use during pregnancy can be harmful and, in some cases, even fatal. Consumption of alcohol during this time increases the chances of miscarriage, stillbirth, preterm birth, and sudden infant death syndrome (SIDS) (Centers for Disease Control

and Prevention). The placenta is a temporary organ that forms in the womb during pregnancy to provide the developing baby with nutrients and oxygen (Mayo Clinic). During pregnancy, the alcohol consumed by the mother crosses the placenta, exposing the fetus to alcohol and affecting its development. Unlike adults, however, a developing fetus does not yet have fully developed enzyme systems to metabolize alcohol efficiently. In adults, alcohol is broken down in the liver through the use of 2 enzymes called alcohol dehydrogenase (ADH) and aldehyde dehydrogenase (ALDH), but these enzymes are not yet fully developed in the fetus (National Institute on Alcohol Abuse and Alcoholism). Although alcohol exposure during the first trimester is strongly associated with abnormal facial features, low birthweight, and behavioral problems, the fetal brain continues to develop throughout pregnancy and can be harmed by alcohol exposure at any stage (Centers for Disease Control and Prevention).

Studying FASD is especially important because it is a common and preventable group of conditions that can cause lifelong physical, cognitive, and behavioral impairments. Individuals with FASD often experience learning challenges, such as poor memory, intellectual disabilities, lower IQ, and difficulty in mathematics and other academic skills (Centers for Disease Control and Prevention). These long-term health challenges require ongoing medical care, specialized therapies, and educational support, contributing to increased healthcare spending over an individual's lifetime. Continued research is essential to improve early diagnosis, develop more effective treatments, and strengthen prevention efforts.

This research paper examines the current scientific understanding of Fetal Alcohol Spectrum Disorder. It reviews existing scientific literature on the causes, biological effects, diagnosis, treatment, and future directions for research while also investigating the effects of neonatal alcohol exposure on the brain using Long-Evans postnatal rats. The experimental

component of this study compares cerebellar tissue from rats with neonatal alcohol exposure to that of a control group to evaluate differences in cerebellar structure and neuron number by focusing on the Purkinje cell layer as well as the interpositus nucleus (IPN). Postnatal rats were utilized to model the human third trimester of brain development. The methods and results from this investigation will be presented in later sections of this paper.

2. Literature Review

Before Fetal Alcohol Syndrome (FAS) was formally recognized, the harmful effects of alcohol consumption during pregnancy were not yet fully understood. Until the early 1970s, researchers could not establish a clear link between prenatal alcohol exposure and a specific pattern of birth defects. In 1973, Jones et al. published the first description of Fetal Alcohol Syndrome (FAS). This publication was groundbreaking because it established FAS as a distinct medical condition and prompted further research on prenatal alcohol exposure. As research progressed, the NIAAA issued government health advisories to limit alcohol use during pregnancy and helped fund research on FASD (National Institute on Alcohol Abuse and Alcoholism).

Fetal Alcohol Spectrum Disorder (FASD) refers to a group of lifelong conditions caused by prenatal alcohol exposure that affect the brain and body, leading to a range of physical, behavioral, and cognitive challenges. As research expanded, the umbrella term FASD was adopted to encompass Fetal Alcohol Syndrome (FAS), Partial Fetal Alcohol Syndrome (pFAS), Alcohol-Related Neurodevelopmental Disorder (ARND), and Alcohol-Related Birth Defects (ARBD) (Williams and Smith). FAS represents the most severe form of FASD. Individuals with FAS usually experience challenges with their Central Nervous System (CNS), distinctive facial features, and growth delays. They may also struggle with learning, memory, attention, communication, vision, or hearing, often showing a combination of these difficulties. pFAS is diagnosed when an individual doesn't meet the full diagnostic criteria for FAS, but has been exposed to alcohol before birth and exhibits some of the characteristics associated with FAS. Individuals with ARND typically have problems with behavior and learning, as well as

intellectual disabilities. They may also experience difficulties with memory, attention, judgment, impulse control, and academic performance. Individuals with ARBD are likely to experience abnormalities with their heart, kidneys, bones, or hearing (Centers for Disease Control and Prevention). Researchers realized that prenatal alcohol exposure caused a wide range of physical, behavioral, cognitive, and emotional effects, which did not meet the full diagnosis for FAS. As pFAS, ARND, and ARBD were also discovered after FAS, the term FASD was adopted to include the full range of conditions caused by alcohol use during pregnancy (Williams and Smith).

FASD occurs when an individual is exposed to alcohol before birth. When a mother consumes alcohol during pregnancy, the alcohol enters her bloodstream and travels to the placenta. The umbilical cord connects the fetus to the placenta, where an interstitial space allows nutrients, oxygen, and waste products to be exchanged between the maternal and fetal blood supplies. Because alcohol molecules are small, they can easily diffuse from the maternal blood to the fetal blood through that interstitial space of the placenta (The Alcohol Pharmacology Education Partnership). There is no known safe amount or safe time to drink during pregnancy because the baby's brain develops continuously. However, research has demonstrated that alcohol use during the first trimester is directly linked to abnormal facial features, low birthweight, and behavioral problems. Overall, it is important to acknowledge that any amount of alcohol has the potential to disrupt fetal development and increase the chances of lifelong physical, cognitive, and behavioral impairments (Centers for Disease Control and Prevention).

In addition to affecting physical growth and behavior, FASD causes a wide range of biological effects, including brain development, oxidative stress, neuroinflammation, apoptosis, and damage to different brain regions. Prenatal alcohol exposure impacts neurodevelopment

through diverse mechanisms. Neuroimaging has revealed abnormal brain structure, cortical development, white matter microstructure, and functional connectivity. These abnormalities contribute to problems such as deficits in cognition, executive function, memory, vision, motor skills, behavior, and social adaptation (Wozniak et al.).

Additionally, prenatal alcohol exposure causes a significant increase in oxidative stress. Oxidative stress occurs when the production of reactive oxygen species exceeds the body's antioxidant defenses, leading to cellular damage and contributing to aging and various diseases. Ethanol exposure leads to the creation of Reactive Oxygen Species (ROS), which produces an imbalance in the intracellular redox state. This imbalance ultimately results in oxidative stress, contributing to neuronal damage and impaired brain development (Brocardo et al.).

Furthermore, FASD causes severe neuroinflammation as well as cell apoptosis. While the molecular basis is still not fully understood, ethanol's neurotoxic impact and resulting neuronal loss likely underlie the remaining pathological mechanisms. Throughout pregnancy, the baby's CNS is continuously developing, which means any exposure to ethanol can induce neuronal apoptosis and reduce neuron number in the developing brain (Zeng et al.).

Many studies have shown that FASD significantly affects specific brain regions, such as the cerebellum, hippocampus, and frontal lobe. Due to prenatal alcohol exposure, all three brain regions are reported to be smaller in volume in individuals with FASD compared with those who are unaffected. The cerebellar vermis is the structure between the right and left hemispheres of the cerebellum. This cerebellar vermis is shown to be abnormal in size and location in individuals with FASD. Because the hippocampus is involved with memory, those with FASD are known to have worse memory than those unaffected due to prenatal alcohol exposure significantly impacting the hippocampus. Similar to the cerebellum and hippocampus, the frontal

lobe was shown to be disproportionately smaller in children with FAS/pFAS than children without them. Because the frontal lobe plays an important role in decision making, individuals with FASD are prone to engage in more problematic and risky behavior (Center for Substance Abuse Prevention). Collectively, these findings demonstrate that FASD negatively impacts brain development through multiple biological mechanisms, including oxidative stress, neuroinflammation, apoptosis, and structural abnormalities in specific brain regions.

When an individual is diagnosed, they are diagnosed with one of the specific conditions within the FASD spectrum. The diagnostic criteria for FAS and pFAS include characteristic facial features, growth deficiencies, and neurobehavioral impairments. To diagnose ARND, there must be significant evidence of severe brain dysfunction. For ARBD, at least one congenital abnormality is required for diagnosis, which is possibly in the cardiac, skeletal, renal, ocular, auditory, or other area (Center for Substance Abuse Prevention). Diagnosing a condition within the FASD spectrum can be challenging, because there is no medical test that can be taken specifically for this diagnosis. Instead, physicians evaluate prenatal alcohol exposure, central nervous system problems (both physical features and behavioral problems), lower than average height and/or weight, and abnormal facial features. Oftentimes, these symptoms may not be clearly visible until later on in an individual's lifetime, which is why many get diagnosed much later (Centers for Disease Control and Prevention).

For individuals with FASD, there are a variety of treatments and services available, including behavioral therapy, occupational therapy, and speech-language therapy to improve communication, daily living skills, and social functioning. Although there is no medication to treat FASD itself, medications may be prescribed to help manage associated symptoms (National Institute on Alcohol Abuse and Alcoholism). Early intervention for children up to the age of 3

years old can help them learn important skills. These services help affected children develop skills, such as walking, talking, and interacting with others. Since one of the effects of FASD is poor academic performance in some children, there are special educational services offered to tailor instruction towards their own specific needs and learning style. In addition to professional treatment, a loving and stable home environment is very important for children with FASD because it can help improve their long-term development and overall well-being (Centers for Disease Control and Prevention). Collectively, these treatments aim to improve the quality of life and help individuals with FASD reach their full potential despite the absence of a cure.

3. Methods

This study used a rat model to investigate the dose-dependent effects of neonatal alcohol exposure on neuron number in the cerebellum. Eight Long-Evans rats (six males, two females) were used in this study. Animals were maintained on a standard light/dark cycle and had unrestricted access to food and water throughout the study. During the early postnatal period (postnatal days 4-9), the pups were assigned to one of three treatment groups: high-dose alcohol group (5.25 g/kg/day (E11.9 = 11.9% v/v)), low-dose alcohol group (4 g/kg/day (E9.06 = 9.06% v/v)), or a sham control group that received no alcohol. Alcohol was administered through intragastric intubation during this early postnatal period, which corresponds to the human third trimester of brain development, a period of rapid brain growth and particular vulnerability to alcohol exposure. This neonatal rat model is widely used to study the effects of alcohol exposure during late fetal brain development. The control group was used to provide a basis for comparison with normal cerebellar development.

After the rats reached the appropriate age, they were deeply anesthetized with isoflurane before tissue collection. A left ventricular cardiac perfusion was then performed to preserve the brain tissue for microscopic analysis. During perfusion, saline was first perfused through the circulatory system to remove blood from the tissues. This was then followed by a fixative solution containing 3% paraformaldehyde and 1.25% glutaraldehyde in 0.2 M phosphate buffer for 15 minutes. Following perfusion, the brains were carefully removed from each skull. Each brain was then dissected into the cerebrum, cerebellum, and brain stem. The cerebrum and brain stem were placed in vials with fixative solution, while the cerebellum was stored separately.

To prepare the cerebellar tissue for microscopic analysis, it was dehydrated through a graded ethanol series (70% for 2 hours, 95% for 1.5 hours, 95% for 2 hours, and 100% for 17 hours). The cerebellum was then infiltrated with graded mixtures of ethanol and infiltration solution (2.5 I.S. / 7.5 EtOH for 24 hours, 50 I.S. / 50 EtOH for 19 hours, 75 I.S. / 25 EtOH for 24 hours, 100% I.S. for 24 hours, and 100% I.S for another 48 hours). Following infiltration, the tissue was embedded in glycol methacrylate resin. The resin blocks were heated until fully hardened, providing sufficient support for thin sectioning.

After embedding, the resin blocks were sectioned into thin slices using a microtome equipped with glass blades. The tissue sections were then stained with cresyl violet, a Nissl stain used to visualize neuronal cell bodies. The stained sections were then examined under a microscope.

Using the optical fractionator method, an unbiased stereological technique, quantitative analysis was conducted to estimate neuron number. Particular attention was given to the Purkinje cell layer and the interpositus nucleus of the cerebellum. These structures were examined to evaluate dose-dependent differences in neuron number and other structural changes associated with neonatal alcohol exposure.

4. Results / Findings

The effects of neonatal alcohol exposure were evaluated by comparing the Purkinje cell layer and the interpositus nucleus among the sham, E9.06, and E11.9 treatment groups. In the sham group, pups were intubated, but no alcohol was given. In the E9.06 group, pups were given 9.06% of alcohol by volume (4 g/kg/day), whereas the pups in the E11.9 group received 11.9% of alcohol by volume (5.25 g/kg/day).

Figure 1

Average Purkinje Cell Count in the Sham, E9.06, and E11.9 Treatment Groups

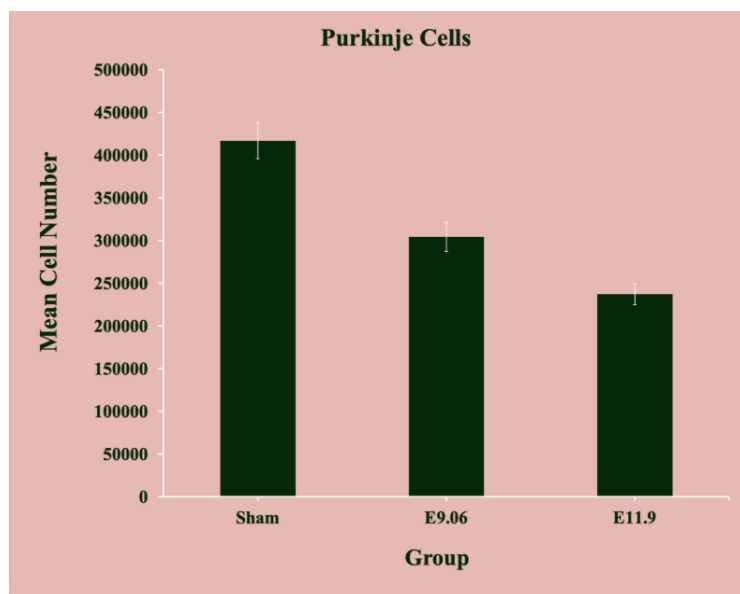


Figure 1 shows the average number of Purkinje cells in each treatment group. The sham group had approximately 400,000 Purkinje cells, the E9.06 group had about 300,000 Purkinje cells, and the E11.9 group had the lowest average of around 250,000 Purkinje cells. As shown in Figure 1, the average number of Purkinje cells decreased as alcohol exposure increased.

Figure 2

Average Interpositus Nucleus Neuron Count in the Sham, E9.06, and E11.9 Treatment Groups

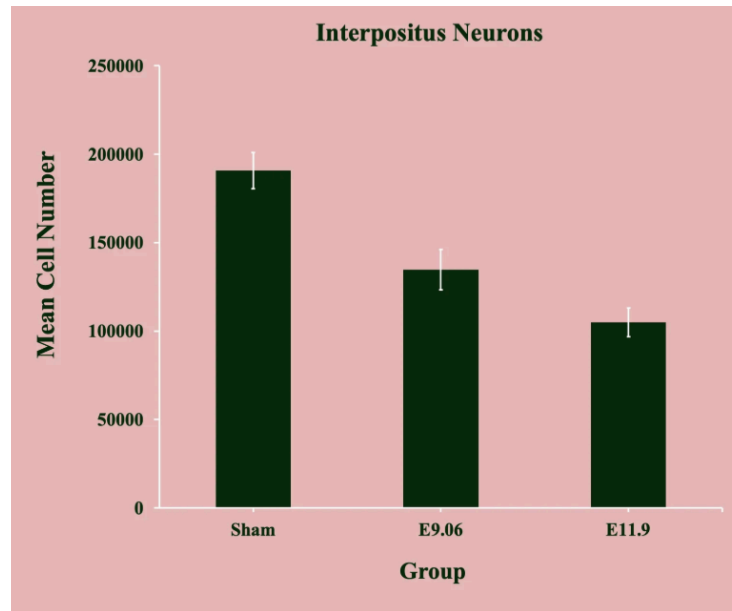


Figure 2 shows a similar pattern in the interpositus nucleus. The sham group had about 200,000 neurons, the E9.06 group had approximately 150,000 neurons, and the E11.9 group once again had the lowest average of around 100,000 neurons. Similar to the Purkinje cell count, increasing alcohol exposure was associated with a decrease in interpositus nucleus neuron number.

Both the Purkinje cell layer and the interpositus nucleus demonstrated a dose-dependent reduction in neuron number following neonatal alcohol exposure. The sham group consistently had the highest neuron number, whereas the E11.9 group always had the lowest. These findings support the hypothesis that increasing levels of neonatal alcohol exposure are associated with reduced neuronal numbers in the cerebellum.

5. Discussion

This study investigated the dose-dependent effects of neonatal alcohol exposure on cerebellar neuron number using a Long-Evans rat model. The results demonstrated that neonatal alcohol exposure (equivalent to the third trimester of human brain development) was associated with reduced neuronal numbers in both the Purkinje cell layer and the interpositus nucleus in the cerebellum. Both alcohol-exposed groups showed lower neuron number than the sham control group, with the E11.9 group being the lowest. These findings support the hypothesis that increased alcohol exposure during a crucial period of brain development contributes to structural changes in the cerebellum and reduction in neuronal numbers.

These findings of this study are consistent with findings from previous research, demonstrating that prenatal alcohol exposure negatively affects the cerebellum. Individuals with FASD often develop abnormalities, including reduced cerebellar volume or differences in the cerebellar vermis (Center for Substance Abuse Prevention). Using neonatal rats to model the human third trimester, this study found that alcohol exposure during rapid brain development can disrupt normal neuronal development. The neurological impairments in individuals with FASD may be partially explained by the observed decrease in Purkinje cells and neurons in the interpositus nucleus.

Purkinje cells are the primary output neurons of the cerebellar cortex that regulate communication between the cerebellum and other parts of the brain, including the brain stem, thalamus, and cerebral cortex. These cells are essential for motor coordination, balance, and motor learning. A reduction in Purkinje cells can significantly interfere with normal cerebellar function, which can contribute to some of the motor and cognitive challenges found in FASD

patients (Machado Filho et al.). Similarly, the interpositus nucleus is also an important structure deep within the cerebellum that is crucial for regulating motor coordination and motor learning. Reduced neuron number in the interpositus nucleus may cause further disruption of cerebellar function and neurological impairments in individuals with FASD (Jiménez-Díaz et al.).

Previous research has shown that prenatal alcohol exposure increases oxidative stress, neuroinflammation, and cell apoptosis, all of which contribute to the disruption of normal brain development and reduced neuron survival (Zeng et al.). During early brain development, neurons go through a series of processes: proliferation, migration, differentiation, and synaptogenesis (establishing connections). Alcohol exposure can disrupt these processes, resulting in long-term functional and structural abnormalities in the brain (Grose-Fifer). The observed reduction in neuron number supports previous findings that alcohol exposure can interfere with normal brain development processes through many biological pathways.

6. Future Directions

While this study has contributed to a deeper understanding of how neonatal alcohol exposure affects cerebellar development in rats, additional research is needed to further explore the underlying mechanisms involved in Fetal Alcohol Spectrum Disorder. Future studies should continue investigating the biological processes contributing to FASD and developing more effective approaches for diagnosis, treatment, and prevention.

Since this study focuses entirely on how neonatal alcohol exposure affects the cerebellum, future studies would benefit from examining additional brain regions, such as the hippocampus and prefrontal cortex. This is supported by previous research from Lebel et al., which found that individuals with FASD had significantly reduced hippocampal volume compared with control groups. In addition, Astley et al. found similar results in the frontal lobe, where children with FASD had reduced frontal lobe volume compared with individuals without prenatal alcohol exposure. Together, these studies highlight the importance of investigating additional brain regions to develop a more comprehensive understanding of the widespread neurological effects of prenatal alcohol exposure.

Although previous studies have identified structural changes in the brains of individuals with FASD, additional research is required to better understand the cellular and molecular mechanisms responsible for these abnormalities and impairments. Studying processes such as oxidative stress, neuroinflammation, and neuronal apoptosis would help explain how prenatal alcohol exposure contributes to long-term neurological impairments and disrupts normal brain development. According to Zeng et al., prenatal alcohol exposure increases oxidative stress and promotes neuroinflammation. These processes ultimately lead to neuronal apoptosis (cell death)

and reduced neuron number in the developing brain. Therefore, further investigation of these cellular mechanisms could provide valuable insight into how prenatal alcohol exposure damages the developing brain and contributes to the long-term effects of FASD.

Future research should not only aim to better understand FASD, but also focus on improving methods for early diagnosis. Early diagnosis would allow children to receive appropriate medical care, educational support, and therapeutic interventions sooner, potentially improving long-term outcomes. Continued research may also contribute to the development of more effective treatments that reduce the severity of cognitive, physical, and behavioral impairments associated with prenatal alcohol exposure.

Because FASD is preventable, future research should continue to evaluate public health education techniques, prenatal counseling programs, and other strategies that promote avoiding alcohol use during pregnancy. Strengthening prevention has the potential to reduce the number of children affected by FASD and lessen the long-term healthcare and educational burden associated with it.

7. Conclusion

Fetal Alcohol Spectrum Disorder (FASD) is a preventable developmental disorder that causes lifelong neurological, physical, cognitive, and behavioral impairments as a result of prenatal alcohol exposure. This paper reviewed current scientific literature describing the causes, biological effects, diagnosis, treatment, and future directions for FASD while also investigating the effects of neonatal alcohol exposure in Long-Evans rats. The experimental findings showed that increasing levels of alcohol exposure caused a greater reduction in the number of neurons in both the Purkinje cell layer and the interpositus nucleus of the cerebellum. These findings support previous research that revealed how alcohol exposure during critical periods of brain development causes lifelong structural and functional abnormalities. Collectively, the literature review and the experimental findings demonstrate the impact of alcohol exposure on the developing brain and further emphasize the importance of avoiding alcohol consumption during pregnancy. Continued research using animal models and clinical studies will provide a better understanding of the underlying biological processes involved in FASD while also helping to develop better diagnostic methods, treatments, and more proactive prevention strategies. Increasing public awareness and strengthening prevention efforts remain crucial to reduce the number of children affected by this entirely preventable disorder.

8. Works Cited

- Astley, Susan J., et al. "Magnetic Resonance Imaging Outcomes From a Comprehensive Magnetic Resonance Study of Children With Fetal Alcohol Spectrum Disorders." *Alcoholism: Clinical and Experimental Research*, vol. 33, no. 10, Oct. 2009, pp. 1671–89, <https://doi.org/10.1111/j.1530-0277.2009.01004.x>.
- Bradley, Regan, et al. "Fetal Alcohol Spectrum Disorder and Iron Homeostasis." *Nutrients*, vol. 14, no. 20, MDPI AG, Oct. 2022, p. 4223, <https://doi.org/10.3390/nu14204223>. Accessed 28 July 2026.
- Brocardo, Patricia S., et al. "The Role of Oxidative Stress in Fetal Alcohol Spectrum Disorders." *Brain Research Reviews*, vol. 67, no. 1–2, June 2011, pp. 209–25, <https://doi.org/10.1016/j.brainresrev.2011.02.001>.
- Centers for Disease Control and Prevention. "About Fetal Alcohol Spectrum Disorders (FASDs)." *Fetal Alcohol Spectrum Disorders*, 15 May 2024, <https://www.cdc.gov/fasd/about/index.html>. Accessed 28 July 2026.
- Centers for Disease Control and Prevention. "Treatment of FASDs." *Fetal Alcohol Spectrum Disorders*, 15 May 2024, <https://www.cdc.gov/fasd/treatment/index.html>. Accessed 28 July 2026.

Centers for Disease Control and Prevention. “About Alcohol Use During Pregnancy.” Alcohol and Pregnancy, 15 May 2024, <https://www.cdc.gov/alcohol-pregnancy/about/index.html>. Accessed 28 July 2026.

Center for Substance Abuse Prevention (US. “Literature Review.” Ncbibooks, Substance Abuse and Mental Health Services Administration (US), 2023, <https://www.ncbi.nlm.nih.gov/sites/books/nbk344235/>. Accessed 28 July 2026.

Grose-Fifer, Jill. “5.5: Stages of Neuronal Development.” Cuny.Edu, Pressbooks, 21 Aug. 2024, <https://pressbooks.cuny.edu/psy320/chapter/stages-of-neuronal-development/>. Accessed 28 July 2026.

Jiménez-Díaz, Lydia, et al. “Role of Cerebellar Interpositus Nucleus in the Genesis and Control of Reflex and Conditioned Eyelid Responses.” The Journal of Neuroscience, vol. 24, no. 41, Society for Neuroscience, Oct. 2004, pp. 9138–45, <https://doi.org/10.1523/jneurosci.2025-04.2004>. Accessed 28 July 2026.

Jones, Kenneth L., and David W. Smith. “Recognition of Fetal Alcohol Syndrome in Early Infancy.” The Lancet, vol. 302, no. 7836, Nov. 1973, pp. 999–1001, [https://doi.org/10.1016/s0140-6736\(73\)91092-1](https://doi.org/10.1016/s0140-6736(73)91092-1).

Lange, Shannon, et al. “Global Prevalence of Fetal Alcohol Spectrum Disorder Among Children and Youth.” JAMA Pediatrics, vol. 171, no. 10, Oct. 2017, p. 948,

<https://doi.org/10.1001/jamapediatrics.2017.1919>. Accessed 28 July 2026.

Lebel, Catherine, et al. “Imaging the Impact of Prenatal Alcohol Exposure on the Structure of the Developing Human Brain.” Neuropsychology Review, vol. 21, no. 2, Mar. 2011, pp.

102–18, <https://doi.org/10.1007/s11065-011-9163-0>.

Machado Filho, Silva, et al. “Neurophysiology of the Cerebellum and Clinical Correlations: A Review.” Arquivos de Neuro-Psiquiatria, vol. 83, no. 08, Thieme Medical Publishers

(Germany), Aug. 2025, pp. 001–08, <https://doi.org/10.1055/s-0045-1811623>.

Mayo Clinic. “Placenta: How It Works, What’s Normal.” Mayo Clinic, 2022,

<https://www.mayoclinic.org/healthy-lifestyle/pregnancy-week-by-week/in-depth/placenta/art-20044425>. Accessed 28 July 2026.

National Institute on Alcohol Abuse and Alcoholism. “Alcohol’s Effects on Health.”

Www.Niaaa.Nih.Gov, May 2022,

<https://www.niaaa.nih.gov/publications/alcohol-metabolism>. Accessed 28 July 2026.

National Institute on Alcohol Abuse and Alcoholism. “Fetal Alcohol Spectrum Disorders |

National Institute on Alcohol Abuse and Alcoholism (NIAAA).” Www.Niaaa.Nih.Gov,

2023, <https://www.niaaa.nih.gov/research/fetal-alcohol-spectrum-disorders>. Accessed 28 July 2026.

Roozen, Sylvia, et al. “Worldwide Prevalence of Fetal Alcohol Spectrum Disorders: A Systematic Literature Review Including Meta-Analysis.” *Alcoholism: Clinical and Experimental Research*, vol. 40, no. 1, Jan. 2016, pp. 18–32, <https://doi.org/10.1111/acer.12939>. Accessed 28 July 2026.

The Alcohol Pharmacology Education Partnership. “Content: How Does Alcohol Get to the Fetus? – The Alcohol Pharmacology Education Partnership.” Duke.Edu, 2019, <https://sites.duke.edu/apep/module-5-alcohol-and-babies/content-how-does-alcohol-get-to-the-fetus/>. Accessed 28 July 2026.

Williams, J. F., and V. C. Smith. “Fetal Alcohol Spectrum Disorders.” *Pediatrics*, vol. 136, no. 5, Oct. 2015, pp. e1395–406, <https://doi.org/10.1542/peds.2015-3113>. Accessed 28 July 2026.

Wozniak, Jeffrey R, et al. “Clinical Presentation, Diagnosis, and Management of Fetal Alcohol Spectrum Disorder.” *The Lancet Neurology*, vol. 18, no. 8, Aug. 2019, pp. 760–70, [https://doi.org/10.1016/S1474-4422\(19\)30150-4](https://doi.org/10.1016/S1474-4422(19)30150-4). Accessed 28 July 2026.

Zeng, Xingdong, et al. “An Overview of Current Advances in Perinatal Alcohol Exposure and Pathogenesis of Fetal Alcohol Spectrum Disorders.” *Journal of Neurodevelopmental*

Disorders, vol. 16, no. 1, BioMed Central, Apr. 2024,

<https://doi.org/10.1186/s11689-024-09537-w>.