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Reducing Artifacts in TMS-Evoked EEG

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Outline

- Introduction: analysis and approach
- Measurements and dataset
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- Acknowledgement

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Introduction (I)

- **Transcranial magnetic stimulation (TMS) may give new insights into the behavior of the human brain.**
- **TMS, along with Navigated Brain Stimulation (NBS) and electroencephalography (EEG), has revealed itself as a powerful non-invasive tool in studies about the brain's excitation threshold or the relation between cortical activity and movement**
- **Only the TMS-evoked brain response is desired; and any other signal corrupts the brain signal registered, complicating brain response analysis.**

Introduction (II)

- **Therefore, several methods used frequently to split up two signals [5-10] are considered in this work:**
  - **Signal-Space Projection (SSP),**
  - **Independent Component Analysis (ICA) and**
  - **Wiener Filtering,**

Introduction (III)

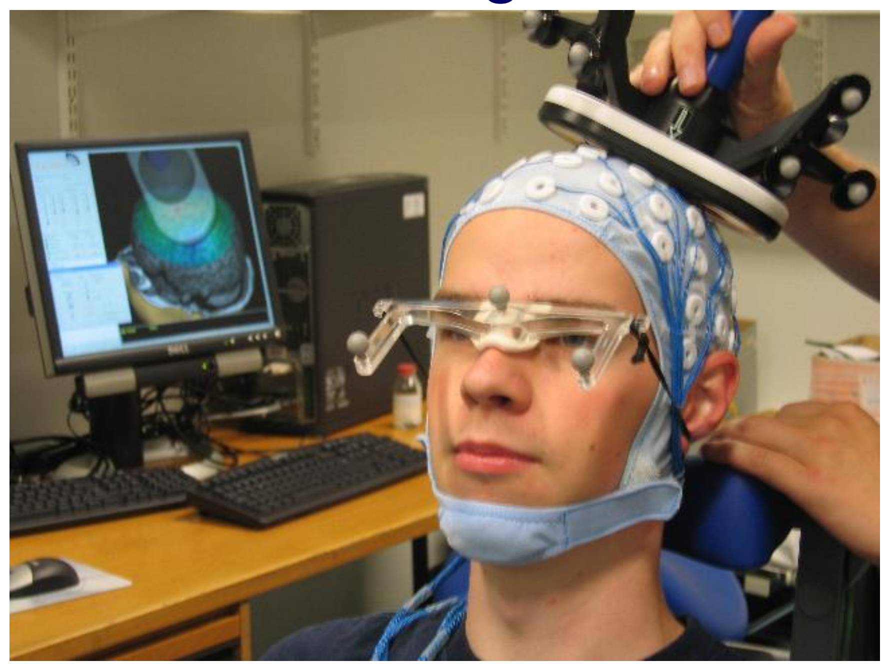
- In order to compare them and propose a novel system to reduce three different artifacts usually found in TMS-evoked responses:
  - Electromagnetic artifact (EM artifact). Artefact resulting from the large electric field induced by TMS in the electrode leads.
  - Blink artifact (B artifact). Artefact resulting from blinks.
  - Auditory artifact (A artifact). Brain response evoked by TMS coil click.

Measurements and dataset (I)

- The global experiment consisted of a set of 8 recordings with the goal of isolating each artifact thanks to the Nexstim eXimia NBS.
- The subject was a young healthy man (age 22, right handed) and he participated in the study after giving a written informed consent.
- The experimental protocol was approved by the Ethical Committee of the Helsinki University Central Hospital, where these data were obtained.

Measurements and dataset (II)

- **The researcher used the Nexstim eXimia TMS stimulator and delivered single pulses using a focal mono-pulse coil.**
- **The subject was seated in a reclining chair wearing earplugs**



Measurements and dataset (III)

- **The TMS-compatible EEG equipment with a 60-electrode cap was used for recording TMS-evoked potentials and its associated artifacts.**
- **The EEG, recorded from 100 ms pre- to 500 ms post-stimulus, was referenced to an additional electrode placed behind right ear, which is far away from the position of the coil (left hemisphere) when the desired location is stimulated.**
- **Simultaneously, an electrooculogram (EOG) was recorded to detect eye movements.**

Measurements and dataset (IV)

- **Measurements 1-3 had the aim of showing EM artifact with no/little brain response (analyzing the relation between brain response and intensity and show that the limit to elicit measurable EEG response is between 20% and 40% of MT).**
- **Measurements 6 and 7 should contain only auditory artifact because the distance prevents the pulse from reaching the brain with enough strength (magnetic field decays rapidly when the distance from the coil is increased).**

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Measurements and dataset (V)

- **Recording 8 contains blinks without any other brain response (the subject is not performing any task but blinking and there is no TMS).**

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Methods and techniques (I)

- **At least, 50 pulses were averaged in every experiment. In the blink recording, the 19 blinks taken in experiment were averaged, extracting them by searching for the maximum point of each blink and then getting a window of 600 ms around it (300 ms before and 300 ms after).**
- **To present the EEG data clearly, it was low-pass filtered after all processing, so that the figures were easier to read while not interfering with the procedures.**

Methods and techniques (II)

- **The filter used a 50th-order Hamming window and a cut-off frequency of 45 Hz.**
- **With the data acquired, the techniques to reduce the three artifacts were applied separately.**

Methods and techniques (III)

Signal-Space Projection (SSP)

- **Considering a d-channel measurement and a matrix m containing the measured value of each channel at each instant of time.**

$$m(t) = \sum_{i=1}^{M} a_i(t) \cdot s_i + n(t)$$

- **where m(t) is the measured signal at t, a_i is the time-varying amplitude of a fixed component s_i, having M different components. This model also includes some noise n(t), independently of the defined components.**

Methods and techniques (IV)

Signal-Space Projection (SSP)

- **Using Signal-Space Projection, the aim is to separate the signal m(t) into contributions of different sets of sources**

$$m(t) = s_{\parallel}(t) + s_{\perp}(t) + n(t)$$

- **The grade of success of SSP depends on SNR and the angles between the component vectors**

$$m(t) = a_1(t) \cdot s_1 + \sum_{i=2}^{M} a_i(t) \cdot s_i + n(t)$$

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Methods and techniques (V)

Signal-Space Projection (SSP)

- **This can be done by carefully planning experiments where the artifacts can be measured alone, as done in 'measurements', and then considering:**

$$\hat{s}_1 = \frac{m(t_1)}{\| m(t_1) \|}$$

being t_1 ideally the time when we have nothing but the artifact being extracted.

Methods and techniques (VI)

Signal-Space Projection (SSP)

- Finally, it must be remarked that the measuring accuracy of the artifact, and only the artifact, will also affect to the effectiveness of SSP.
- Moreover, if the artifact consists of several different directions at different proportions at different moments, t_1 would not represent the whole artifact, resulting in more inaccuracy in this model

Methods and techniques (VII)

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Independent Component Analysis (ICA)

- **The ICA model assumes having d linear mixtures of signal components si, $x_1 \ldots x_d$, each of which has the form:**

$$x = \sum_{i=1}^{d} a_i \cdot s_i$$

- **where d is the number of channels, x the measured signal in one channel and a is a weighting coefficient.**

Methods and techniques (VIII)

Independent Component Analysis (ICA)

- **Using a vector-matrix notation, it can be rewritten as:**

$$x = A \cdot s$$

- **The components s_i must be statistically independent (s_i provides no information about s_j) and only one of them may follow a Gaussian distribution.**

Methods and techniques (IX)

Independent Component Analysis (ICA)

- We are considering the brain responses and the artifacts to be non-Gaussian and independent from each other.
- The method will compute the inverse of A, then obtaining our components as follows:

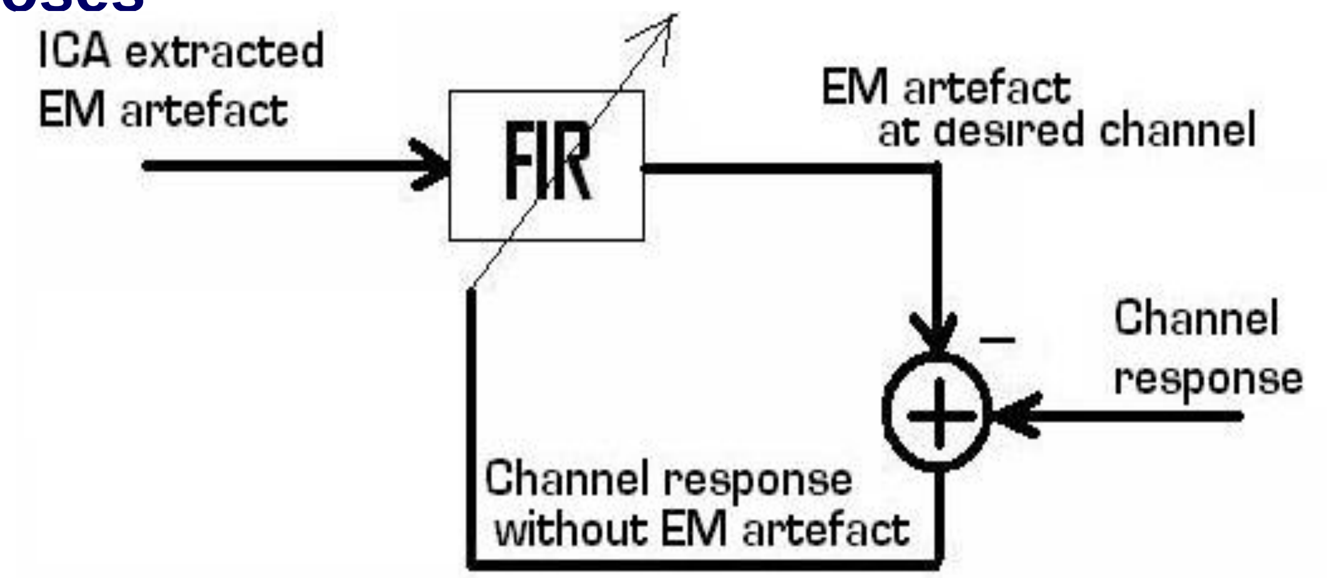
$$s = A^{-1} \cdot x$$

- A second step will be finding a way to make the extracted components useful. This last issue is accomplished with Wiener filtering.

Methods and techniques (X)

Wiener Filtering

- The so-called Wiener solution to design filters based on a desired output from a given input is widely known. These principles can be used for purposes



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Results (I)

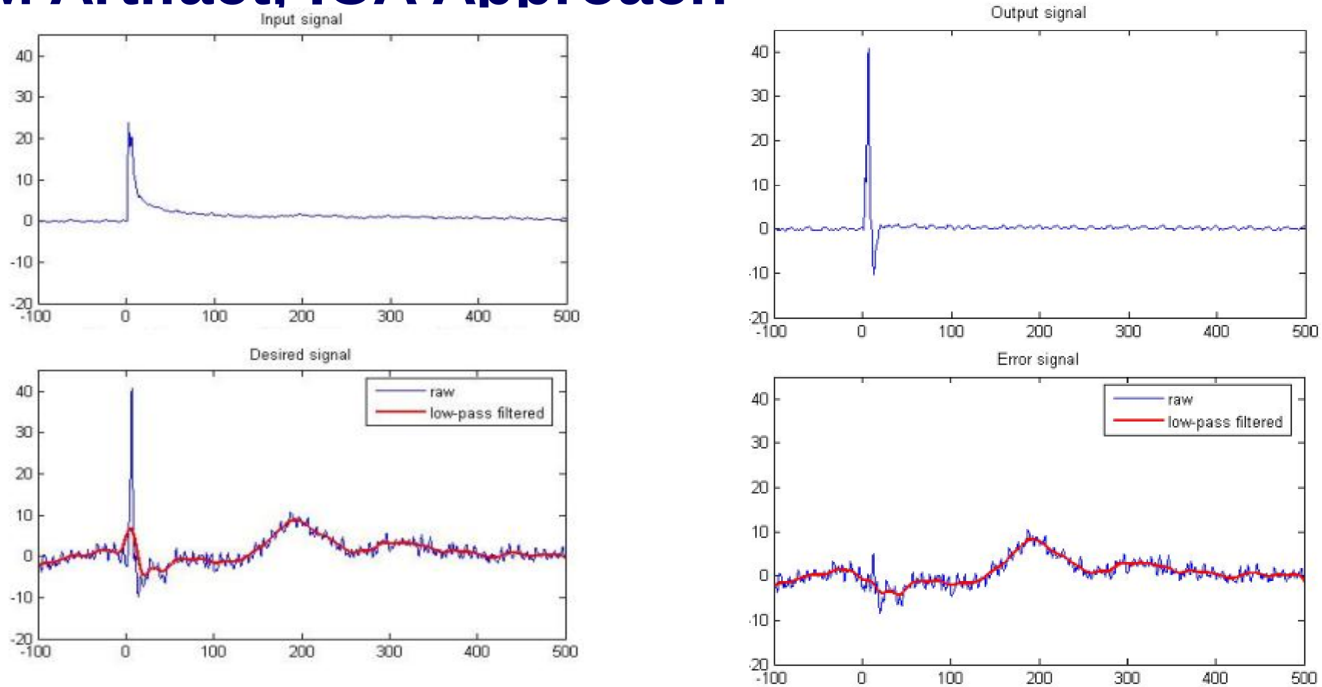
- **EM Artifact, SSP Approach**
- **We need to discover the direction of the EM artifact in the signal space.**
- **There are two main features of this artifact: high amplitude and short duration.**
- **The second feature turns the method less useful, as it is not possible to choose a common point among all the channels where the artifact is maximal.**
- **Hence, the artifact will be reduced less and/or the brain signal will be distorted.**

Results (II)

- **EM Artifact, ICA Approach**
- **An Independent Component Analysis was carried out to separate the components of the registered EEG and isolate the EM artifact.**
- **60 channels distributed across space makes ICA possible, but current understanding of brain signals may not be enough to identify the different independent components (ICs).**
- **Fortunately, the EM artifact has very well defined features (high frequency, large amplitude) which make it easy to be distinguished among the rest of the ICs.**

Results (III)

- **EM Artifact, ICA Approach**



- **Input signal (ICA extracted EM artifact); Desired signal (channel response); Output signal (EM artifact at desired channel) and error signal (cleaned channel response). Filter order M=20.**

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Results (IV)

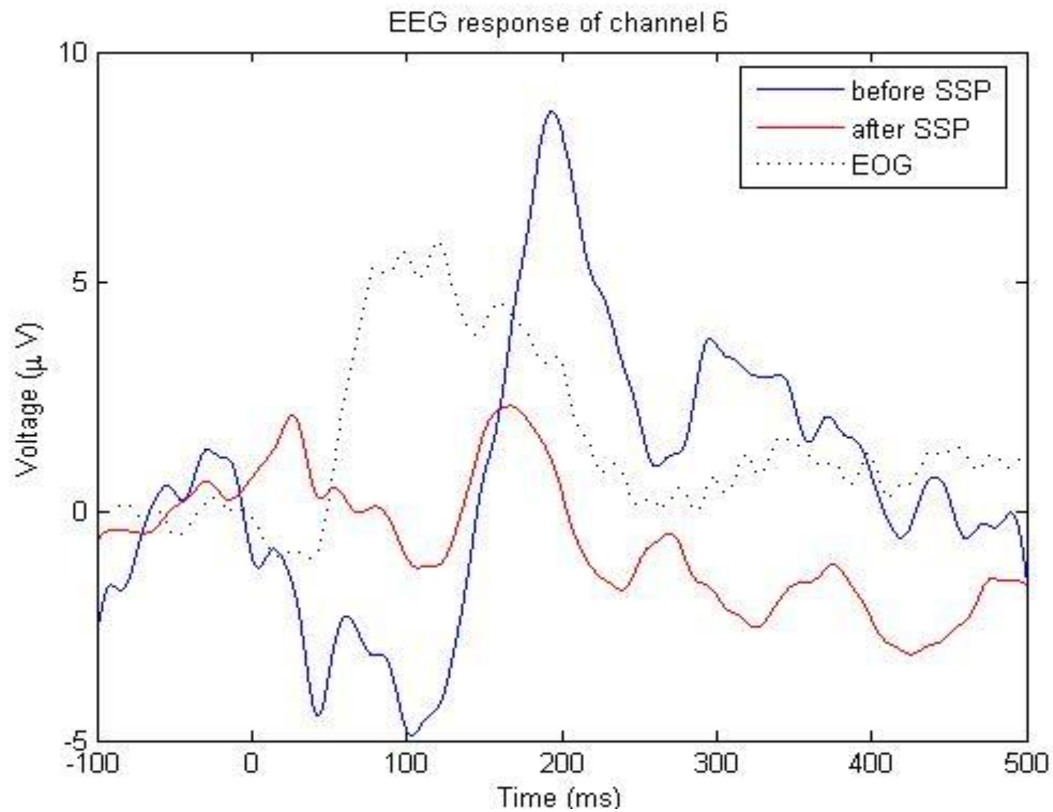
- **EM Artifact, ICA Approach**
- **The output of the filter represents the EM artifact at the desired channel (since it is what input and desired signals have in common) and finally, the minimized error signal used to calculate the filter coefficients is the EEG signal in the processed channel with the EM artifact reduced**

Results (V)

- **B Artifact, SSP Approach**
- **The SSP method is applied to remove the B artifact. The novelty here is having separate blink measurements (recording 8 of measurements).**
- **This allows us to estimate the blink artifact direction in the signal space and then use it to project the artifact away from the EEG signal**

Results (VI)

- **B Artifact, SSP Approach**



Results of SSP projecting away the B artifact.

Results (VII)

- **A Artifact, Direct Subtraction Approach**
- **Before going to SSP, the feasibility of direct subtraction (subtracting recordings 6 and 7 from a TMS-EEG signal) was tested.**
- **The N100 response, identified as the main consequence of the auditory artifact, is reduced in both cases; however, the rest of the waveforms are modified, especially the second one where the vibrations of the plastic distort them even more.**

Results (VIII)

- **A Artifact, SSP Approach**
- **As done in the previous approach, recordings 6 and 7 are considered as auditory response.**
- **They are used for estimating the direction of the artifact in the signal space.**
- **To select the right moment of time to estimate this artifact, direction vectors have been calculated at each instant of time for both the plastic and the no-plastic cases.**

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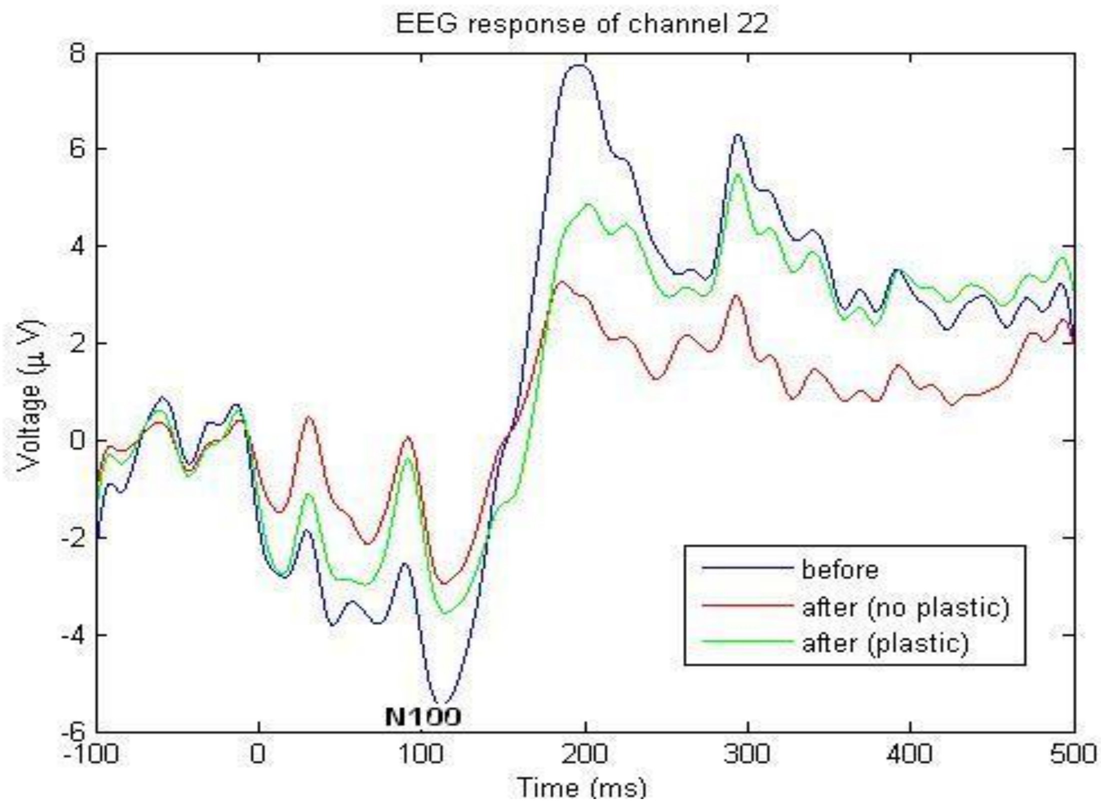
Results (IX)

- **A Artifact, SSP Approach**



Application of SSP in the right temporal area.

Discussion and Conclusions (I)

- **EM Artifact - Results achieved using SSP are poor when trying to reduce the EM artifact.**
- **The large amplitude and short duration characteristics cause problems in estimating the direction of the artifact in the signal space.**
- **On contrary, these features make it possible to be clearly identified with ICA.**
- **Wiener filtering makes good use of the ICA-extracted EM artifact to clean every channel from the EM artifact.**

Discussion and Conclusions (II)

- **B Artifact - SSP reduce the B artifact, but it is impossible to determine whether the modification is due to the reduction of blink artifact or not and in what measure.**
- **The vector used to project the artifact is a key factor to the expert on this point, not only because it determines how the artifact has been projected away, but also tells how the non-artifact sources have been modified.**

Discussion and Conclusions (III)

- **A Artifact - The direct subtraction method modifies the brain waveform to an unacceptable level.**
- **Its results should not be trusted until deeper understanding of the effects of the auditory response is achieved to prevent information loss.**
- **SSP provides a more conservative approach, reducing only the contamination of the coil click regarding the N100 response.**

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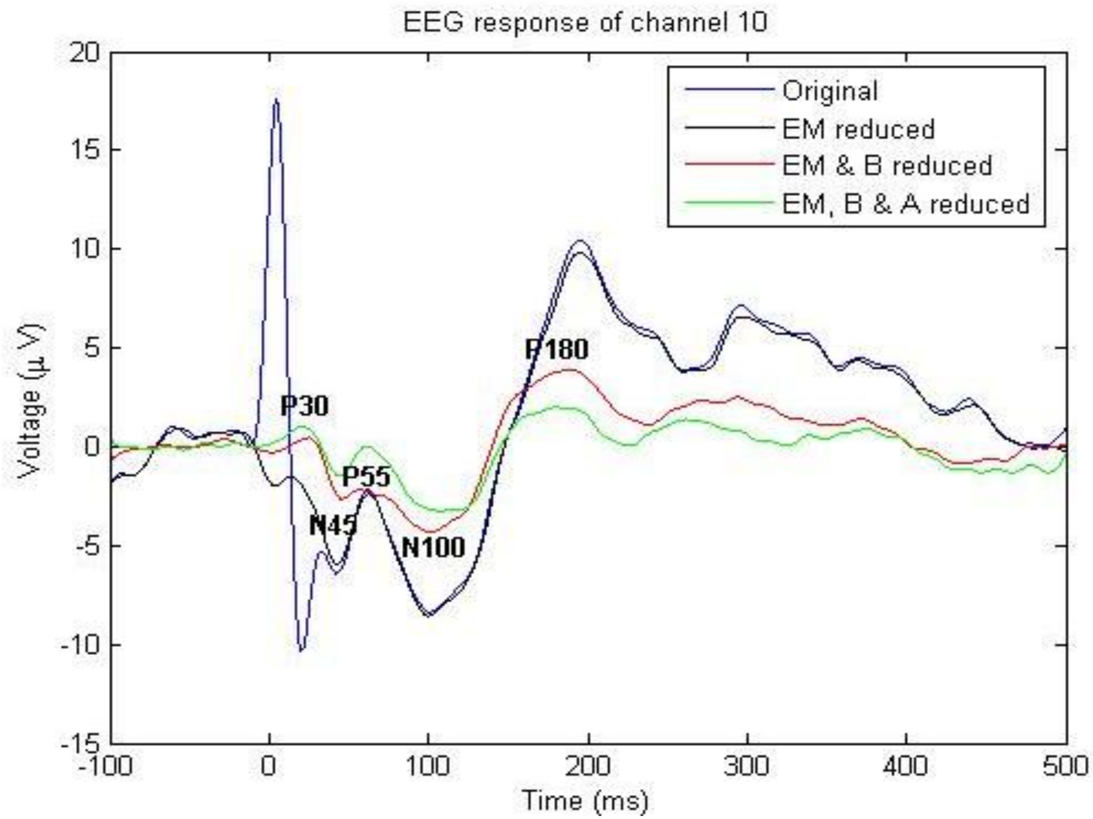
Discussion and Conclusions (IV)

- **It is easy to conclude that a system that combines the EM (ICA-Wiener), B (SSP) and A (SSP) artifact methods consecutively, would improve the quality of the information presented to physicians with TMS-EEG equipmen**

Discussion and Conclusions (V)

- **Signal evolution after each step of the whole procedure**



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