# Electrocardiographic artifact suppression in local field potentials

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Deep brain stimulation (DBS) is a neurological procedure involving the implantation of a medical device called a neurostimulator, which is used to treat several neurological diseases, such as Parkinson's disease, essential tremor, and dystonia (Lozano et al., 2019). In the current standard of care, DBS is continuously delivered to the patients without an automated feedback system that allows them to adjust their therapy in response to changes in their motor symptoms. A recent focus of research has been on the development of adaptive DBS (aDBS), a system for monitoring the patient's clinical state and modulating stimulation in response to a biomarker detected in the patient's brain (Lozano et al., 2019). Local field potentials (LFPs) recorded from the DBS lead itself are widely accepted as potential feedback signals for aDBS systems. Several studies have shown that beta-band oscillations (13–35 Hz) of the subthalamic nucleus (STN) are associated with Parkinson's disease motor symptoms (Beudel et al., 2017), while beta-band power has been utilized in laboratory-based implementations of aDBS as a control signal (Velisar et al., 2019). As a key characteristic of pathological beta oscillations, their amplitudes do not persist continuously, but instead appear in short bursts of variable duration and intensity that are indicative of concurrent motor impairments (Tinkhauser et al., 2017). Hence, the success of aDBS implementation using subcortical LFP biomarkers, particularly within the frequency bands of interest, depends on the ability to accurately detect neural signals.

In 2020, Medtronic Percept™ PC became the first neurostimulator equipped with sensing technology approved by the Food and Drug Administration (Jimenez-Shahed, 2021). Despite this, it has been difficult to record LFPs that are of good quality with sensing-enabled neurostimulators due to electrocardiographic (ECG) artifacts (Anidi et al., 2018). Several studies have reported significant data loss as a result of ECG contamination (Quinn et al., 2015; Swann et al., 2017). Consequently, the researchers had to choose LFP channels that did not contain ECG contamination, which greatly constrained the precision of the exact positions of the recorded LFP signals (Swann et al., 2017).

Even though several methods are available for the removal of ECG artifacts from electrophysiological signals (Chatterjee et al., 2020), only a few of them can be applied to LFP recordings. An earlier study demonstrated the removal of ECG artifacts in a real-time scenario by using template subtraction (Zhou et al., 2007). This method is also used in recent studies, in which ECG R-peak detection algorithms are used to detect ECG artifacts and a spike template is subtracted from contaminated recordings (Chen et al., 2021; Hammer et al., 2022). Another popular method is QRS interpolation, which is provided in the Perceive Toolbox developed specifically for the Medtronic Percept JSON dataset (Neumann et al., 2021). Using this method, the most prominent peak in the ECG artifact (QRS complex) is identified, and the ECG artifact is replaced with interpolation. Recently, Singular Value Decomposition (SVD) was also implemented on LFP recordings for ECG removal (Chen et al., 2021; Hammer et al., 2022). In brief, epochs of samples were extracted at timestamps of ECG incidence (identified by the same technique used with template subtraction). Based on the SVD of this epoch matrix, a set of projections can be produced, which correspond to projections onto the principal component eigenvectors. By visual inspection, eigenvector projections that extracted signals consistent with ECG morphology were identified as being artifact related. Using these artifact-related components, ECG signals can be reconstructed and subsequently subtracted. In an exploratory study, the performance of these three common approaches has been compared, showing the possibility of ECG artifact removal from LFP recordings (Hammer et al., 2022).

In this volume of *Clinical Neurophysiology*, Stam and colleagues present a deeper and objective evaluation of the common ECG suppression approaches with a larger sample size (Stam et al., 2023). In this study, automated detection of R-peaks did not achieve the same level of accuracy as human visual inspection in detecting ECG artifacts. It should be noted that the R-peak of the ECG can be located close to neural activity in some cases, which makes human visual inspection even more challenging. Thus, an additional recorded ECG signal can assist in determining the time stamp of the peak and facilitate the performance of the ECG suppression technique. Alternatively, ECG measurements can be performed via a monopolar recording channel between the titanium case and one contact (Chen et al., 2021). However, this feature is not currently available in Medtronic Percept. Among the approaches mentioned above, the most effective ECG suppression was achieved by SVD (Stam et al., 2023). It is also consistent with an earlier study by Hammer and colleagues (Hammer et al., 2022) where they conducted analysis using only the first principal component eigenvector.

One key contribution of the paper is its in-depth analysis of SVD performance in various settings. With the ability of SVD to decompose a signal into a given number of principal components, Stam and colleagues attempted different numbers of decomposition.

They revealed that when dealing with a longer time window of ECG artifacts, a greater number of component decomposition preserved the least beta peak (Stam et al., 2023). A possible explanation for this could be that additional signal information can add extra weight to the complexity of the signal. As a result, the artifact-related component contains a higher percentage of beta information, which is subtracted during subsequent processing, resulting in less beta peak preservation. Even though they demonstrated a smaller difference in beta band power compared to the reference signal, it should be considered that there might be loss of beta information.

As described in this article, several ECG suppression methods previously demonstrated effective performance on the removal of ECF artifacts. It is important to note that the methods rely on automated R-peak detection algorithms that require an additionally recorded ECG signal in order to achieve the most accurate performance. When using an SVD approach, the trade-off between an optimal time window and the number of principal components might present a barrier and challenge for generalized usage in aDBS. Despite the need to further explore a generalized solution for the removal of artifacts from ECGs based on individual variability, the characteristics of the currently available methods are likely to serve as an alternative solution for different cases, shaping the future of aDBS.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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