Innovation in Health for Society

ISSN: 2798-7094

BIOMEDICAL INNOVATION

Submitted 24/12/2024
Revised 16/1/2025
Accepted 27/1/2025
Published 27/1/2025

Impact of Mozart music exposure on neuronal apoptosis in newborn *Rattus norvegicus*: a comparative study between light and dark conditions

Eka Nasrur Maulana, Mira Kusuma Wardhani

Author information
Department of Obstetrics and Gynecology, Universitas Wijaya Kusuma Surabaya, Indonesia

eka.nasrur@uwks.ac.id

https://doi.org/10.31603/ihs.12884

Abstract
Emerging evidence suggests that Mozart music can positively impact neurodevelopment, but whether the timing of exposure during light or dark periods affects its efficacy remains unexplored. This experimental study aimed to identify the optimal timing for Mozart music exposure—either 1 hour during the dark or 1 hour during the light period—starting from the 10th day of gestation in *Rattus norvegicus*, and its effect on neuronal apoptosis in newborn brain cells. Using a randomized post-test only control group design, *Rattus norvegicus* was employed as the model for Mozart music stimulation. A total of 24 pregnant rats were randomly divided into three groups: a control group (no music exposure), treatment group 1 (1 hour of Mozart music during the dark period), and treatment group 2 (1 hour of Mozart music during the light period), with 8 mother rats per group. After birth, the two heaviest female pups from each litter were selected, resulting in 15 pups per group. These pups were sacrificed, and their brain tissues were analyzed using the TUNEL assay under 1000x magnification to determine the neuronal apoptosis index. The study reported no miscarriages or maternal deaths across all groups. The mean apoptosis index was significantly lower in treatment group 1 (24.87 ± 3.45) and treatment group 2 (23.82 ± 3.89) compared to the control group (55.98 ± 4.12) ($p = 0.002$ and $p = 0.009$, respectively). However, no significant difference was observed between treatment group 1 and treatment group 2 ($p = 0.836$). The findings suggest that exposure to Mozart music significantly reduces neuronal apoptosis in the brains of newborn *Rattus norvegicus*, regardless of whether it is played during light or dark periods. This indicates that Mozart music can be utilized flexibly, offering potential implications for neurodevelopmental interventions.

Keywords: Biomedical innovation, brain cells, fundamental study, Mozart music, neurodevelopment

Introduction

The pursuit of optimizing children's cognitive potential is a common priority among parents. To achieve this goal, they often focus on providing nutritious food, stimulating environments, and appropriate educational opportunities (Puri et al., 2023; Taylor et al., 2016; Rehnberg et al., 2024). Intelligenceis the biopsychosocial potential to process information, which can be activated within a cultural context to solve problems or create beneficial products for society (Colom et al., 2010). This suggests that intelligence is not merely an innate ability but rather a dynamic trait shaped by genetic, biological, and environmental factors (Da Silveira et al., 2023). From a psycho neuroscientific and pre- and perinatal psychological perspective, intelligence is influenced by cognitive stimulation and the number of neurons, glial cells, dendrites, synapses, and the glia-to-neuron ratio (Goriounova et al., 2019). These components form the structural basis for optimal brain function and cognitive abilities, which can be influenced by various prenatal and postnatal interventions. One key strategy to enhance neuronal development is through nutritional intake, particularly DHA (docosahexaenoic acid), an essential omega-3 fatty acid that plays a critical role in brain development (Cusick et al., 2022). Another effective approach is stimulation, with auditory stimulation being one of the simplest yet most powerful methods. Studies emphasized that prenatal auditory stimulation (such as exposure to classical music) may promote synaptogenesis and enhance the connectivity between neurons and cognitive growth (Zaatar et al., 2023).

Given the rapid advancement of neuroscientific research, there is growing interest in identifying the specific mechanisms by which prenatal stimulation can enhance brain function and improve cognitive outcomes in children (Gualtieri et al., 2022). The human central nervous system (CNS) develops rapidly during pregnancy, with neuronal

IHS
ISSN: 2798-7094

proliferation and apoptosis (Leibovitz et al., 2022). The first two years of life represent a critical period for brain development, during which extensive neural connections are formed (Thomason et al., 2020). During the third trimester, the human brain undergoes an exponential increase in size, expanding five to six times compared to early pregnancy (Bouyssi-Kobar et al., 2016). Approximately the sixth month of gestation, the formation of new neurons in the fetal brain reaches completion, marking the transition from neuronal proliferation to functional maturation, myelination, and synaptic pruning **(Figure 1)**. These processes continue well into postnatal development, shaping an individual's cognitive abilities and neurological health (van Dyck et al., 2017). Once neuronal proliferation ceases, the remaining processes—neuronal maturation, synapse formation, and apoptosis regulation—become crucial in determining brain capacity. Apoptosis, or programmed cell death, is a natural mechanism that eliminates excess neurons and ensure efficient neural networks (Elmore, 2007). However, inhibiting excessive apoptosis become an attractive and often necessary therapeutic approach (Li et al., 2021). This underscores the importance of early interventions that regulate neuronal survival which could improve long-term brain function.

Figure 1. Illustration of human brain (Courtesy of www.neurospinesurgical.com).

A study further explained that the survival of neurons depends on the number of synapses (Bell & Hardingham, 2011). A greater number of dendritic connections allows for increased synaptic activity, which in turn reduces apoptosis and promotes neural plasticity. An investigation also highlighted the significant impact of environmental factors on neuronal survival as it demonstrates the stimulation of environments encourage synapse formation and reduce neuronal loss. Since the prenatal stage represents a critical window for neurodevelopment, providing sensory stimulation, particularly through auditory inputs, may serve as an effective intervention to enhance fetal brain development (Pino et al., 2023). Pregnancy, therefore, is a unique opportunity for parents to optimize brain development before birth. The potential for prenatal interventions, such as music therapy, to enhance neuronal survival and cognitive outcomes, has been a topic of increasing scientific interest (Partanen et al., 2013). A study emphasized that environmental stimulation during pregnancy not only influences brain growth but may also shape behavioral and cognitive traits later in life (Lubrano et al., 2024). With growing evidence supporting the role of auditory stimulation in neurodevelopment, researchers are now focusing on identifying the most effective condition for implementing such interventions. Previous study on prenatal Mozart music stimulation have shown promising results in promoting brain-derived neurotrophic factor (BDNF) production (Jenkins, 2001). BDNF is a key

IHS
ISSN: 2798-7094

protein that supports neuronal growth, differentiation, and survival. However, despite these findings, there is currently no standardized protocol to determine the optimal duration or conditions for prenatal music exposure. The effectiveness of light versus dark exposure in modulating neuronal apoptosis remains an area requiring further investigation.

To address this gap, the present study seeks to determine the optimal exposure duration of Mozart music by comparing 1-hour exposures in light and dark conditions. Using *Rattus norvegicus* as an experimental model, this research investigates the effects of prenatal Mozart music exposure starting from the 10th day of gestation on the neuronal apoptosis index in newborn rats. Assessing whether lighting conditions influence neuronal survival contribute to the development of evidence-based recommendations for prenatal music therapy. The experimental approach focuses on understanding the relationship between auditory stimulation and apoptosis regulation, which may have important implications for fetal brain development. If Mozart music exposure under specific lighting conditions is found to be significantly more effective in reducing apoptosis, it could provide valuable insights for designing prenatal stimulation programs for pregnant women. Furthermore, this research may serve as a foundation for future studies exploring music-based neurodevelopmental interventions for at-risk pregnancies and preterm infants. Investigating the timing and environmental conditions of prenatal music exposure support to the growing body of knowledge on fetal brain development. The findings may provide the integration of music-based interventions into prenatal care practices which generate non-invasive strategies to enhance cognitive potential before birth.

Method

This study was conducted at the Experimental Laboratory, Faculty of Medicine, Universitas Wijaya Kusuma Surabaya and Universitas Airlangga, from April to July 2024. The research employed an analytic experimental design using a randomized post-test-only control group design, with *Rattus norvegicus* serving as the experimental model for Mozart music stimulation. The study aimed to evaluate the effects of Mozart music exposure under different lighting conditions on neuronal apoptosis in newborn *Rattus norvegicus*. To ensure a systematic approach, the subjects were randomly divided into three groups, each consisting of fifteen *Rattus norvegicus*. These groups were subjected to different experimental conditions: one group was exposed to Mozart music for one hour under light conditions, another for one hour under dark conditions, and the control group received no music exposure. To facilitate the experimental process, superovulation was induced in the female *Rattus norvegicus* through hormonal stimulation **(Figure 2)**. Each subject received a 10 IU injection of Pregnant Mare Serum Gonadotropin (PMSG), followed by a 10 IU injection of Human Chorionic Gonadotropin (hCG) after 48 hours. This hormonal induction enhanced ovulation, increasing the likelihood of successful fertilization. Following hormone administration, monomating was performed to ensure controlled breeding. Once pregnancy was confirmed, musical exposure began on the 10th day of gestation, during which 14 compositions of Mozart music were played nightly at a consistent volume for the experimental groups.

After birth, offspring selection was carried out to maintain consistency in the experimental samples. To ensure comparable physical development, the two heaviest female offspring from each mother were selected for the study. This selection process resulted in a total of 15 offspring per group, providing a controlled sample size for apoptosis analysis. Once selected, these offspring underwent euthanasia by decapitation following ethical guidelines for experimental research. The collected brain tissues were then processed for histological examination to assess neuronal apoptosis levels. To quantify neuronal apoptosis, the TUNEL (Terminal deoxynucleotidyl transferase dUTP Nick End Labeling) assay was used, a widely recognized method for detecting DNA fragmentation in apoptotic cells. Brain tissue samples from the newborn *Rattus norvegicus* were prepared and stained using the TUNEL technique, allowing precise identification of apoptotic neurons. These stained samples were then analyzed under a microscope with 1000x magnification to determine the apoptosis index. The apoptosis index was used as a key measurement parameter, providing insights into the potential neuroprotective effects of Mozart music stimulation under varying lighting conditions. Employing a systematic and controlled experimental design provide robust evidence on the role of auditory stimulation in neuronal survival. The statistical testing used were descriptive statistic, normality testing, ANCOVA, and post hoc comparison test. The ethical clearance was obtained from Institutional Review Board, Faculty of Medicine, Universitas Wijaya Kusuma Surabaya (No. 16 /SLE/FK/UWKS/2024).

Results

All *Rattus norvegicus* mothers in this study experienced full-term pregnancies, with gestational durations ranging from 19 to 21 days. Table 1 reveals that the most common gestational age in the control group was 19 days, while in the dark treatment group, it was 20 days, and in the light treatment group, it was 19 days. The shortest gestational period of 19 days was most

IHS
ISSN: 2798-7094

frequently observed in the 1-hour light treatment group, whereas the longest gestational period of 21 days was primarily recorded in the control group. These findings indicate minor variations in gestational age across the groups **(Table 1)**. The characteristics of *Rattus norvegicus* offspring based on body weight are summarized. The most common body weight range for the control group, the 1-hour dark treatment group, and the 1-hour light treatment group was 4.00–4.49 grams. This range was observed in 12 individuals (80%) from the control group, 13 individuals (86.67%) from the dark treatment group, and 10 individuals (66.67%) from the light treatment group. The smallest body weight category was observed in the 1-hour light treatment group, with 5 individuals (33.33%), while the largest body weight was found in both the control group, with 3 individuals (20%), and the dark treatment group, with 2 individuals (13.33%) **(Table 2)**. The table highlights the head weight characteristics of *Rattus norvegicus* offspring. In the control group, the most common head weight range was between 1.20–1.29 grams, observed in 9 individuals (60%). In the 1-hour light treatment group, the most common head weight was between 1.40–1.49 grams, also seen in 9 individuals (60%). Interestingly, the smallest head weight was recorded in the 1-hour dark treatment group, between 1.00–1.09 grams, in 1 individual (6.67%), while the largest head weight, between 1.60–1.69 grams, was also found in the dark treatment group, in 1 individual (6.67%) **(Table 3)**. The characteristics of *Rattus norvegicus* offspring based on the apoptosis index are also presented in the table, which indicates that a score of 50–59 (apoptosis index) was observed in 7 samples from the control group and 2 samples from the 1-hour dark treatment group **(Table 4)**

Figure 2. Laboratory research processes.

Prior to comparing the neuronal apoptosis index across the groups, a Shapiro-Wilk normality test was conducted. This test was necessary because each group had a sample size below 50, requiring an evaluation of data distribution to select the appropriate statistical method. The normality test results showed that most variables were not normally distributed, except for head weight. As a result, the Kruskal-Walli's test was employed for the analysis. The study used a significance threshold of $p < 0.05$ to determine statistical significance. Results with p-values below this threshold were considered significant, while those above were deemed non-significant. The analysis indicated that neither body weight nor gestational age influenced the neuronal apoptosis index, ruling them out as confounding variables. In contrast, head weight significantly affected the apoptosis index and was thus controlled as a confounding variable using an ANCOVA test. The neuronal apoptosis index was then compared among the control group, the dark treatment group (exposure to Mozart music

IHS
ISSN: 2798-7094

for 1 hour in dark conditions), and the light treatment group (exposure to Mozart music for 1 hour in light conditions) **(Table 5)**. The table provides the calculated apoptosis index for each group **(Table 6)**. These comparisons were adjusted for the confounding effect of head weight. Statistical analysis revealed no significant difference in the neuronal apoptosis index between the dark treatment group and the light treatment group, with a p-value of 0.836 ($p > 0.05$). This finding suggests that exposure to Mozart music for 1 hour under light or dark conditions produces a similar effect on neuronal apoptosis in newborn *Rattus norvegicus*. However, significant differences in the apoptosis index were observed when comparing the control group to the treatment groups. The control group differed significantly from the dark treatment group, with a p-value of 0.002 ($p < 0.05$), and from the light treatment group, with a p-value of 0.009 ($p < 0.05$). These results indicate that exposure to Mozart music, regardless of lighting conditions, significantly reduces neuronal apoptosis compared to the absence of music exposure **(Table 7)**. This finding highlights the potential neuroprotective effects of auditory stimulation, specifically with classical music, on brain cell survival during early development. The absence of significant differences in apoptosis index between the light and dark treatment groups suggests that the beneficial impact of Mozart music on neuronal health is not influenced by environmental lighting conditions.

Table 1. Characteristics of *Rattus norvegicus* mothers based on gestational age.

Gestational Age (Days)	Group						Total	
	Control		1-Hour Dark Treatment		1-Hour Light Treatment			
	f	%	f	%	f	%	f	%
19	6	40	4	26.67	8	53.33	18	40
20	5	33.33	8	53.33	7	46.67	20	44.44
21	4	26.67	3	20	0	0	7	15.56

Table 2. Characteristics of *Rattus norvegicus* mothers based on body weight.

Body Weight (gram)	Group						Total	
	Control		1-Hour Dark Treatment		1-Hour Light Treatment			
	f	%	f	%	f	%	f	%
3.00 – 3.49	-	-	-	-	-	-	-	-
3.51 – 3.99	-	-	-	-	5	33.33	5	11.1
4.00 – 4.49	12	80	13	86.67	10	66.67	35	77.8
4.50 – 4.99	3	20	2	13.33	-	-	5	11.1

Table 3. Characteristics of *Rattus norvegicus* mothers based on head weight.

Head Weight (Gram)	Group						Total	
	Control		1-Hour Dark Treatment		1-Hour Light Treatment			
	f	%	f	%	f	%	f	%
1.00 – 1.09	-	-	1	6.67	-	-	1	2.22
1.10 – 1.19	3	20	2	13.33	-	-	5	11.11
1.20 – 1.29	9	60	3	20	-	-	12	26.67
1.30 – 1.39	3	20	3	20	6	40	12	26.67
1.40 – 1.49	-	-	2	13.33	9	60	11	24.44
1.50 – 1.59	-	-	3	20	-	-	3	6.67
1.60 – 1.69	-	-	1	6.67	-	-	1	2.22
1.70 – 1.79	-	-	-	-	-	-	-	-

Discussion

This study was conducted to determine the optimal exposure time to Mozart music under different conditions—specifically, for 1 hour in dark and light environments. The hypothesis proposed was that the apoptosis index would be lower when music exposure occurred in the dark compared to the light condition. Understanding how auditory stimuli, particularly music, affect cellular processes such as apoptosis in developing brains is crucial for advancing knowledge in neurodevelopmental

ISSN: 2798-7094

research. Thus, it can be concluded that there is a significant effect between the control and treatment groups on the apoptosis index, independent of the influence of head weight. This finding underscores the importance of the treatment conditions in modulating neuronal health. This study utilized a control group with no exposure to Mozart music.

Table 4. Characteristics of *Rattus norvegicus* mothers based on apoptosis index.

Apoptosis Index	Group						Total	
	Control		1-Hour Dark Treatment		1-Hour Light Treatment			
	f	%	f	%	f	%	f	%
10 – 19	-	-	11	73.33	3	20	14	31.11
20 – 29	-	-	-	-	7	46.67	7	15.55
30 – 39	2	13.33	1	6.67	3	20	5	11.11
40 – 49	6	40	-	-	1	6.67	7	15.55
50 – 59	7	46.67	2	13.33	-	-	9	20
60 – 69	-	-	-	-	-	-	-	-
70 – 79	-	-	-	-	-	-	-	-
80 – 89	-	-	1	6.67	1	6.67	2	4.44
90 – 99	-	-	-	-	-	-	-	-

Table 5. Analysis of *Rattus norvegicus* mothers based on apoptosis index.

Variables	Group			*p*
	Control (X±SD)	Treatment 1 (X±SD)	Treatment 2 (X±SD)	
Body Weight (grams)	4.38 ± 0.20	4.31 ± 0.15	4.47 ± 0.22	0.314
Head Weight (grams)	1.23 ± 0.42	1.34 ± 0.12	1.39 ± 0.26	0.003
Gestational Age (days)	19.94 ± 0.67	20.00 ± 0.75	19.50 ± 0.53	0.280

Table 6. ANCOVA test on neuronal apoptosis index with dependent variables.

Variables	*p*
Corrected Model	0.000
Head Weight	0.005
Group	0.000

Table 7. Post Hoc comparison test between control group, treatment group 1, and treatment group 2.

Group	Group	*p*
Control	1-Hour Dark	0.002
	1-Hour Light	0.009
1-Hour Dark	Control	0.002
	1-Hour Light	0.836
1-Hour Light	Control	0.009
	1-Hour Dark	0.836

Statistical tests revealed significant differences in the apoptosis index between the control group and both treatment groups, regardless of whether the exposure occurred for 1 hour in the dark or in light conditions. A study noted that brains developed in a stimulus-rich environment exhibit thicker cortices, larger neuron cell nuclei, and an increased number of glial cells (Han et al., 2022). Furthermore, neurons in such environments have more dendritic sites which facilitating the formation of additional synapses (Nguyen et al., 2021). The number of cells undergoing apoptosis is inversely related to the number of synapses—more synapses correlate with less apoptosis. As dendritic sites increase, synapse formation rises, thereby reducing the incidence of apoptosis (Chen & Wang, 2010). Consequently, brains nurtured in a stimulus-rich

IHS
ISSN: 2798-7094

environment experience less apoptosis and it enhance overall brain capacity. Numerous studies have examined the effect of music stimulation during pregnancy on the apoptosis index (Nadila et al., 2021); however, the exact mechanisms by which this stimulation inhibits apoptosis remain unclear. It is likely that this process involves neurotrophic factors known as neurotrophins, including Nerve Growth Factor (NGF), BDNF, and neurotrophins 3/4/5. BDNF, in particular, plays a critical role in cell proliferation and differentiation (Pansri et al., 2021). Music stimulation may enhance the production of various growth factors, including BDNF, CREB (which influences learning and memory), and synapsin 1 (a synaptic protein that supports synapse growth) **(Figure 3).**

Figure 3. Illustration of baby listening music (www.bbc.co.uk).

Target cells produce neurotrophins, and neurons compete for these essential factors to sustain their survival. If neurons do not receive sufficient neurotrophins, they undergo death and apoptosis (Friedman, 2010). Target cells have a limited capacity to produce the necessary neurotrophins to support neuron survival and function. When the ability of target cells to produce neurotrophins increases, the number of cells undergoing apoptosis tends to decrease (Putra, 2019). This suggests that neurotrophins are pivotal in maintaining neuron survival, particularly in preventing programmed cell death. However, the precise mechanisms by which external stimuli enhance the ability of target cells—specifically other neurons—to produce and release neurotrophins remain to be fully elucidated. Further research is necessary to uncover the underlying mechanisms of this process. Campbell (2001) conducted a study comparing rats exposed to Mozart music with those subjected to noisy sounds which finding that the former group exhibited higher intelligence levels. Examination of the rats' brains revealed increased expression of BDNF, CREB, and synapsin I in the Mozart-exposed group compared to the control rats. In our study, the average apoptosis index between treatment group 1 (Mozart music exposure for 1 hour in the dark) and treatment group 2 (Mozart music exposure for 1 hour in the light) was relatively similar, with values of 24.875 ± SE 3.45 and 23.825 ± SE 3.89, respectively. Statistical testing yielded a p-value of 0.836 ($p > 0.05$), which indicating no significant difference. This finding does not align with the initial hypothesis that the apoptosis index of newborn *Rattus norvegicus* brain cells exposed to Mozart music for 1 hour in the dark would be lower than in the light condition.

Almost all living organisms exhibit circadian rhythms, which in adults are controlled by the biological clock located in the suprachiasmatic nucleus (SCN) (Farhud & Aryan, 2018). The SCN influences heart rate through the sympathetic nervous

ISSN: 2798-7094

system. However, whether the SCN in the fetus plays a similar role to that in adults remains unclear. Evidence suggests the presence of numerous glucocorticoid receptors in the fetal SCN which indicating that the fetal brain may be involved in circadian rhythm regulation (Kundarti et al., 2024). The mechanisms governing the daily cycles of fetal movements, breathing, and heart rate patterns are not yet fully understood. Factors such as maternal melatonin and adrenal corticosteroids may influence these patterns. The regulation of circadian rhythms in the fetus requires further investigation. The findings of this study present opportunities for innovation in clinical research involving humans, particularly in exploring the benefits of Mozart music exposure for enhancing fetal development. The discovery that Mozart music can reduce the apoptosis index in animal models provides a strong foundation for studying similar applications in humans, especially for pregnant women and their unborn babies. Potential benefits of music exposure include improved neuroplasticity, reduced risk of neurodevelopmental disorders, and enhanced cognitive functions in newborns. Well-designed clinical studies are essential to establish optimal protocols—such as duration, timing, and intensity of Mozart music exposure—to effectively support fetal brain development. Thus, this research holds significant implications not only for scientific advancement but also for public health, particularly in utilizing music therapy as a non-invasive intervention during pregnancy.

Despite the promising findings, there are several limitations to this study. First, while the results indicate that Mozart music can reduce the neuron apoptosis index in *Rattus norvegicus*, further clinical studies are necessary to explore these benefits in humans, particularly concerning the most effective duration and type of music exposure during pregnancy. Second, although Mozart's music showed positive effects, this study only employed one type of auditory stimulus. Exploring other music genres is crucial to determine whether these benefits are unique to Mozart or if they can be replicated with other structured auditory stimuli. Third, the study does not elucidate how Mozart music affects specific brain areas. Future research utilizing neuroimaging techniques could help identify which brain regions are most influenced by music exposure. Lastly, while *Rattus norvegicus* serves as a valuable model for studying brain development, significant differences exist in sensory processing and environmental interactions between rodents and humans. Therefore, translational studies are needed to confirm whether the same benefits apply to human populations. The findings suggest that Mozart music exposure has a protective effect against neuronal apoptosis in newborn rats, irrespective of environmental lighting conditions. This could have implications for using music therapy in prenatal and neonatal care. The flexibility of applying music stimulation during either light or dark conditions could make such interventions more practical and accessible. This flexibility offers practical implications for implementing music-based interventions in real-world settings, where factors such as time of day or lighting conditions may vary. These results are particularly relevant for prenatal and neonatal care, where such interventions could be employed to support healthy brain development during critical periods of growth.

Conclusion

There was no significant difference in the apoptosis index of neuronal brain cells in newborn *Rattus norvegicus* exposed to Mozart music for 1 hour under light conditions compared to those exposed for 1 hour under dark conditions. This absence of difference suggests that, when applied to humans, Mozart music stimulation can be provided at any time, whether in the morning or at night. This flexibility is expected to improve the compliance of pregnant women in using Mozart music as fetal stimulation during pregnancy, facilitating the broader implementation of this stimulation program. Consequently, babies born under such a program may have a relatively higher number of brain cells which potentially supporting better brain development. For future research, it is recommended to investigate the long-term effects of prenatal Mozart music stimulation on cognitive and neurological development in humans. Studies could also explore the integration of music stimulation into prenatal healthcare practices, evaluating its acceptability, feasibility, and impact on maternal and fetal well-being. Additionally, further research should assess the effects of different types of music and varying exposure durations to optimize the stimulation program for practical application in diverse healthcare settings. Additionally, investigating different genres or durations of music exposure could help optimize the intervention.

Author declaration

All the authors contributed to the entire research process, including manuscript preparation.

AI statements

No generative-text artificial intelligence tools were used during the writing this manuscript.

Funding

None.

IHS
ISSN: 2798-7094

Availability of data and materials
All data are available from the authors.

Competing interests
The authors declare no competing interest.

Acknowledgments
The authors express their gratitude to Universitas Wijaya Kusuma Surabaya for the support.

References
Bell, K. F., & Hardingham, G. E. (2011). The influence of synaptic activity on neuronal health. Current opinion in neurobiology, 21(2), 299–305. https://doi.org/10.1016/j.conb.2011.01.002
Bouyssi-Kobar, M., du Plessis, A. J., McCarter, R., Brossard-Racine, M., Murnick, J., Tinkleman, L., Robertson, R. L., & Limperopoulos, C. (2016). Third Trimester Brain Growth in Preterm Infants Compared With In Utero Healthy Fetuses. Pediatrics, 138(5), e20161640. https://doi.org/10.1542/peds.2016-1640
Campbell, D. G. (2001). Efek Mozart [The Mozart effect]. Gramedia Pustaka Utama.
Chen, M., & Wang, J. (2010). Programmed cell death of dendritic cells in immune regulation. Immunological reviews, 236, 11–27. https://doi.org/10.1111/j.1600-065X.2010.00916.x
Colom, R., Karama, S., Jung, R. E., & Haier, R. J. (2010). Human intelligence and brain networks. Dialogues in clinical neuroscience, 12(4), 489–501. https://doi.org/10.31887/DCNS.2010.12.4/rcolom
Cusick, S. E., Barks, A., & Georgieff, M. K. (2022). Nutrition and Brain Development. Current topics in behavioral neurosciences, 53, 131–165. https://doi.org/10.1007/7854_2021_244
Da Silveira, T. B. N., & Lopes, H. S. (2023). Intelligence across humans and machines: a joint perspective. Frontiers in psychology, 14, 1209761. https://doi.org/10.3389/fpsyg.2023.1209761
Elmore S. (2007). Apoptosis: a review of programmed cell death. Toxicologic pathology, 35(4), 495–516. https://doi.org/10.1080/01926230701320337
Farhud, D., & Aryan, Z. (2018). Circadian Rhythm, Lifestyle and Health: A Narrative Review. Iranian journal of public health, 47(8), 1068–1076.
Friedman W. J. (2010). Proneurotrophins, seizures, and neuronal apoptosis. The Neuroscientist: a review journal bringing neurobiology, neurology and psychiatry, 16(3), 244–252. https://doi.org/10.1177/1073858409349903
Goriounova, N. A., & Mansvelder, H. D. (2019). Genes, Cells and Brain Areas of Intelligence. Frontiers in human neuroscience, 13, 44. https://doi.org/10.3389/fnhum.2019.00044
Gualtieri, S., & Finn, A. S. (2022). The Sweet Spot: When Children's Developing Abilities, Brains, and Knowledge Make Them Better Learners Than Adults. Perspectives on psychological science: a journal of the Association for Psychological Science, 17(5), 1322–1338. https://doi.org/10.1177/17456916211045971
Han, Y., Yuan, M., Guo, Y. S., Shen, X. Y., Gao, Z. K., & Bi, X. (2022). The role of enriched environment in neural development and repair. Frontiers in cellular neuroscience, 16, 890666. https://doi.org/10.3389/fncel.2022.890666
Jenkins J. S. (2001). The Mozart effect. Journal of the Royal Society of Medicine, 94(4), 170–172. https://doi.org/10.1177/014107680109400404
Kundarti, F. I., Titisari, I., & Andrianto, S. (2024). Buku ajar patofisiologi dalam kasus kebidanan [Textbook of pathophysiology in obstetric cases]. UNISMA PRESS.
Leibovitz, Z., Lerman-Sagie, T., & Haddad, L. (2022). Fetal Brain Development: Regulating Processes and Related Malformations. Life (Basel, Switzerland), 12(6), 809. https://doi.org/10.3390/life12060809
Li, K., van Delft, M. F., & Dewson, G. (2021). Too much death can kill you: inhibiting intrinsic apoptosis to treat disease. The EMBO journal, 40(14), e107341. https://doi.org/10.15252/embj.2020107341
Lubrano, C., Parisi, F., & Cetin, I. (2024). Impact of Maternal Environment and Inflammation on Fetal Neurodevelopment. Antioxidants (Basel, Switzerland), 13(4), 453. https://doi.org/10.3390/antiox13040453
Nadila, S., Joewono, H. T., & Sulistyono, A. (2022). Murottal Sura Al-Fatiha during pregnancy increased the number of neuron cells in the cerebrum and cerebellum of the newborn Rattus Norvegicus. International Journal of Health Sciences, 6(3), 1383–1390. https://doi.org/10.53730/ijhs.v6n3.12734
Nguyen, T. T. M., Gillet, G., & Popgeorgiev, N. (2021). Caspases in the Developing Central Nervous System: Apoptosis and Beyond. Frontiers in cell and developmental biology, 9, 702404. https://doi.org/10.3389/fcell.2021.702404

Pansri, P., Phanthong, P., Suthprasertporn, N., Kitiyanant, Y., Tubsuwan, A., Dinnyes, A., Kobolak, J., & Kitiyanant, N. (2021). Brain-derived neurotrophic factor increases cell number of neural progenitor cells derived from human induced pluripotent stem cells. PeerJ, 9, e11388. https://doi.org/10.7717/peerj.11388

Partanen, E., Kujala, T., Tervaniemi, M., & Huotilainen, M. (2013). Prenatal music exposure induces long-term neural effects. PloS one, 8(10), e78946. https://doi.org/10.1371/journal.pone.0078946

Pino, O., Di Pietro, S., & Poli, D. (2023). Effect of Musical Stimulation on Placental Programming and Neurodevelopment Outcome of Preterm Infants: A Systematic Review. International journal of environmental research and public health, 20(3), 2718. https://doi.org/10.3390/ijerph20032718

Puri, S., Shaheen, M., & Grover, B. (2023). Nutrition and cognitive health: A life course approach. Frontiers in public health, 11, 1023907. https://doi.org/10.3389/fpubh.2023.1023907

Putra, S. T. (Ed.). (2019). Psikoneuroimunologi kedokteran [Psychoneuroimmunology in medicine] (2nd ed.). Airlangga University Press.

Rehnberg, J., Huisman, M., Fors, S., Marseglia, A., & Kok, A. (2024). The Association between Education and Cognitive Performance Varies at Different Levels of Cognitive Performance: A Quantile Regression Approach. Gerontology, 70(3), 318–326. https://doi.org/10.1159/000535717

Taylor, L., Watkins, S. L., Marshall, H., Dascombe, B. J., & Foster, J. (2016). The Impact of Different Environmental Conditions on Cognitive Function: A Focused Review. Frontiers in physiology, 6, 372. https://doi.org/10.3389/fphys.2015.00372

Thomason M. E. (2020). Development of Brain Networks in Utero: Relevance for Common Neural Disorders. Biological psychiatry, 88(1), 40–50. https://doi.org/10.1016/j.biopsych.2020.02.007

van Dyck, L. I., & Morrow, E. M. (2017). Genetic control of postnatal human brain growth. Current opinion in neurology, 30(1), 114–124. https://doi.org/10.1097/WCO.0000000000000405

Zaatar, T. M., Alhakim, K., Enayeh, M., & Tamer, R. (2023). The transformative power of music: Insights into neuroplasticity, health, and disease. Brain, behavior, & immunity - health, 35, 100716. https://doi.org/10.1016/j.bbih.2023.100716

Authors' perspective

Innovation points

- The study examines how exposure to Mozart music influences neuronal apoptosis.
- After receiving Mozart music, the finding provided insights into the potential developmental and neurological impacts of auditory stimulation during early life stages.
- The research compares the effects of Mozart music under two environmental conditions (light and dark) to determine how these factors interact.

Potential areas of interest

- How does exposure to Mozart music influence neuronal apoptosis in newborn *Rattus norvegicus*?
- What are the differences in the effects of Mozart music on neuronal apoptosis between light and dark conditions?
- Why were newborn *Rattus norvegicus* chosen as the subject for studying the impact of auditory stimulation on neuronal development?

How to cite this article (APA style)

Maulana, E. N., & Wardhani, M. K. (2025). Impact of Mozart music exposure on neuronal apoptosis in newborn *Rattus norvegicus*: a comparative study between light and dark conditions. Innovation in Health for Society, 5(1), 41-50. https://doi.org/10.31603/ihs.12884