

# Towards non-invasive BCI controlled grasp neuroprostheses - systematic analysis of FES-induced artefacts on EEG-signals

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**Abstract.** This work aims at the investigation of the artefacts in EEG-signals caused by Functional Electrical Stimulation (FES) of arm muscles. In a first step an “in-vitro” testbed for simulation of the situation in humans has been set up. The simulation of different FES- and EEG-electrode conditions revealed that the EEG amplifier impulse response is independent from electrode parameters like size, position or interelectrode distance. In a second step these results have been confirmed in healthy subjects with a low-frequency stimulation of forearm muscles. Finally, a reference artifact signal has been determined and several methods for artefact suppression have been tested.

**Keywords:** Functional Electrical Stimulation, EEG, BCI, artefact, grasp neuroprostheses

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## 1. Introduction

Among the goals of the European project TOBI (FP7-224631) is the improvement of the upper extremity function in very high level spinal cord injured patients by a hand and arm neuroprosthesis based on FES combined with a lockable elbow orthosis. In these patients, only limited residual functions are preserved for control of such a device and therefore a non-invasive Brain-Computer Interface (BCI) based on EEG-signal alterations during motor imagery (MI) is introduced.

Up to now, it is still unclear in which way FES stimulation pulses influence the performance of a MI-BCI [Müller-Putz et al., 2006]. Since the common FES stimulation frequencies are in the range of 16-20 Hz, which overlap with frequency bands analysed for operation of a MI-BCI (5-40 Hz), a simple band elimination filter approach does not suppress the artefacts. Although it has already been shown that FES leads to artefacts in EEG signals [Allen et al., 2010], the influence of different FES electrode parameters on the shape of these artefacts has not been quantified yet.

Therefore the shape of the FES artefacts has been systematically examined in an “in-vitro” (experiment A1) and afterwards validated in an “in-vivo” (A2) setup. In a second step two approaches for artefact suppression by hardware blanking (B1) and software filtering (B2) has been investigated.

## 2. Material and Methods

In a first step, experiments A1 and A2 have been carried out. In A1 FES generated artefacts has been recorded in an “in-vitro” testbed, in which three parameters namely arm length, distance between two stimulation electrodes and size of these electrodes have been varied. Herewith variations in the shape of the artefact can be detected. In A2, investigations with healthy human subjects about the transfer of the results from the testbed to the “in-vivo” situation have been performed.

### 2.1 Test setup

The BCI system consists of a computer with an EEG amplifier (g.USBamp, gtec, Graz), BCI software from TU Graz and an FES system (Motionstim, Krauth & Timmermann, Hamburg). In A1, a set of sponges soaked in a predefined dose of physiological saline solution is used in order to simulate the electrical conductivity of a human body. In A2, two volunteers with different arm lengths have participated in the experiment. Each trial of simultaneous stimulation and EEG-recording consisted of a permutation of the three parameters mentioned above and was repeated 30 times. In both A1 and A2,

rectangular current impulses with a pulse width of 400  $\mu\text{s}$  and an amplitude of 20 mA were used. The cut-off frequencies of the bandpass filter of the EEG amplifier have been set to 0.5 and 100 Hz and a notch filter (50 Hz) has been activated. Data were recorded with a sample rate of 256 Hz.

## 2.2 Data processing and comparison

The FES-artefacts have been detected by the help of a proprietary threshold algorithm. The algorithm searches within EEG time series for samples, whose absolute amplitude is higher than a predefined threshold. Each time the threshold is exceeded, a section of 0,5 s is marked as an artefact, which is then normalized by the peak amplitude. After this period only low-frequency components of the artefact remain in the EEG signal that can be easily filtered out. At the end of this section, the algorithm starts a new search. For each trial, an averaged artefact was computed by arithmetic averaging of the artefacts found in the trial. The artefacts of all trials have been averaged (“reference artefact”) and compared by a variant of the Pearson correlation coefficient.

## 2.3 Methods for minimisation of artefacts

A hardware based suppression method has been realized, in which a trigger signal from the FES device was sent to the blanking-port of the EEG amplifier with every stimulation pulse (B1). Furthermore, a software comb filter implemented in Matlab was used (B2) for removal of FES induced artefacts. Such a filter is typically used to remove a dedicated frequency band and its harmonics from a given signal and therefore seems to be ideally suited for the artefact removal in this application.

## 3. Results

The most important result of the experiments is that the averaged artefacts from all trials correlate to approx. 95%. In Figure 1 the artefact averaged over all trials with volunteers (“reference artefact”) is shown. It was found that the artefact looks very similar to the impulse response of a software filter with the same characteristics like the inbuilt filter of the EEG amplifier. Therefore this has been identified as the main cause for the artefacts. Experiment B1 revealed that the input stage of the EEG amplifier shows the behavior of a step response when switching back from muting to normal operation. Therefore this method cannot be employed since the artefacts were even higher during hardware blanking. Experiment B2 shed light on a general drawback of the software comb filter, namely that it does not only rejects the narrow bandwidth of the artefact but also frequency components of the desired signal. Therefore, this method cannot be recommended for minimising the artefact in the given application.

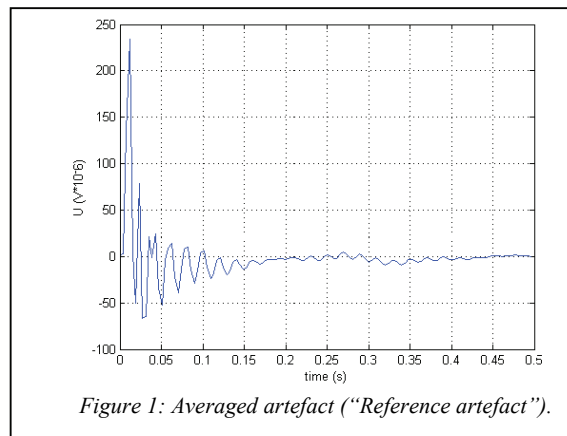


Figure 1: Averaged artefact (“Reference artefact”).

## 4. Discussion and outlook

For the first time, a systematic analysis of FES-induced artefacts on EEG-signals has been accomplished. “In-vitro” as well as “in-vivo” test setups showed that the shape of the artefacts can be assumed to be independent from electrode size, the position of FES electrodes in relation to EEG electrodes and the distance in between FES electrodes. An initial run for determination of the exact dimensions (amplitude and length) of the reference artefact in a given configuration has been performed. Based on these findings a threshold algorithm for detection of the onset of the artifacts in the raw EEG-signals is proposed, with which a detected artifact can be removed from the EEG-signals in real-time by simple subtraction of the reference artifact.

## References

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