Deconvolution of Overlapping Responses and Frequency Domain-Based Artifact Rejection Methods using Randomized Stimulation and Averaging

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International Evoked Response Audiometry Study Group

- Good morning. My name is Joaquín Valderrama. I am with the University of Granada, in the south of Spain, and during the following 10 minutes I will present the work entitled "Deconvolution of overlapping responses and frequency domain-based artifact rejection methods using randomized stimulation and averaging".

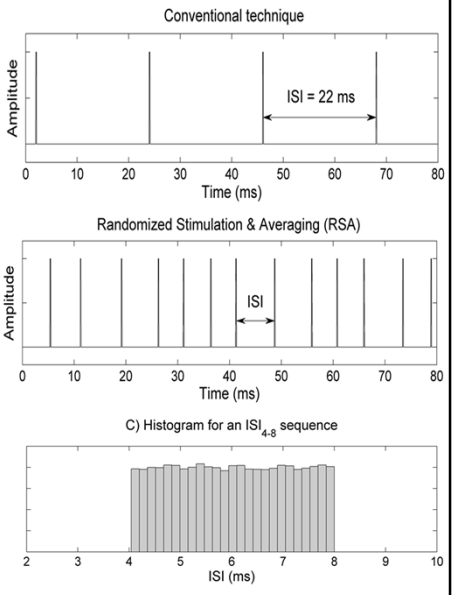
Structure

- Introduction. RSA method.
- Randomized Stimulation & Deconvolution (RSD)
- Results
- Conclusions

- I have structured this speech with a brief introduction about stimulating at high rates and the methodology RSA, I will describe a methodology that can be used to obtain deconvolved transient evoked potentials using randomized stimulation (RSD), I will present the results of this work and I will summarize the main conclusions.

Introduction. RSA method

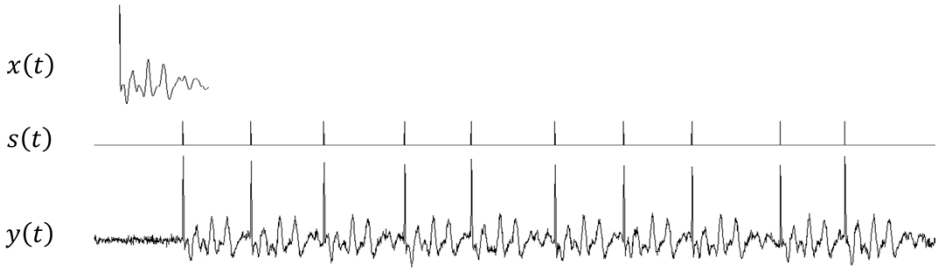
- The conventional methodology uses fixed ISI stimuli
- Advantages of stimulating at high rates
  - MLS (Eysholdt and Schreiner, 1982)
  - CLAD (Delgado and Ozdamar, 2004 ; Ozdamar and Bohorquez, 2006)
  - QSD (Jewett et al., 2004)
- Randomized stimulation and averaging
  - RSA (Valderrama et al., 2012)
  - Averages auditory responses corresponding to stimuli whose ISI vary according to a predefined probability distribution
  - Noise associated to overlapping responses
  - Motivation for RSD



- The conventional technique for ABR recording consists of averaging several auditory responses whose corresponding stimuli are periodically presented.
- This technique has the limitation that the stimulation rate cannot be higher than the averaging window to avoid the contamination of the recording by the adjacent response.
- However, the recording of evoked potentials at high stimulation rates could have many benefits, such as exploring the neural adaptation effect.
- For this purpose, many techniques have emerged to overcome the limitation imposed by the conventional technique. Some of the most influencing techniques are MLS (Eysholdt and Schreiner, 1982), CLAD (Delgado and Ozdamar, 2004; Ozdamar and Bohorquez, 2006), and QSD (Jewett et al., 2004).
- On this framework, about a year ago the methodology RSA was born. This methodology consists of the averaging of auditory responses whose ISI vary according to a predefined probability distribution. This example shows an stimulation signal whose ISI vary with a uniform distribution between 4 and 8 ms.
- In comparison to the preceding techniques, RSA does not perform deconvolution. It just averages the auditory responses. Therefore, this technique needs to handle with noise associated to the overlapping responses. The effect of this noise will depend on the distribution of the jitter.
- In consequence, there was a big motivation for finding a methodology that could perform deconvolution with randomized stimulation, the RSD methodology.

Randomized Stimulation & Deconvolution (RSD)

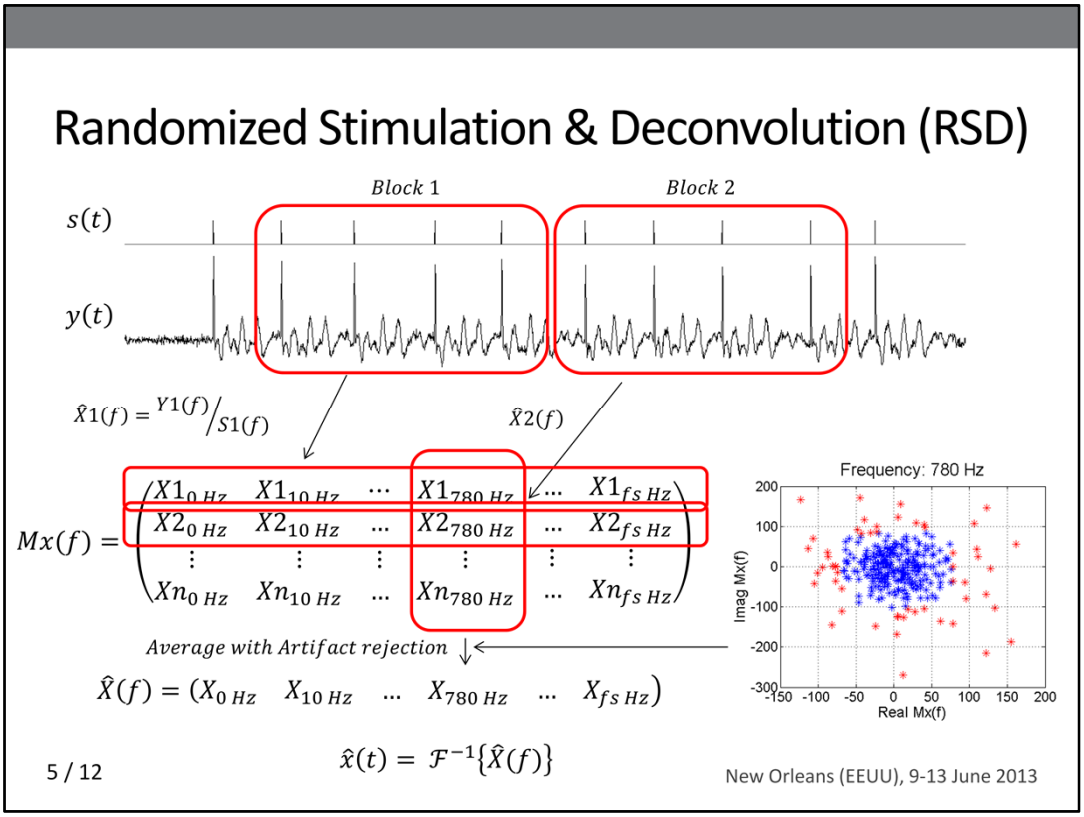
- Basics of deconvolution. Some easy maths



$$y(t) = x(t) * s(t) + n(t) \xrightarrow{\mathcal{F}} Y(f) = X(F) \cdot S(f) + N(f)$$

$$\hat{X}(f) = \frac{Y(f)}{S(f)} - \frac{N(f)}{S(f)} \qquad \hat{x}(t) = \mathcal{F}^{-1}\{\hat{X}(f)\}$$

- First of all, I will describe some basics of the principle of deconvolution with easy maths. The recorded EEG y(t) could be modeled as the convolution of a transient evoked response x(t) and the stimulation signal s(t) plus noise n(t).
- The transient evoked response could be estimated in the frequency domain through the direct and inverse Fourier Transform.
- This process should be controlled carefully since a coefficient of the stimulation signal in the frequency domain near zero could increase the noise at that frequency.

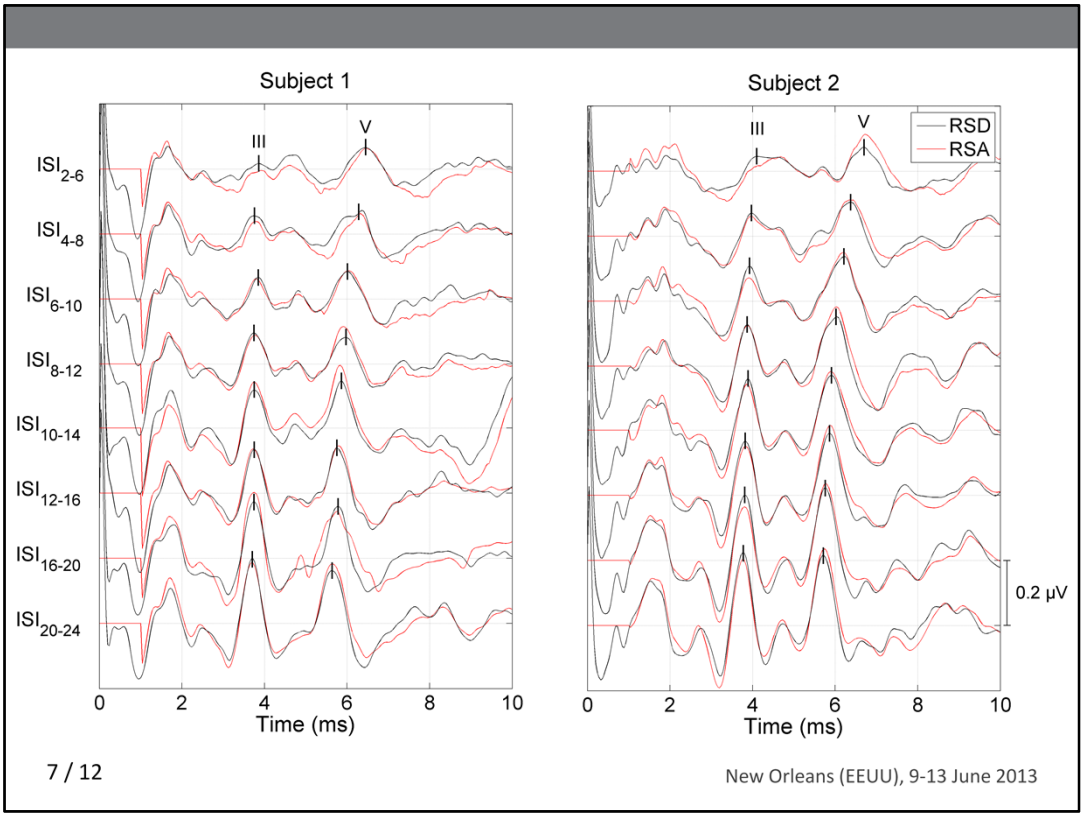


- The first step on the RSD technique is to divide the recorded EEG and the stimulation signal in blocks of a fixed size that contains a number of auditory responses.
- An estimated transient evoked response would be obtained from each block, building the matrix of estimated responses Mx(f).
- In the RSD technique, the average process is performed in the frequency domain.
- Each component of a corresponding frequency would be averaged to build the estimated transient evoked response on the frequency domain, eliminating from the average process those outliers either on the real or on the imaginary part.
- The transient evoked response on the time domain will be obtained through the inverse Fourier Transform.

Results. A study on ABR

- A study on ABR obtained with the RSD and RSA methodologies
- Parameters of the study
  - 8 normal hearing subjects
  - Ipsilateral stimulation at 70 dBnHL
  - Blocks of 16 responses
  - Analog filter settings: 2^{th} order, BW [100 - 4000] Hz
  - Digital filter settings: 4^{th} order, BW [150 - 3500] Hz
  - 20.000 averaged sweeps
  - 4 ms jitter uniformly random distributed on the intervals [20 – 24], [16 – 20], [12 – 16], [10 – 14], [8 – 12], [6 – 10], [4 – 8], [2 – 6] ms
- Questions
  - Is RSD a valid methodology to record ABR at high stimulation rates?
  - Are there significant differences between RSA and RSD?

- The described RSD methodology has been tested through a study on ABR obtained in a group of 8 normal hearing subjects, etc.
- The objective of this study was to answer to the following questions:


Subject 1
Subject 2
III
V
RSD
RSA
ISI2-6
ISI4-8
ISI6-10
ISI8-12
ISI10-14
ISI12-16
ISI16-20
ISI20-24
0.2 µV
0
2
4
6
8
10
Time (ms)
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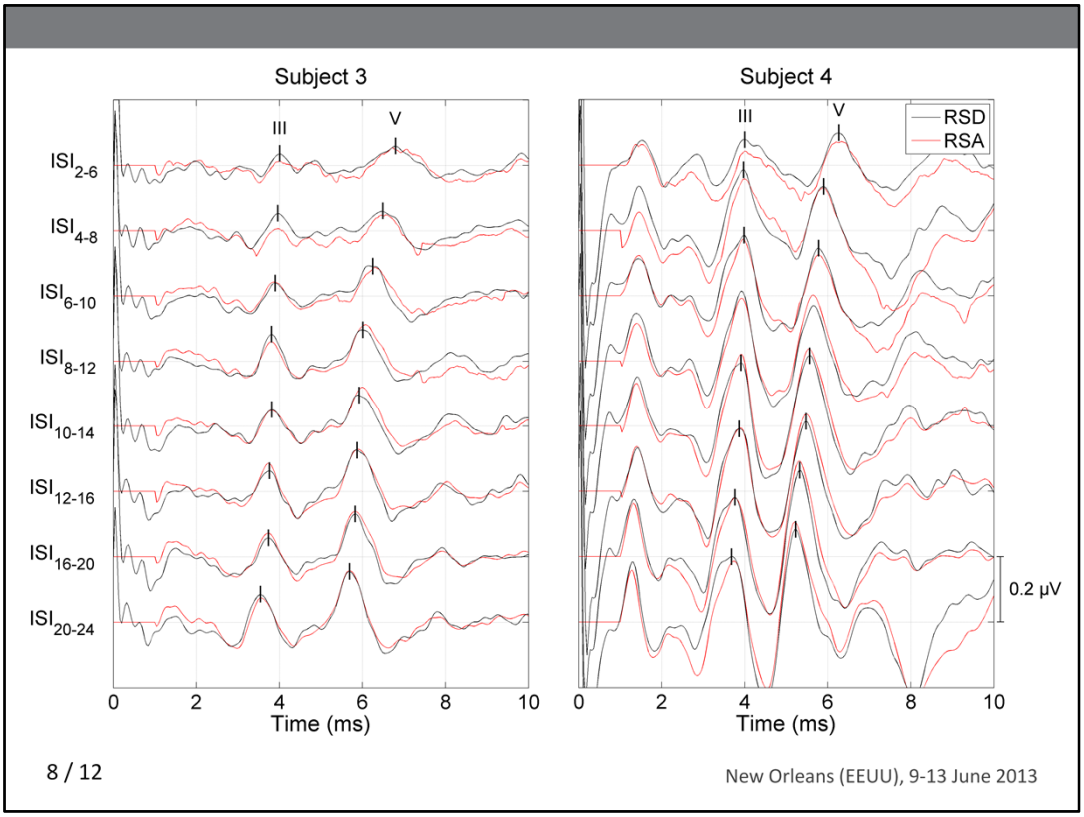
Subject 3
Subject 4
III
V
RSD
RSA
ISI2-6
ISI4-8
ISI6-10
ISI8-12
ISI10-14
ISI12-16
ISI16-20
ISI20-24
0.2 µV
0 2 4 6 8 10
Time (ms)
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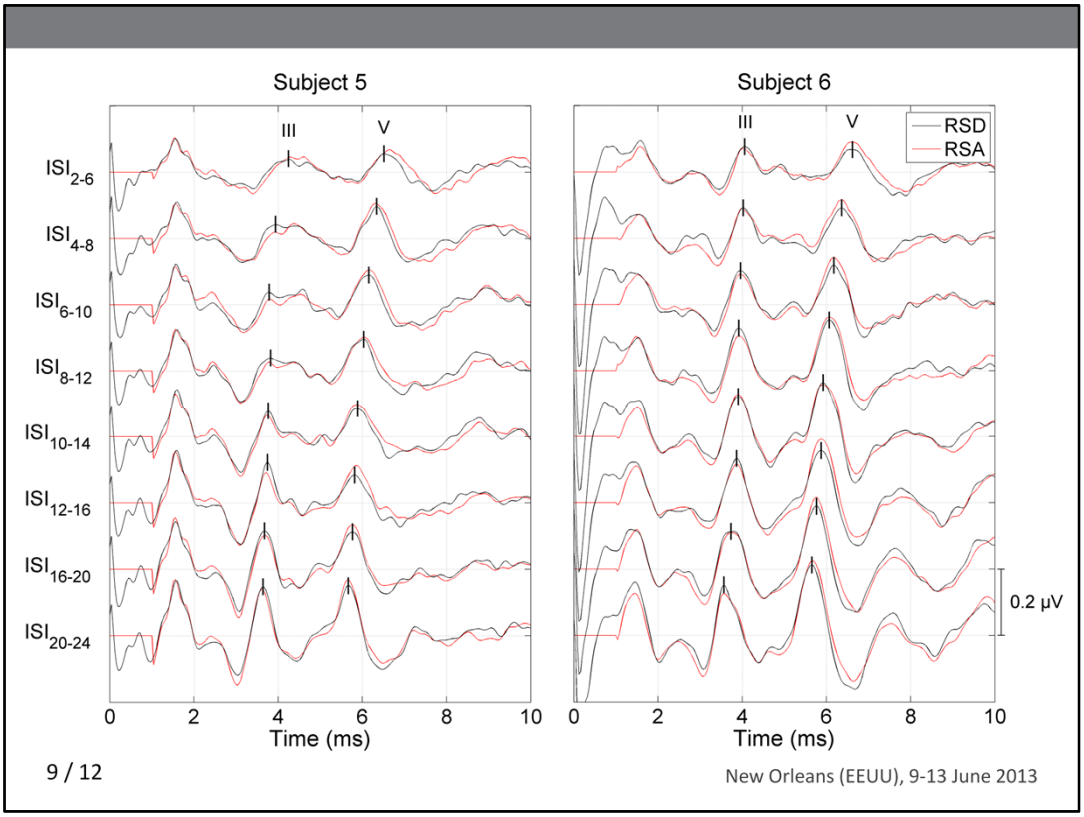
Subject 5
Subject 6
III
V
RSD
RSA
ISI2-6
ISI4-8
ISI6-10
ISI8-12
ISI10-14
ISI12-16
ISI16-20
ISI20-24
0.2 µV
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Time (ms)
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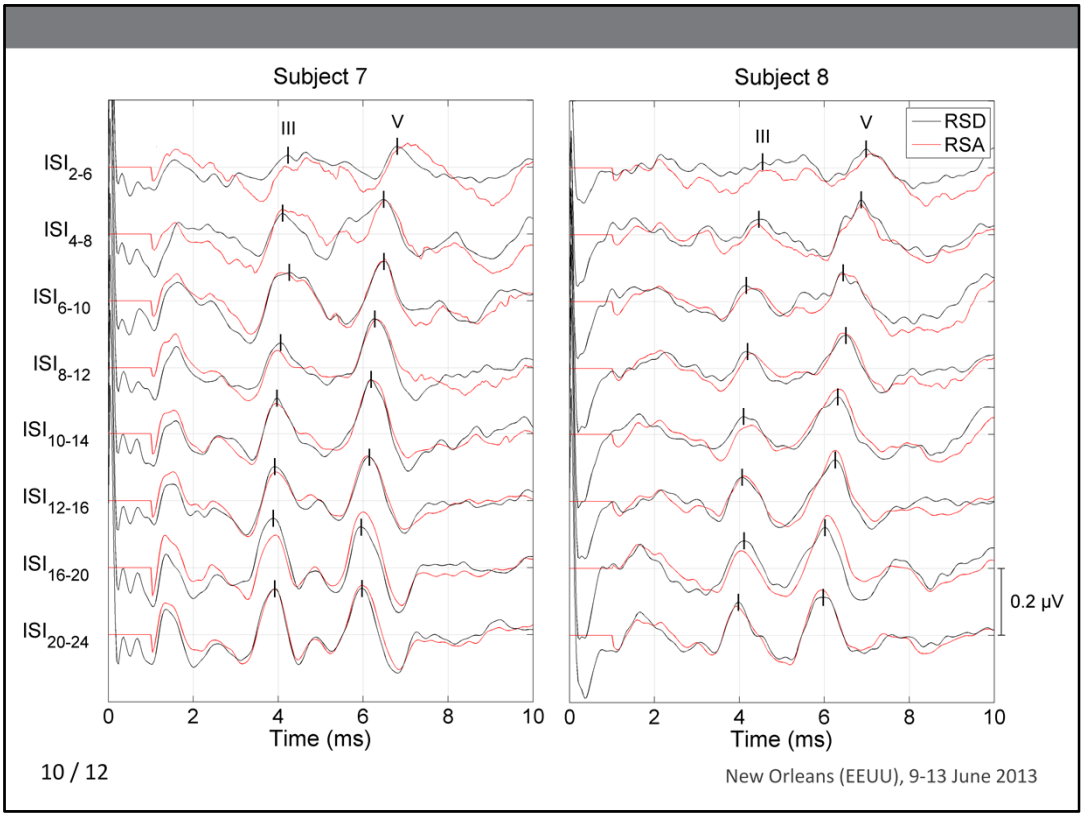
Subject 7
Subject 8
III
V
RSD
RSA
ISI2-6
ISI4-8
ISI6-10
ISI8-12
ISI10-14
ISI12-16
ISI16-20
ISI20-24
0.2 µV
0 2 4 6 8 10
Time (ms)
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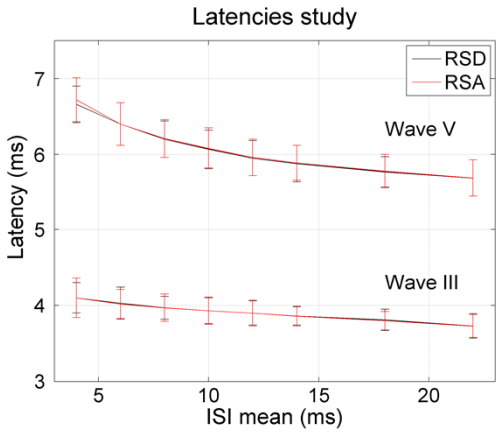
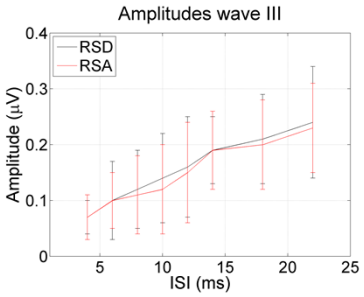
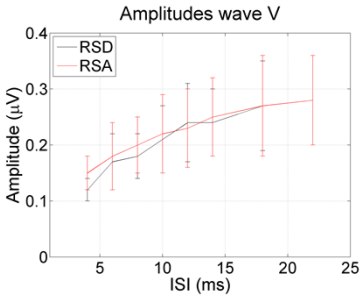
Results. A study on ABR







- Similar performance of RSA to RSD

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- This slide shows the results of an analysis of amplitudes and latencies from the ABR signals obtained with the RSA and RSD techniques at various stimulation rates.
- This analysis shows a normal variation of latencies and amplitudes with stimulation rate: (1) a positive shift of waves III and V as stimulation rate increases, with a shift of wave V deeper than in wave III, and (2) a decrease on the amplitude of both waves as stimulation rate increases
- Furthermore, this analysis shows a similar performance of the RSA and RSD technique.
- The morphology of the responses, their changes with stimulation rate and the analysis of these results suggest that the signals analyzed in this study are real ABR, which indicates that the RSD technique could be a valid procedure to record ABR at rates up to 220 Hz.

Summary & conclusions

- Description of a methodology that allows the deconvolution of overlapping responses evoked by randomized stimulation, RSD.
- The RSD methodology could be used to obtain ABR signals at rates up to 220 Hz (averaged ISI of 4 ms).
- We observed a similar performance of between the RSA and RSD methodologies using stimulation sequences with a jitter of 4 ms.
  - The noise associated to overlapping responses in RSA may be reduced when the jitter of the stimulation sequence is large enough.
- And what would happen with RSA if the jitter is not high enough?

- In this work, we have described a methodology that allows the deconvolution of overlapping responses evoked by randomized stimulation, the RSD technique.
- We have developed a study on ABR obtained from a group of 8 subjects. The results of this study point out that the RSD is a valid methodology to obtain ABR at rates up to 220 Hz.
- We observed a similar performance of the RSA and RSD techniques, which suggest that the noise associated to overlapping responses inherent to RSA may be reduced when a the jitter of the stimulation sequence is large enough.
- What would be the performance of the RSA methodology when the jitter is not large enough? The RSA technique will present some limitations that I will describe on the following speech.
- Thank you very much for your attention.