Neuromorphic Computing in the Study of Neuroplasticity in Astronauts in Microgravity.

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Abstract

Long-duration space missions expose astronauts to a unique set of challenges—microgravity, ionizing radiation, disrupted circadian rhythms, and isolation—that can induce significant alterations in the central nervous system (CNS). These stressors are linked to neurovestibular dysfunction, cognitive impairments, and shifts in brain fluid dynamics, yet our understanding of the underlying neuroplastic changes remains limited. This gap in knowledge impedes the development of effective countermeasures to safeguard astronaut health on extended missions. Neuroimaging studies employing techniques such as magnetic resonance imaging (MRI), diffusion tensor imaging, and functional MRI have identified structural and functional modifications in key brain regions, notably within the cerebellum, sensorimotor cortex, and vestibular pathways. Although these studies have highlighted short-term adaptations, their heterogeneous experimental setups and focus on peripheral functions leave unanswered questions regarding the long-term effects of spaceflight on the CNS. To address these challenges, we propose an innovative framework that integrates neuromorphic computing to simulate and analyze neuroplastic responses under spaceflight conditions. By employing deep learning models to process neural signals and MRI data, alongside spiking neural networks that capture the temporal dynamics of brain activity, our approach offers a computational alternative to direct in-flight experimentation. This methodology builds upon recent findings (Yin et al., 2023; Chibás-Muñoz, 2024; IBM, 2025) and is designed to model the impact of microgravity and other space-related stressors on neural connectivity and plasticity. We anticipate that our approach will yield a detailed mapping of neuroplastic adaptations in astronauts, identifying key biomarkers associated with CNS alterations during and after space missions. These insights are expected to inform the development of targeted countermeasures, ultimately enhancing astronaut safety and performance for future long-duration interplanetary missions and space tourism endeavors.

Keywords: Microgravity, Astronaut, Space Life Sciences, Neuromorphic Computing, Neuroplasticity, Artificial Neural Networks.

References

[1] Yin Y, Liu J, Fan Q, Zhao S, Wu X, Wang J, Liu Y, Li Y, Lu W. Long-term spaceflight composite stress induces depression and cognitive impairment in astronauts–insights from neuroplasticity. *Transl Psychiatry.* 2023 Nov 8;13(1):342. doi:10.1038/s41398-023-02638-5. PMID: 37938258; PMCID: PMC10632511.

[2] IBM. (n.d.). Neuromorphic computing. IBM. Retrieved from https://www.ibm.com/blogs/neuromorphic-computing

[3] Song Z, Zhou Y, Feng J, Juusola M. Multiscale 'whole-cell' models to study neural information processing – New insights from fly photoreceptor studies. *J Neurosci Methods.* 2021;357:109156. doi:10.1016/j.jneumeth.2021.109156.

[4] Van Ombergen A, Demertzi A, Tomilovskaya E, Jeurissen B, Sijbers J, Kozlovskaya IB, Parizel PM, Van de Heyning PH, Sunaert S, Laureys S, Wuyts FL. The effect of spaceflight and microgravity on the human brain. *J Neurol.* 2017 Oct;264(Suppl 1):18-22. doi:10.1007/s00415-017-8427-x. Epub 2017 Mar 7. PMID: 28271409; PMCID: PMC5610662.

[5] Van Ombergen A, Laureys S, Sunaert S, Tomilovskaya E, Parizel PM, Wuyts FL. Spaceflight-induced neuroplasticity in humans as measured by MRI: what do we know so far? *NPJ Microgravity.* 2017 Jan 10;3:2. doi:10.1038/s41526-016-0010-8. PMID: 28649624; PMCID: PMC5445591.

[6] Demertzi A, Van Ombergen A, Tomilovskaya E, Jeurissen B, Pechenkova E, Di Perri C, Litvinova L, Amico E, Rumshiskaya A, Rukavishnikov I, Sijbers J, Sinitsyn V, Kozlovskaya IB, Sunaert S, Parizel PM, Van de Heyning PH, Laureys S, Wuyts FL. Cortical reorganization in an astronaut's brain after long-duration spaceflight. *Brain Struct Funct.* 2016 Jun;221(5):2873–2876. doi:10.1007/s00429-015-1054-3. Epub 2015 May 12. Erratum in: *Brain Struct Funct.* 2016 Jun;221(5):2877. doi:10.1007/s00429-016-1209-x. PMID: 25963710; PMCID: PMC4884200.

[7] Koppelmans V, Erdeniz B, De Dios YE, Wood SJ, Reuter-Lorenz PA, Kofman I, Bloomberg JJ, Mulavara AP, Seidler RD. Study protocol to examine the effects of spaceflight and a spaceflight analog on neurocognitive performance: extent, longevity, and neural bases. *BMC Neurol.* 2013 Dec 18;13:205. doi:10.1186/1471-2377-13-205. PMID: 24350728; PMCID: PMC3878338.

[8] Newberg AB, Alavi A. Changes in the central nervous system during long-duration space flight: implications for neuro-imaging. *Adv Space Res.* 1998;22(2):185–196. doi:10.1016/s0273-1177(98)80010-0. PMID: 11541396.

[9] Rezaei S, Seyedmirzaei H, Gharepapagh E, Mohagheghfard F, Hasankhani Z, Karbasi M, Delavari S, Aarabi MH. Effect of spaceflight experience on

human brain structure, microstructure, and function: systematic review of neuroimaging studies. *Brain Imaging Behav.* 2024 Oct;18(5):1256–1279. doi:10.1007/s11682-024-00894-7. Epub 2024 May 22. PMID: 38777951; PMCID: PMC11582179.

[10] Hur C, Ibrokhimov B, Kang S. N3-CPL: Neuroplasticity-based neuromorphic network cell proliferation learning. *Neurocomputing.* 2020;411:193–205. doi:10.1016/j.neucom.2020.06.012.

[11] Allam, Z. Achieving Neuroplasticity in Artificial Neural Networks through Smart Cities. *Smart Cities.* 2019;2:118–134. https://doi.org/10.3390/smartcities2020009.