# Transient and steady-state auditory responses

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For many decades the history of objective methods in audiology is closely connected with transient auditory evoked responses. However, beginning in the last decade of the 20th century, auditory steady-state responses have attracted more and more notice. Auditory steady-state responses (ASSR) may theoretically be recorded more quickly and recognized more objectively than the more widely accepted auditory brainstem responses (ABR) or cortical electric response audiometry (CERA). Additionally, ASSR may provide a more frequency-specific assessment of hearing than the ABR because the amplitude modulated tones used to elicit ASSRs have a narrower spectral representation.

However, for most applications, a major drawback of ABR and ASSR elicited with modulation rates between 80 and 100 Hz is their low amplitude relative to the physiological background noise resulting in a poor signal-to-noise ratio (SNR). Thus the uncertainties and failures that have occurred both in research and clinical application of transient and steady-state responses may be attributed to the variable influence of the residual background noise. For both methods whether or not a response can be recognized depends upon its amplitude and the amplitude of the background EEG noise. The residual noise level in a recording varies from subject to subject mainly with the level of muscle activity, being much lower in relaxed or sleeping subjects. The two plots in figure 1 show ABR recordings in a quite and in a noisy subject. It is clearly visible, that the high residual noise level in right plot makes a decision "response not present" impossible.

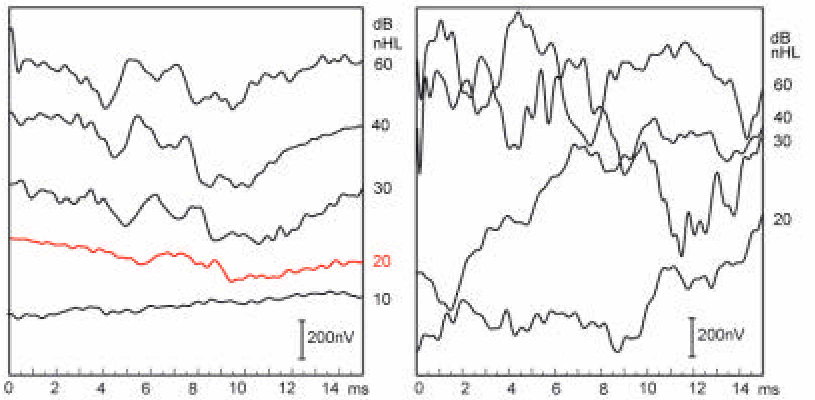


*Fig. 1: ABR recordings in a quite (left panel) and a noisy subject (right panel) for descending stimulation levels and a constant number of 2000 averages per curve. The curve representing the electrophysiological threshold is marked in red.*

The term 'residual noise', closely connected with the quality estimation of transient as well as steady-state responses was introduced by Don and Elberling (1994) more then 10 years ago. They demonstrated the validity of the well known "square-root-law" of averaging and emphasized that "obviously, the most important issue is *overall* noise level. From the perspective of testing time, the required averaging increases with the *square* of the input noise level" and "If the input (EEG) noise is a factor of 3 larger, theoretically nine time as many sweeps are required to reduce residual noise to comparable levels."

Reproducing Don's experiment with our ASSR data, we could demonstrate the effect of *overall* EEG noise level on the quality of threshold estimation with steady-state responses. The left two plots of Figure 2 show residual noise as a function of measuring time, covering app. 9 minutes. The right two plots of figure 2 show the amplitude spectra at the end of the recording time with red spectral bins representing the responses. The mean EEG amplitude in the subject plotted in the lower row is by a factor of 2 larger than in the upper row. The influence of different residual noise levels on the detectability of the responses is clearly visible.

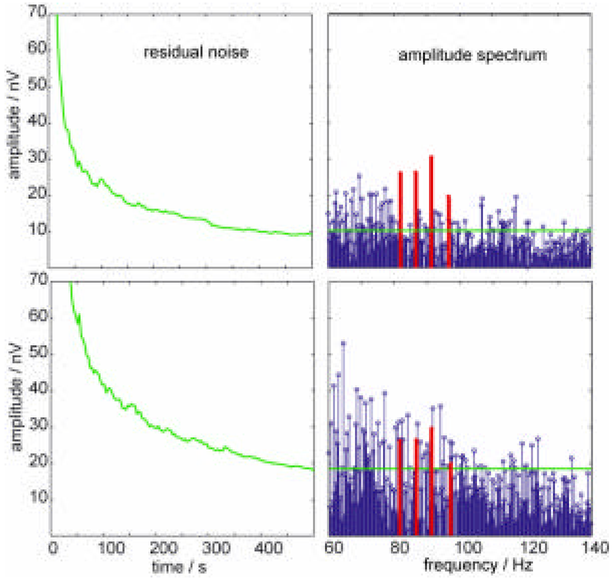


*Fig. 2: Residual noise (left column) and amplitude spectra (right column) for ASSR recordings in a quite (upper row) and a noisy subject (lower row). The red spectral bins in the right plots represent the responses to a multifrequency stimulus.*

The great importance of input EEG noise and residual noise for a "no-response criterion" has been demonstrated for brainstem responses by Don & Elberling in 1996. They could show, that the number of sweeps required to achieve various residual noise levels can be predicted for different input EEG noise levels. We have reproduced the idea of their experiment with our ASSR data. From raw EEG recordings we calculated the mean EEG amplitude and the residual noise as a function of measuring time.

In Experiment 1 we were able to predict the residual noise for a fixed test time, only using the simple "square-root-law". As our results in the left plot of figure 3 show, this prediction is in good correlation with the real noise data. In a second experiment we predicted the test time required to achieve a fixed noise level. And, as shown in the right plot of figure 3, we have found the same good correlation between predicted and real data.

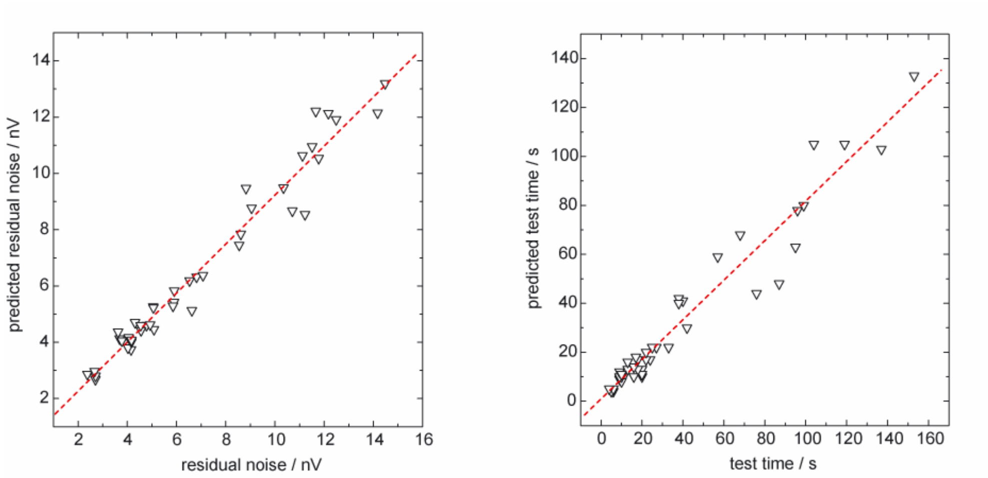


*Fig. 3: Predicted residual noise for a fixed test time as a function of measured residual noise (left) and predicted test time required to achieve a fixed noise level as a function of measured test time(right) for 65 ASSR recordings in 20 adults.*

## Conclusions

Auditory steady-state responses (ASSR) have proven a useful tool for estimating hearing thresholds. They can support frequency-specific methods with transient responses effectively. Successful clinical application of ASSR requires reliable estimation of response quality. Algorithms for automatic response detection should consider different input EEG noise levels and different residual noise levels.

## References

Don M and Elberling C (1994). Evaluating residual background noise in human auditory brain-stem responses. J.Acoust.Soc.Am. **96**, 2746-2757.

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