Artifact removal in real-time for hdEEG-BCI systems

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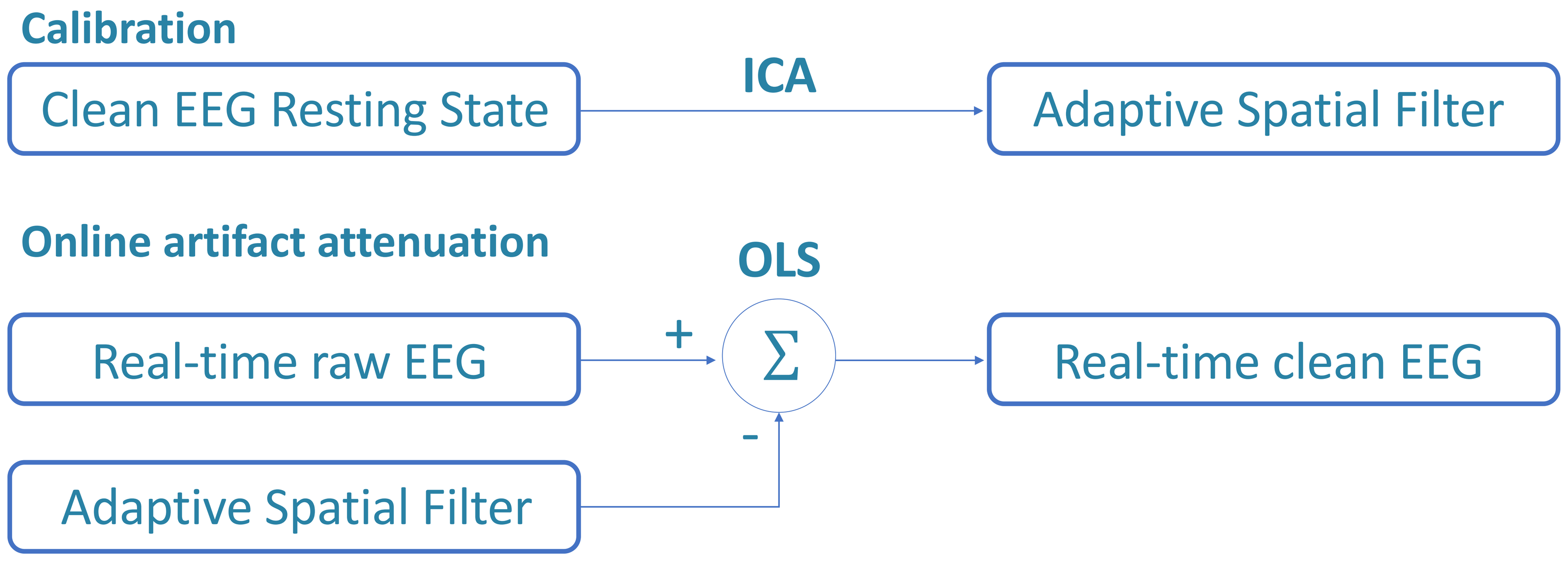
Background

In recent years, high-density EEG electroencephalography (hdEEG) have become available, permitting to increase the spatial resolution of the reconstructed neural activity. These developments have opened the doors to the use of hdEEG as a brain imaging tool [1]. For this reason, recent developments lead to innovative brain-computer interface (BCI) applications requiring hdEEG recordings. The performance of hdEEG-BCI systems strongly depends on the effective attenuation of artifacts mixed in the recordings. As such, we introduce an artifact removal solution (ICA-OLS) that combines Independent Component Analysis (ICA) [2] and Ordinary Least Square Regression Method (OLS) [3], providing high accuracy and algorithmic efficiency. After the method development, we performed an optimization of the ICA-OLS parameters and finally we validated our approach comparing it with respect to other methods.

Methods



- hdEEG data collected in 8 healthy participants using 256-channels system during resting state (4 minutes) and visual oddball tasks (3 minutes).

Optimization

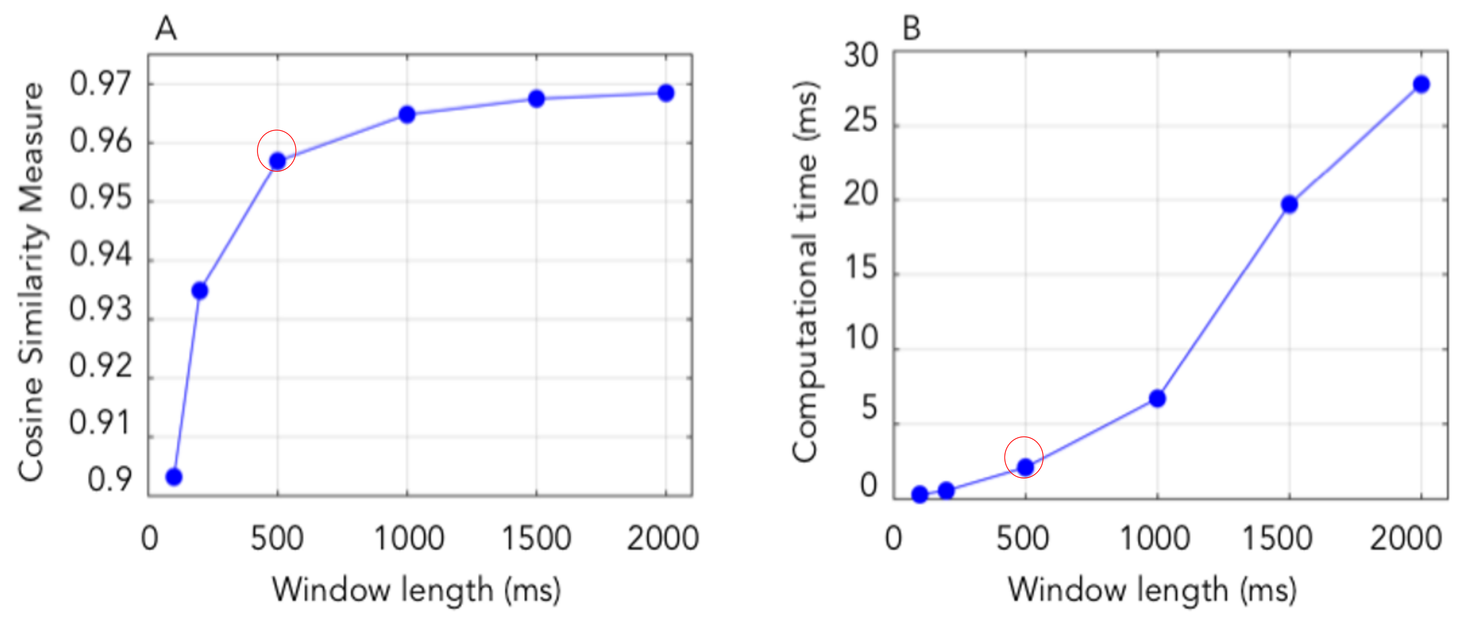


Fig. 1 - Optimization of ICA-OLS performance in a pseudo-online test. The size of the data buffer influences the reconstruction of the ocular artifact. A) Cosine Similarity Measure (CSM) and B) computational time. Since the EEG signal was sampled at 200 Hz, 5 ms is the maximum delay that could be accepted in online EEG processing. Therefore, we selected 500 ms as the standard buffer size for ICA-OLS.

Results

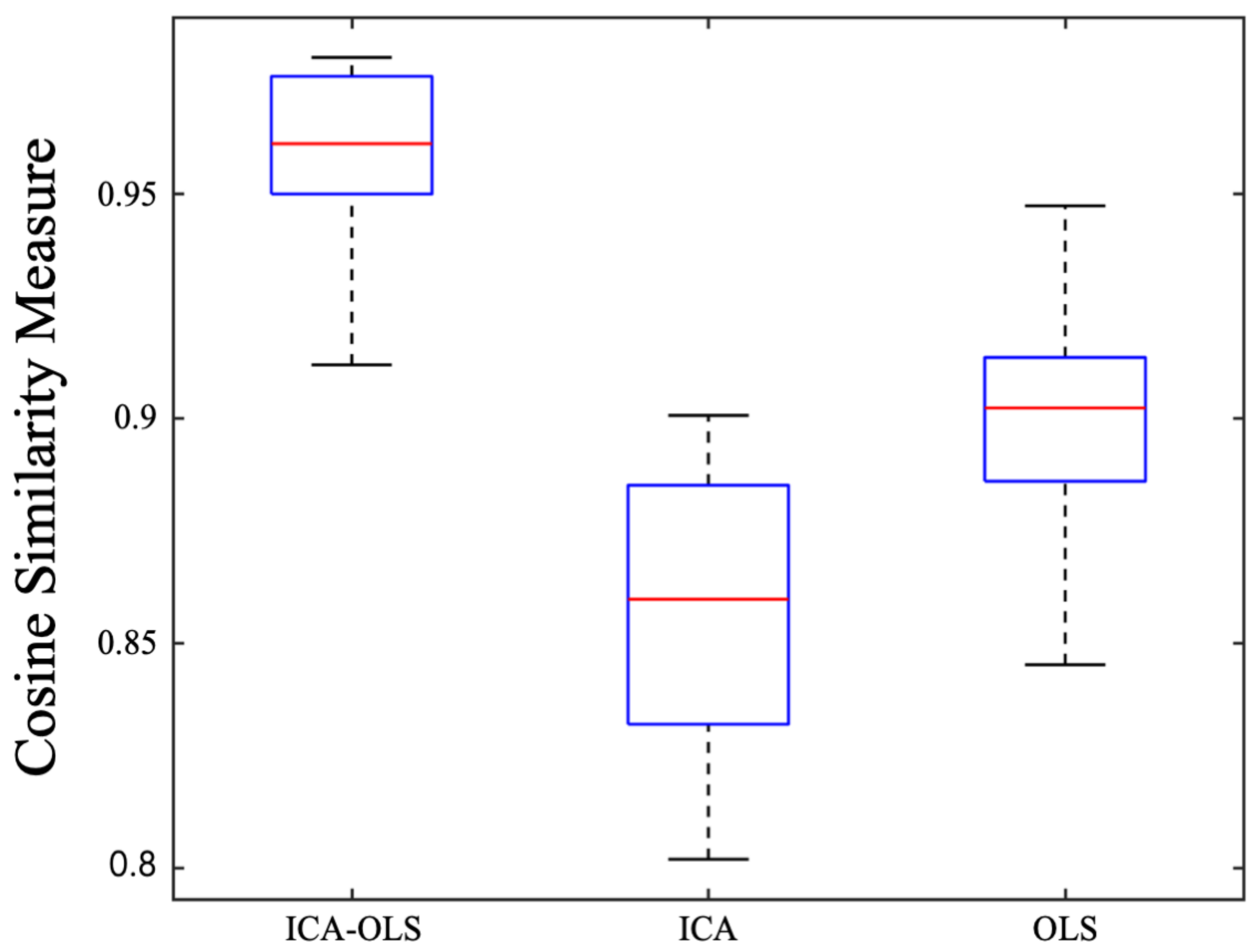


Fig. 2 - Quantitative assessment of EOG artifact attenuation across methods. Comparison is performed by examining the CSM and box plots are provided. ICA-OLS, ICA and OLS methods were applied for removing the EOG artifact from the EEG recordings. ICA-OLS method outperforms the other methods in term of EOG artifact attenuation.

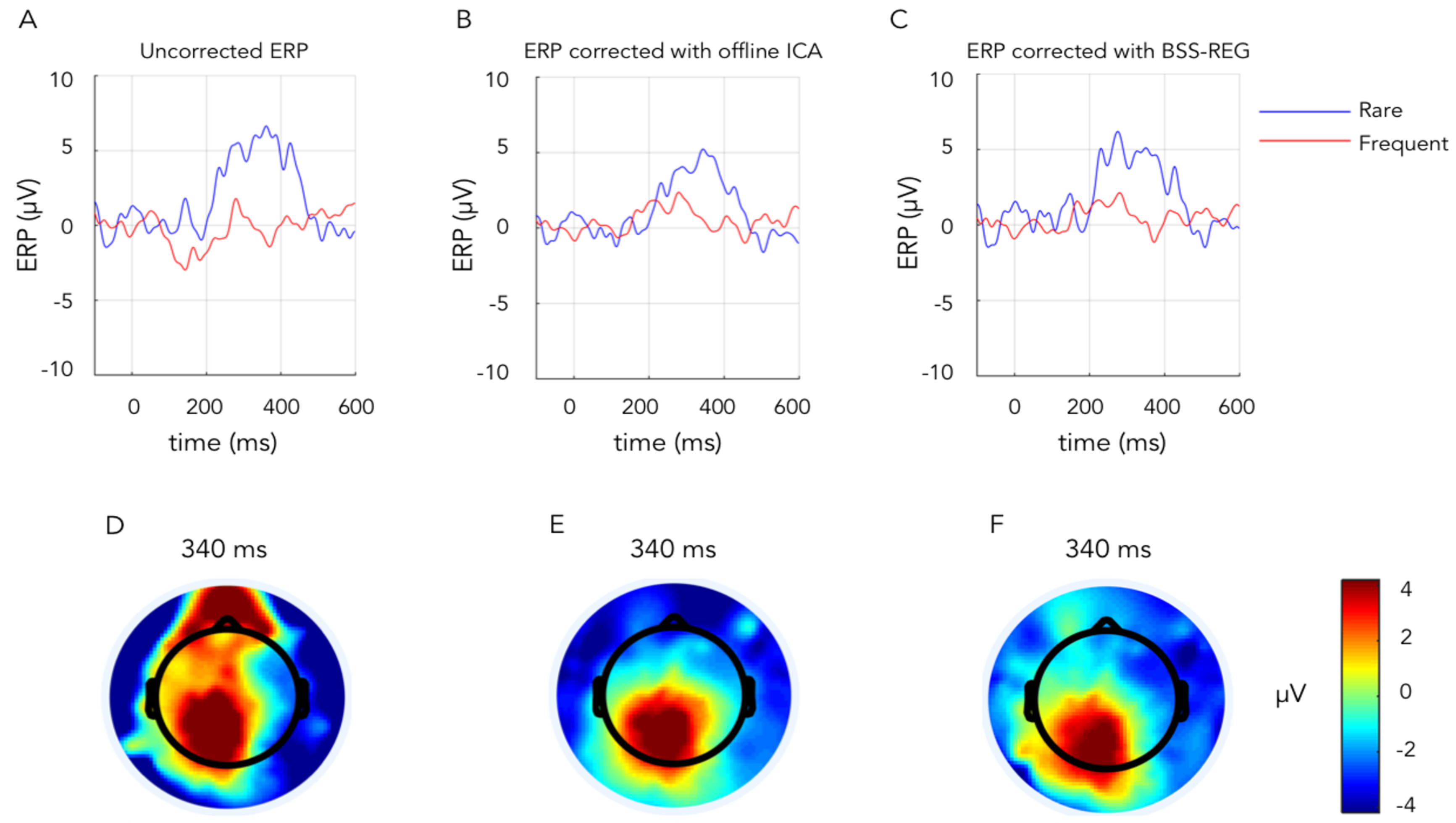


Fig. 4 - Single-subject ERP analysis of real EEG signals at the electrode Pz with rare and frequent events and scalp topography of ERPs associated with P300 response at 340 ms during oddball task. We evaluated whether ICA-OLS can be used for the removal not only of ocular artifacts, but also muscular artifacts. A) Uncorrected dataset; B) corrected dataset with offline ICA; and C) corrected dataset with ICA-OLS.

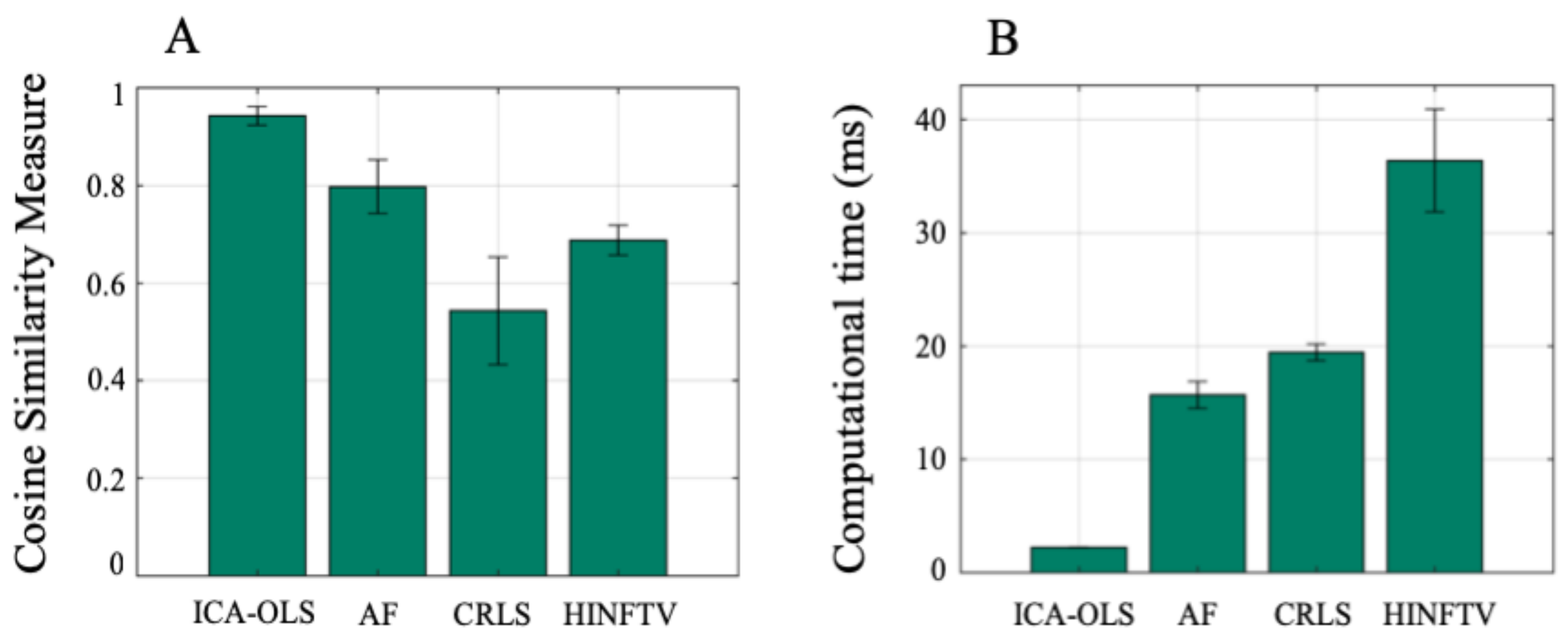


Fig. 3 - A) Cosine Similarity Measure in ICA-OLS, AF [4], CRLS [4] and HINFTV [5]. Paired t-tests denoted significant differences between ICA-OLS and AF, CRLS and H^{∞} ($p = 0.0042$, $p < 0.0001$ and $p < 0.0001$, respectively); B) bar plots showing the computational time for each method for a single data buffer of 500 ms. Paired t-tests revealed significant differences between BSS-REG and all the methods ($p < 0.0001$).

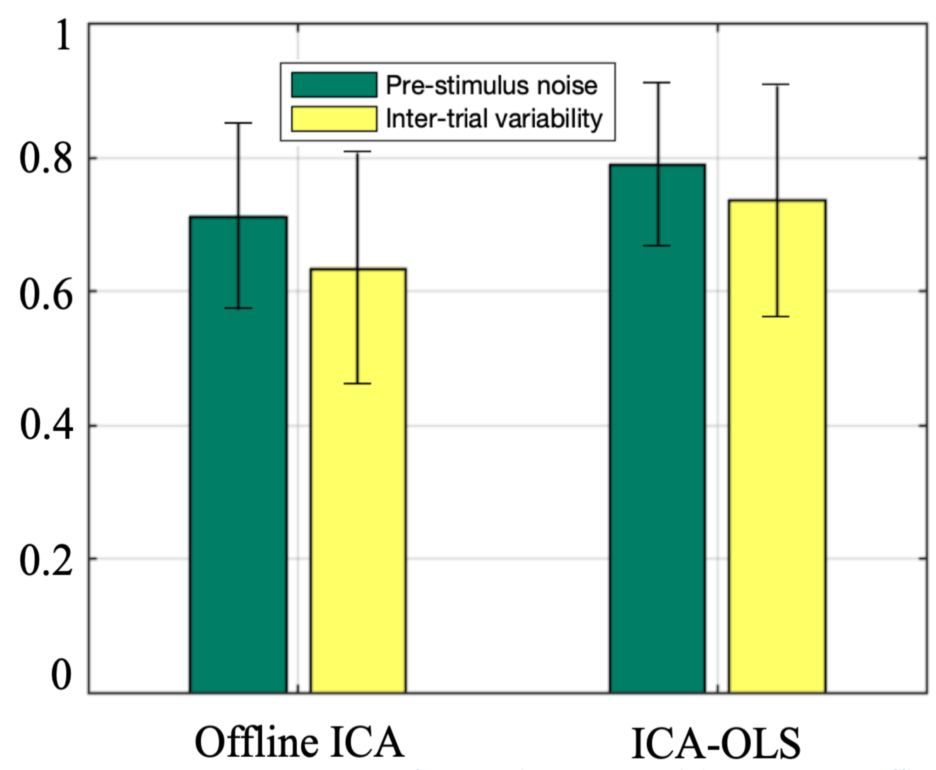


Fig. 5 - Quantitative assessment of ERP analysis using real data across ICA offline and ICA-OLS. Inter-trial variability and pre-stimulus noise are relatively larger for ICA-OLS, but there are no significant differences between methods ($p > 0.05$).

Conclusions

ICA-OLS has been developed for online artifact removal from EEG signals. It performs better than alternative methods for the removal of ocular artifact. Moreover, we have successfully applied ICA-OLS on real hdEEG data, leading to comparable performance to those of a standard offline ICA approach. Based to these findings, we argue that ICA-OLS may consent the development of novel BCI applications using hdEEG recordings, such as closed-loop neuromodulation and source-based neurofeedback.

Acknowledgments

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