JJBS
Volume 19, Number 2,June 2026
ISSN 1995-6673
Pages 177 – 180
https://doi.org/10.54319/jjbs/190201
Jordan Journal of Biological Sciences

Electrophysiological Analysis of Dopamine's Modulatory Effects on the Retina and Central Visual Structures

Khuraman Miryusifova[1,2], Arzu Allahverdiyeva[1], Nigar Huseynova[1,*]

[1] Research Institute of Living Systems, Ministry of Science and Education, Baku, Azerbaijan; [2]Baku State University, Baku, Azerbaijan

Received: July 4, 2025; Revised: September 9, 2025; Accepted: September 20, 2025

Abstract

This study examined the effects of electrical stimulation of the substantia nigra on dopaminergic modulation of bioelectrical activity in the retina and key structures of the visual analyzer in rabbits. These structures included the superior colliculus, the dorsal part of the lateral geniculate nucleus (pars dorsalis), and the visual cortex. Assessments were based on analyses of the electroretinogram (ERG), evoked potentials (EP), and electroencephalogram (EEG). Stimulation of the substantia nigra increased the amplitude of the ERG recorded from the retina. In contrast, it reduced the amplitude of EPs in the superior colliculus, the dorsal part of the lateral geniculate nucleus, and the visual cortex. Spectral analysis of the EEG showed a significant decrease in low-frequency rhythms (delta and theta bands) in the superior colliculus and visual cortex. No significant changes were detected in these parameters in the dorsal part of the lateral geniculate nucleus compared to the control group.

These findings indicate that the substantia nigra selectively modulates dopaminergic activity across visual system structures. This supports its critical role in the differential regulation and functional integration of retino-colliculo-cortical pathways.

Keywords: retina, dopamin, visual cortex, lateral geniculate body, superior colliculus.

1. Introductıon

Dysfunction of the dopaminergic system is linked to various neurological and ophthalmological disorders, including Parkinson's disease, depression, schizophrenia, diabetic retinopathy, and Alzheimer's disease. In Alzheimer's disease, degenerative changes are frequently observed in the substantia nigra (SN) and its dopaminergic pathways (Bayer et al., 2021; Williams et al., 2019). Dopamine plays a key role not only in motor functions but also in cognitive and sensory integration, with evidence supporting its protective effects against depression (Auwal Adamu et al., 2023).

The substantia nigra, a brainstem structure rich in dopaminergic neurons, has traditionally been studied in the context of motor control. However, recent research highlights its modulatory influence on sensory systems, particularly the visual pathway. Dopaminergic projections from the SN extend to the retina and central visual structures, including the colliculus superior (CS), lateral geniculate body (LGB), and visual cortex (VC). Within the retina, dopamine regulates essential processes such as light adaptation, contrast sensitivity, and color discrimination, underscoring its importance in visual processing.

Electrophysiological techniques provide high temporal and spatial resolution to investigate how dopamine modulates neuronal connectivity and activity in visual pathways. Studies have shown that dopamine alters the response properties of retinal ganglion cells and neurons in the visual cortex, shaping their activity in response to visual stimuli (Zhou et al., 2023). It also influences bipolar cell receptive fields and light–dark adaptation, effects that are partly mediated through GABA_A receptors (Farshi et al., 2020). Furthermore, dopamine has been shown to modulate synaptic activity in retinal ganglion cells and participate in non-image-forming visual functions (Bergum et al., 2024).

Despite these insights, the functional impact of direct dopaminergic modulation from the SN on peripheral and central visual structures remains insufficiently explored. This study addresses this gap by using an experimental rabbit model to evaluate the effects of electrical stimulation of the SN on bioelectrical activity in the retina and central visual structures, including the CS, LGB, and VC. These findings will advance our understanding of dopaminergic mechanisms in the visual system and may contribute to early diagnostic and therapeutic strategies for neurodegenerative disorders affecting vision (Miryusifova et al., 2022, 2024).

2. Materials and Methods

The experiments were conducted on Chinchilla rabbits maintained under standard vivarium conditions with a controlled 12:12 h light–dark cycle, free access to food and water, and regular veterinary monitoring.

All procedures were performed in accordance with the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes and the Law of the Republic of Azerbaijan and

* Corresponding author. e-mail: nigarhus@mail.ru.

were approved by the Institutional Animal Care and Use Committee (Approval No. 1/643-IIQD).

Under general anesthesia (urethane, 1.0 g/kg, intraperitoneally), electrodes were stereotaxically implanted into the CS, LGB, VC and SN. The coordinates were determined according to the stereotaxic atlas of Fifkova et al. (1962) (Table 1).

Table 1. Structure coordinates

Structure	AP (Anterior-Posterior-mm)	ML (Medial-Lateral-mm)	DV (Dorsal-Ventral-mm)
SN	5-6	3-4	14-15
CS	9-10	2,5-3	8-9
LGB	4-5	6-7	9-10
VC	9	9	1-2

Monopolar nichrome electrodes were used, with diameters of 0.5 mm for cortical and 1.5 mm for subcortical structures. The electrodes were insulated except at the tip. A stainless-steel screw placed in the cranial bone served as the reference electrode.

Electrical stimulation of the SN was delivered using a current intensity of 200 µA, pulse duration of 0.2 ms, frequency of 50 Hz, for 10 s per trial. Neural activity was recorded using the Neuron-Spectrum 5 system (Neurosoft, Russia). Signals were sampled at 1 kHz, band-pass filtered between 0.5 and 100 Hz, and stored for offline analysis.

Spectral and amplitude analyses of EEG and ERG, along with evoked potential (EP) parameters, were performed using the system's built-in software. Statistical analyses were conducted in Microsoft Excel using one-way ANOVA, with significance set at $p < 0.05$.

3. Results and Discussion

The study was conducted in two main stages. First, baseline activity of the visual system was recorded to establish control parameters. Then, the SN was electrically stimulated, and its effects on the ERG, EP and EEG in the CS, LGB, VC (Tab. 1, Fig. 1).

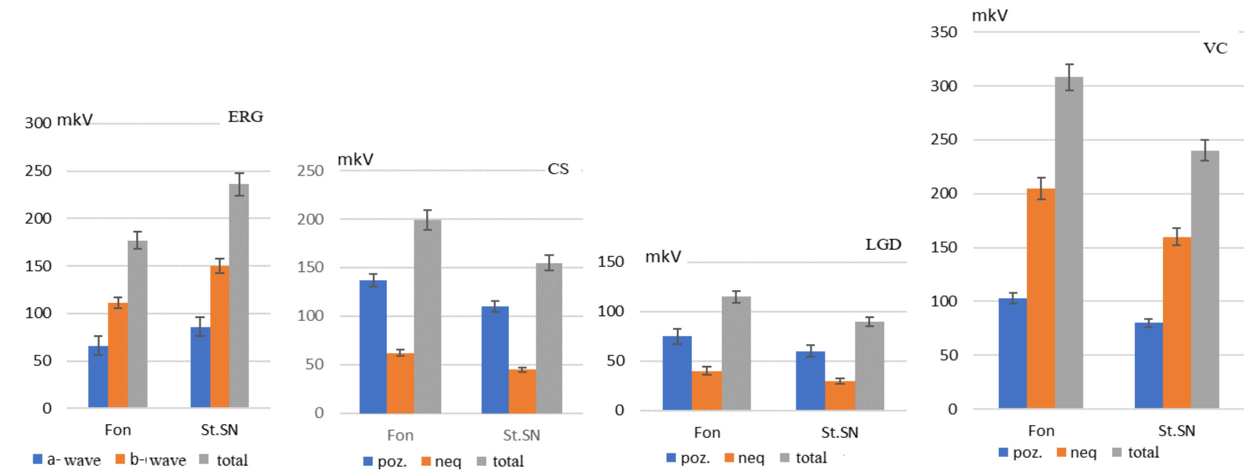

Figure 1. Effect of Substantia Nigra stimulation on the amplitude parameters of evoked potentials in the retina and central structures of the visual analyzer (CS, LGD, VC).

Table 2. Percentage changes in the amplitude parameters of evoked potentials in the retina and visual analyzer structures following stimulation of the SN.

Structure	Component	Change (%)
ERG	a-wave amplitude	+26.3%
	b-wave amplitude	+36.4%
	Total amplitude	+25.0%
CS	Positive wave amplitude	–18.5%
	Negative wave amplitude	–27.8%
	Total amplitude	–22.0%
LGD	Positive wave amplitude	–5.9%
	Negative wave amplitude	–7.1%
	Total amplitude	–6.7%
VC	Positive wave amplitude	–18.2%
	Negative wave amplitude	–14.3%
	Total amplitude	–15.6%

Immediately after stimulation, retinal responses were absent, likely reflecting a delay in neurochemical signaling. After several minutes, ERG amplitudes increased (Fig. 1), indicating enhanced visual signal transmission at the retinal level. This facilitation is consistent with increased dopamine release from the SN and its modulatory action on photoreceptors, bipolar cells, and Müller cells (Witkovsky, 2004; Djamgoz et al., 1997). Upregulation of dopamine acting via D1/D2 receptors is known to influence Na^+/K^+ permeability and enhance visual responses (Jackson et al., 2012).

In the SC, stimulation led to a marked reduction in EP amplitudes and in the low-frequency (delta and theta) bands of the EEG (Fig. 2). These findings suggest an inhibitory modulation of SC activity by SN projections, as consistent with earlier anatomical and electrophysiological studies showing dopaminergic and GABAergic regulation of this midbrain structure (Appel & Behan, 1990; Kayama & Koyama, 1984).

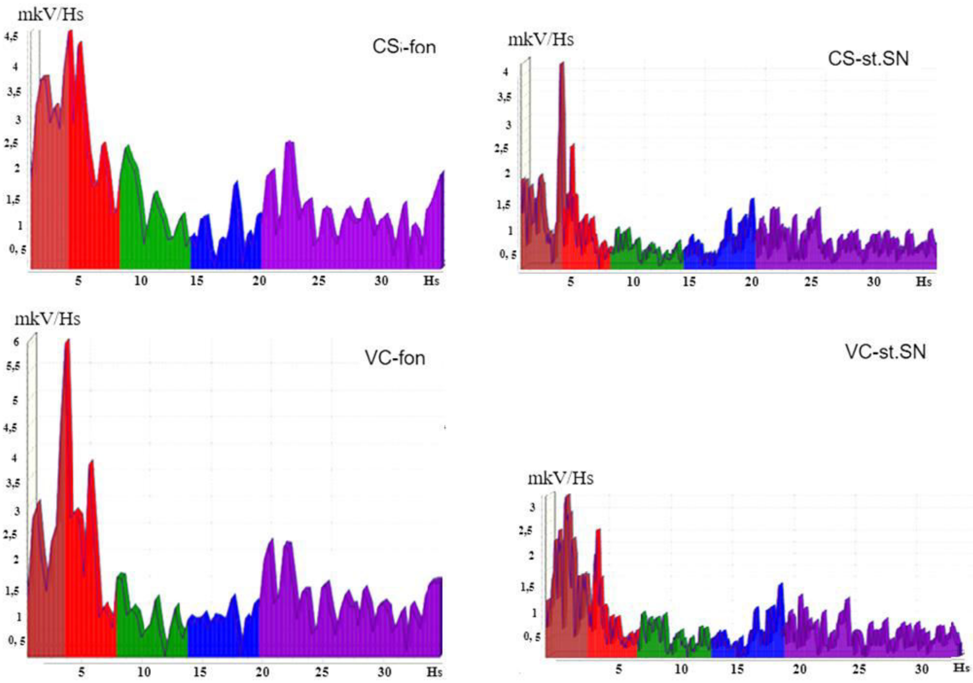

Figure 2. Effect of substantia nigra stimulation on the amplitude parameters of evoked potentials in the central structures of the visual analyzer (superior colliculus, visual cortex).

In the LGB, changes were minor and not statistically significant, indicating relatively stable functional activity or possible compensatory mechanisms. The laminar organization and strong inhibitory interneuron network in the LGB (Sherman & Guillery, 2002) may contribute to this stability.

In the VC, a moderate reduction in EP amplitudes was observed, along with decreased low-frequency EEG power (Fig. 2). This suggests that SN stimulation modulates cortical excitability, potentially through dopaminergic and GABAergic pathways that influence cortical network dynamics (Lewis et al., 2001). Reduced low-frequency activity is consistent with increased cortical inhibition, possibly mediated by D1-receptor–dependent mechanisms (Seamans & Yang, 2004).

This study demonstrated that electrical activation of dopaminergic neurons in the SN exerts a selective and multidirectional modulatory influence on the visual system of rabbits. At the retinal level, a marked enhancement of bioelectrical activity was observed, whereas in the SC and VC, a reduction in the amplitude of evoked potentials and a decrease in the power of low-frequency EEG rhythms were detected. No significant changes were found in the LGB, which may reflect the stability of its neuronal networks or the engagement of compensatory mechanisms in this structure.

The novelty of this work lies in the comprehensive, integrated assessment of ERG, EP, and EEG within a single experimental model to evaluate functional changes in both peripheral and central components of the visual system under SN stimulation. These findings broaden current understanding of the neuromodulatory role of dopamine in sensory integration and visual pathway plasticity, aligning with modern research priorities in experimental neurobiology and neurophysiology.

The practical significance of the study stems from its potential to provide an experimental basis for developing methods of early diagnosis and targeted therapy for neurodegenerative disorders such as Parkinson's and Alzheimer's diseases, where disturbances in dopaminergic transmission and visual function are prominent. These results also lay the groundwork for future studies aimed at exploring strategies for modulating dopaminergic systems to improve cognitive and sensory functions.

4. Conclusion

This study demonstrates that dopaminergic stimulation of the substantia nigra selectively modulates neuronal activity across different levels of the rabbit visual system. Retinal responses were enhanced, while activity in the CS and VC decreased, indicating region-specific modulation. The LGB, by contrast, showed relative stability, suggesting compensatory or homeostatic regulation.

These results provide new experimental evidence that the substantia nigra exerts differential **neuromodulatory** control over retino-colliculo-cortical pathways. This highlights the importance of dopaminergic mechanisms in visual information processing and offers insights relevant to the early diagnosis and potential therapeutic targeting of visual and cognitive dysfunctions associated with neurodegenerative diseases.

5. Conflict of interests

The authors declare no competing interests.

6. Ethical approval

All procedures described in this study were carried out following the recommendations of the Institutional Animal Ethics Committee (IAEC) of the institute.

References

Appel, N. M., & Behan, M. (1990). Substantia nigra projections to the superior colliculus in the rabbit. Brain Research, 534(1-2), 141–146.

Auwal Adamu et al. (2023). Moringa oleifera (Lam) Root Extracts Elevate Catecholamine Levels in Experimental Rats: Potential Role of Ethnopharmacology in Combating Depressive Conditions, 16 (2), 329–334 https://doi.org/10.54319/jjbs/160217

Bayer, T. A., Falkai, P., & Maier, W. (2021). The dopamine hypothesis of Alzheimer's disease: A new insight into pathophysiological mechanisms. Progress in Neurobiology, 199, 101954. https://doi.org/10.1016/j.pneurobio.2020.101954

Bergum, N., Berezin, C.-T., & Vigh, J. (2024). Dopamine enhances GABA_A receptor-mediated current amplitude in a subset of intrinsically photosensitive retinal ganglion cells. Journal of Neurophysiology. https://doi.org/10.1152/jn.00457.2023

Bergum, S. L., McMahon, D. G., & Cao, Y. (2024). Dopaminergic modulation of non-image-forming visual circuits in the retina. Frontiers in Neural Circuits, 18, 102311. https://doi.org/10.3389/fncir.2024.102311

Djamgoz, M. B. A., Hankins, M. W., Hirano, J., & Archer, S. N. (1997). Neurobiology of retinal dopamine in relation to degenerative states of the eye. Vision Research, 37(24), 3509–3529.

Farshi, P., Hafizi, S., & Bloomfield, S. A. (2020). Dopamine regulation of GABAergic signaling in the retina: Involvement of GABA_A receptors. Journal of Neurophysiology, 123(4), 1352–1363. https://doi.org/10.1152/jn.00564.2019

Farshi, S., et al. (2020). Inhibitory components of retinal bipolar cell receptive fields are differentially modulated by dopamine D1 receptors. Visual Neuroscience, 37, E01. https://doi.org/10.1017/S0952523819000129

Fifkov, E., Marshal, J. (1962). Stereotaxic atlases of the cat, rabbit, and rat brain. In: Electrophysiological Methods of Investigation. Foreign Literature Publishing House, p. 456.

Jackson, C. R., Ruan, G. X., Aseem, F., Abey, J., Gamble, K., Stanwood, G., & McMahon, D. G. (2012). Retinal dopamine mediates multiple dimensions of light-adapted vision. Journal of Neuroscience, 32(27), 9359–9368.

Kayama, Y., & Koyama, Y. (1984). The effects of substantia nigra stimulation on visual cortical evoked potentials. Brain Research, 301, 235–240.

Lewis, D. A., Melchitzky, D. S., & Sesack, S. R. (2001). Dopamine and prefrontal cortical function: implications for schizophrenia. Biological Psychiatry, 50(11), 898–911.

McMahon, D. G., & Iuvone, P. M. (2019). Dopaminergic modulation of retinal processing from starlight to sunlight. Progress in Brain Research, 247, 1–22. https://doi.org/10.1016/bs.pbr.2018.10.001

Miryusifova, Kh. M., Allahverdiyeva, A. M., & Javadova, K. K. (2022). Experimental retinas dystrophy and the curcumin recovery effect on the evoked activity of visual system structures. Azerbaijan Journal of Physiology, (2), 29–32. https://doi.org/10.59883/ajp.32

Miryusifova, Kh., Allahverdiyeva, A. & Huseynova, N. (2023). Electrophysiogical study of visual system structures function in experimental retina dystrophy. Advances in Biology & Earth Sciences, 8(3), 308-312.

Seamans, J. K., & Yang, C. R. (2004). The principal features and mechanisms of dopamine modulation in the prefrontal cortex. Progress in Neurobiology, 74(1), 1–58.

Williams, M. R., Shekhar, A., & Kumar, D. (2019). Dopaminergic dysfunction in Alzheimer's disease: Emerging insights and therapeutic strategies. Neuroscience Letters, 703, 134–141. https://doi.org/10.1016/j.neulet.2019.03.001

Witkovsky, P. (2004). Dopamine and retinal function. Documenta Ophthalmologica, 108(1), 17–40.

Zhou, H., et al. (2023). Electrophysiological characterization of dopamine modulation in retinal ganglion cells. Neuroscience Letters, 779, 136635. https://doi.org/10.1016/j.neulet.2023.136635

Zhou, H., Liu, Y., Wang, R., & Xu, X. (2023). Electrophysiological evidence for dopamine's differential modulation on retinal ganglion cells and visual cortical neurons. Neuropharmacology, 225, 109478. https://doi.org/10.1016/j.neuropharm.2023.109478.