 DOI: 10.3217/978-3-99161-050-2-123

# Star-Burst paradigm: implementation of an “invisible” dry-EEG reactive BCI

**J. Gomel[1*] , J. Torre-Tresols, P. Cimarosto[1], K. Cabrera Castillos[1], F. Dehais [1]**
[1]*Fédération ENAC ISAE-SUPAERO ONERA, Université de Toulouse, France;*
[*]10, Avenue Marc Pélegrin, 31055, Toulouse, France. E-mail: jules.gomel@isae-supaero.fr

*Introduction:* Code Visually Evoked Potentials (c-VEP) have become increasingly popular in the rBCI community, leveraging pseudo-random visual flickers that offer shorter calibration times compared to Steady State VEP [1]. However, the application of c-VEP-based reactive BCIs has largely remained confined to laboratory settings due to the reliance on wet EEG systems and synchronous paradigms with fixed decoding times. To address these challenges, our team used innovative repetitive visual stimuli called StAR (Stimuli for Augmented Response). These stimuli are engineered with specific, mostly invisible textures that elicit neural responses ranging from retinal ganglion cells (contrast detection) to visual cortex cells (orientation selectivity) [2]. Our StAR stimuli are activated using a burst-code VEP paradigm, featuring brief, aperiodic visual flashes presented at a slower rate of three flashes per second. This approach elicits stronger visual evoked responses compared to traditional maximum length sequences [3]. Each stimulus (e.g., a letter or digit) is presented with its own unique pseudo-random code comprising an alternating sequence of '1' (on) and '0' (off). This innovative approach dramatically reduces calibration time to under one minute, as the algorithms only need to differentiate brain responses to the presence (visual ERP) or absence of a flash (no visual ERPs).

*Material, Methods and Results:* The online StAR-Burst rBCI was developed using Timeflux framework [4]. This system was specifically designed for an 11-class classification task to predict participants' attention in real time based on visual stimuli. It utilizes a combination of XDawn spatial filtering and Riemannian-based tangent space classifiers for optimal performance. The 11 commands corresponding to the T9 keypad were encoded using 11 unique burst codes [3], carefully designed to maximize discrimination between commands. The classification pipeline was followed by a correlation-based accumulation method, allowing flexible, self-paced decoding time. Eighteen participants were equipped with an 8-channel dry EEG system (Enobio), with electrodes placed over the occipital and parieto-occipital cortex areas (PO7, O1, Oz, O2, PO8, PO3, POz, PO4) to capture visually evoked potentials (VEPs). They underwent an 40-second calibration procedure before performing an online T9 pinpad self-paced task consisting of 10 sequences, each containing four targets, resulting in a total of 40 targets per participant. The StAR-Burst rBCI demonstrated high performance, achieving a mean accuracy of 96.3% (SD = 4.79) and a mean decoding time of 4.2 seconds (SD = 5.5). A video showcasing the BCI can be seen here https://nextcloud.isae.fr/index.php/s/dxLqYXRAMEep98C.

*Conclusion:* Collectively, these findings highlight the transformative potential of StAR-Burst paradigm driving the evolution to make BCIs more user friendly and efficient. Our implementation achieved high accuracy levels with a dry EEG system, requiring only minimal calibration data (40s). This paradigm, characterized by comfort and subtle perceptibility in peripheral vision, show potential for applications in various reactive BCI paradigms such as P300 speller, SSVEP, and oddball-based BCI. The application of the proposed StAR approach may be extended beyond technological innovation to fundamental cognitive neuroscience research, providing a valuable avenue for exploring cognition.

*Acknowledgments and Disclosures:* This work is funded by Agence Innovation Defense (VIPER)

*References:*

[1] Martínez-Cagigal, V., Thielen, J., Santamaria-Vazquez, E., Pérez-Velasco, S., Desain, P., & Hornero, R. (2021). Brain–computer interfaces based on code-modulated visual evoked potentials (c-VEP): a literature review. Journal of Neural Engineering, 18(6), 061002.

[2] Dehais, F., Cabrera Castillos, K., Ladouce, S., & Clisson, P. (2024). Leveraging textured flickers: a leap toward practical, visually comfortable, and high-performance dry EEG code-VEP BCI. Journal of neural engineering, 21(6), 10.1088/1741-2552/ad8ef7

[3] Castillos, K. C., Ladouce, S., Darmet, L., & Dehais, F. (2023). Burst c-VEP based BCI: optimizing stimulus design for enhanced classification with minimal calibration data and improved user experience. NeuroImage, 284, 120446.

[4] P Clisson, R Bertrand-Lalo, Marco Congedo, G Victor-Thomas, J Chatel-Goldman. Timeflux: an open-source framework for the acquisition and near real-time processing of signal streams. *BCI 2019 - 8th International Brain-Computer Interface Conference*





Published by Verlag der Technischen Universität Graz