FP-2

Simultaneous deconvolution of multiple auditory evoked potentials in a reduced representation space

A. de la Torre[1,2], I. Sanchez[1,3], J. T. Valderrama[1,2,4], I. M. Alvarez[1,2], J. C. Segura[1,2], N. Muller[5], J. L. Vargas[5]
[1]*University of Granada, Department of Signal Theory, Telematics and Communications, Granada, Spain*
[2]*University of Granada, Research Centre for Information and Communications Technologies (CITIC-UGR), Granada, Spain*
[3]*AVVALE España S.L., Madrid, Spain*
[4]*Macquarie University, Department of Linguistics, Sydney, Australia*
[5]*Hospital Universitario Clínico San Cecilio, ENT Service, Granada, Spain*

Keywords: Deconvolution, least squares estimation, multi-response deconvolution, latency-dependent filtering and down-sampling (LDFDS).

Background: Deconvolution algorithms allow the estimation of transient auditory evoked potentials (AEPs) that are overlapped. Least squares deconvolution can be formulated as a linear system of equations, or equivalently, as a matrix equation. The deconvolution of AEPs involves a matrix division with a J x J matrix (being J the length of the response, in samples) [1,2]. Multi-response deconvolution with M categories of responses requires a matrix division with a (J x M) x (J x M) matrix, and the computational complexity of the deconvolution increases in scenarios involving several different stimuli (i.e., a large M) or longer duration responses (i.e., a large J).

Multi-response deconvolution: A method is proposed to effectively achieve multi-response deconvolution when long-duration AEPs and/or several categories of stimuli are considered. The method relies on the dimensionality reduction that provides latency-dependent filtering and down-sampling (LDFDS) [3], a procedure that progressively reduces the filter bandwidth and the sampling rate as the AEP latency increases. In LDFDS, wider filter bandwidths and higher sampling rates are used in early latencies (appropriate for auditory brainstem components), and narrower bandwidths and lower sampling rates in later components (appropriate for middle latency and cortical components). De la Torre et al. (2020) showed that a full-range AEP comprising auditory brainstem, middle latency, and cortical components (which usually requires J = 10.000 samples at a constant sampling rate) could be correctly represented without information loss in the reduced representation space with only J_r = 120 samples [3]. The dimensionality reduction provided by LDFDS is appropriate for deconvolution. In fact, de la Torre et al. (2022) showed that performing deconvolution of a single-category response in the reduced representation space reduces noise and computational cost [4]. Here we show that reducing the dimensionality is critical to perform multi-response deconvolution, as this reduces the size of the squared matrix to be inverted to (J_r x M) x (J_r x M) (being $J_r \ll J$).

Method validation: [*Methods*] The performance of the proposed method was evaluated in terms of its capability to accurately estimate overlapping AEPs evoked by different stimuli and the time required to perform deconvolution. Four normal-hearing adults (1 female, 23–38 years) participated in a study involving 84.000 click repetitions presented with an inter-stimulus interval that varied randomly between 15–30 ms, in which the stimulus level was also randomised between 0–80 dB HL. The EEGs (Fz–combined mastoid) were filtered using a 20–3300 Hz bandwidth to let pass both brainstem and middle-latency components. This experimental design allowed click events to be categorised in terms of different level intervals. For example, we considered (i) 20 dB intervals leading to M = 4 categories; (ii) 10 dB intervals leading to M = 8 categories, (iii) 5 dB intervals leading to M = 16 categories; and (iv) 2.5 dB intervals leading to M = 32 categories. The AEPs from each category were estimated via multi-response deconvolution, which was performed both in the complete representation space (using J = 3277) and in the reduced representation space (using J_r = 91).

[*Results*] The morphology of the deconvolved AEPs was consistent with previous literature. The components of brainstem and middle-latency responses could be identified in all participants, and followed the expected amplitude reduction and latency increase as level reduced. Increasing the number of categories (or equivalently, reducing the level interval) led to higher resolution in level but since less events belonged to each category, the AEPs were more affected by noise. Performing deconvolution in the reduced space led to a substantial reduction in processing time. For example, when 8 categories were considered, the multi-response deconvolution required 304 seconds in the complete space and 23 seconds in the reduced space. Importantly, deconvolution in the complete space could not be computed when more than 8 categories were considered due to memory overflow. However, multi-response deconvolution in the reduced space could be achieved in all scenarios.

Conclusion: Performing multi-response deconvolution in a reduced representation space significantly reduces processing time, and enables deconvolution when long-duration AEPs and/or several categories are considered. This overcomes an important technical barrier that has prevented a generalised use of this technology. Multi-response deconvolution is a tool that enables researchers design experiments with great flexibility, and may help advance knowledge in hearing neuroscience. For example, this tool may help understand how the human auditory system encodes complex sounds like real speech, binaural hearing processes, and characterise the well-known non-linearities of the auditory system.

[1] Bardy F, Dillon H, Van Dun, B (2014). Least-squares deconvolution of evoked potentials and sequence optimization for multiple stimuli under low-jitter conditions. Clinical Neurophysiology 125, 727-737. doi: 10.1016/j.clinph.2013.09.030.

[2] de la Torre A, Valderrama J, Segura JC, Alvarez I (2019). Matrix-based formulation of the iterative randomized stimulation and averaging method for recording evoked potentials. Journal of the Acoustical Society of America 146, 4545-4556. https://doi.org/10.1121/1.5139639.

[3] de la Torre A, Valderrama J, Alvarez I, Segura JC (2020). Latency-dependent filtering and compact representation of the complete auditory pathway response. Journal of the Acoustical Society of America 60, 96-103. https://doi.org/10.1121/10.0001673.

[4] de la Torre A, Valderrama J, Segura JC, Alvarez I, Garcia-Miranda J (2022). Subspace-constrained deconvolution of auditory evoked potentials. Journal of the Acoustical Society of America 151, 3745-3757. https://doi.org/10.1121/10.0011423.

e-mail corresponding author: atv@ugr.es