SmartNRI: algorithm and mathematical basis

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Background and objectives

Modern cochlear implants support objective measurements such as recording of the electrically evoked Compound Action Potential (eCAP) to complement behavioural measures. In the HiResolution® Bionic Ear® the eCAP is measured through Neural Response Imaging (NRI). If NRI is to be useful in setting program levels clinically for individuals who cannot provide behavioural feedback, then the neural responses must be easily identifiable by all clinicians. However, the inherent overlap of a large stimulus artefact with the much smaller neural response, as well as the presence of noise, sometimes makes the determination of accurate NRI thresholds a task requiring considerable skill and experience. A rigorous automatic statistical method based on rejection of non-biological signals was developed for determining whether a real neural component was present in a set of NRI responses and for more reliably obtaining the thresholds (Litvak and Emadi, 2005). This new system was called SmartNRI. The aims of this paper are to present the concept developed by Litvak and Emadi and to show preliminary results with SmartNRI.

Methods

The development of the SmartNRI system was based on the assumption that all NRI recordings consisted of neural responses, noise, and residual artefact. First, noise was reduced before using a principle-component analysis which showed that the NRI traces could be reconstructed using a linear sum of seven basic functions. The noise could be reduced up to 50% and therefore the number of required averages could be decreased while maintaining the same waveform quality. A best-fit artefact model was then constructed: the sum of two decaying exponentials (respectively with high and low time constants). In the first millisecond, this model could be further simplified by the sum of the highest time constant exponential and a linear component. An analysis of over 1,000 NRI traces verified that the model accurately represented the residual artefact. The process then considered only traces that differed significantly from the artefact model to be true neural responses. A Strength of Response metric (SOR) was then computed to quantify how far any response deviated from artefact: SOR=(response-artefact)/noise. Preliminary observations using recordings below psychophysical threshold (assumed to be only artefact and noise and to contain no neural response) made it possible to establish a criterion value for the SOR: if the SOR was higher than the criterion value for a given NRI trace then it could be concluded that the trace contained a response. The SmartNRI algorithm was then developed to automatically produce the NRI growth function and estimate the NRI threshold (tNRI) with little clinician input (only starting and maximum stimulation levels).

The current system is based on obtaining four responses and two non-responses to extrapolate to tNRI. The principle is to obtain a measurement, calculate its SOR and compare it to the criterion value: if the SOR is below the criterion value there is no neural response, and the stimulation level is increased; if the SOR is above the criterion value a neural response is present and the stimulation level is decreased. The system runs through the algorithm until four responses and two non-responses are obtained.

Results

Preliminary testing and validation were performed to verify the use of the SOR criterion. Testing was conducted at the University of Iowa (Litvak and Emadi, 2005) and in Europe through an internal Advanced Bionics validation (Arnold et al. 2006). Those preliminary tests led to algorithm refinements. A multi-centre study recently began validation of the automatic classification on a larger number of traces. The study is being conducted in compliance with the Declaration of Helsinki. In a pilot phase, NRI is recorded with the clinical SoundWave™ fitting software following specific guidelines. Four stimulating/recording electrode pairs are studied with the sites selected to evenly cover the cochlea. Both extrapolated thresholds (tNRI) and the first responses which may be visually identified (1stNRI) are estimated. Additionally the loudness perception produced with the NRI stimulus is recorded, particularly focusing on detection and most comfortable levels. The recordings are then examined offline by experienced clinicians and classified as “responses” or “non-responses” using a custom designed interface (Figure 1).

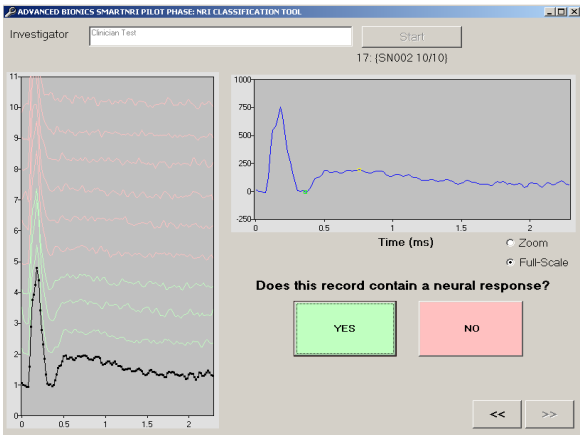

Figure 1. Response screen used by the clinicians to classify the presence or absence of a neural response

A trace is considered a response or a non-response only when all clinicians agree upon it. The traces unanimously agreed upon are then processed through the auto-detection algorithm. Outcomes are compared to validate the system. Preliminary results were collected at Hôpital Avicenne in France (Frachet et al. 2007). Ethical approval was obtained and all subjects signed a consent form prior to inclusion in the study. Four experienced clinicians examined 452 NRI traces and agreed on 268 of them (59%). According to the clinicians, 81 traces contained a neural response whereas 187 did not. The subset of measurements that were agreed upon by all reviewers was assessed against the performance of the automatic classification system. Ninety-nine percent of the "responses" were correctly classified as responses by the algorithm and 96% of the "non-responses" were identified. Thus, there were seven false positives and one false negative, yielding an error rate of less than 3%. In addition, significant correlations between 1stNRI and detection and most comfortable levels with the NRI stimulus were observed (Figure 2).

Stim/rec pair	3/1	7/5	11/9	15/13
Pearson's R, threshold	0.742**, p=0.009	0.880**, p=0.000	0.945**, p=0.000	0.798*, p=0.01
Pearson's R, comfort level	0.853**, p=0.003	0.855**, p=0.003	0.851**, p=0.004	0.834*, p=0.02

*Figure 2. Correlation coefficients (Pearson's R) between 1stNRI (visual NRI threshold) and detection threshold and comfort levels obtained with the NRI stimulus for each stimulating/recording electrode pair. The level of significance is indicated: * means p<0.05, ** means p<0.01. The least significant correlations were obtained at the most basal electrode tested.*

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Conclusion

An encouragingly accurate automated detection of evoked responses was achieved. There appears to be the potential to remove the subjective element from the interpretation of NRI recordings. The novel SmartNRI algorithm has already been incorporated into the Advanced Bionics Research Platform for Objective Measures (RSPOM, Van Immerseel et al. 2007). The multi-centre study is ongoing, aiming to validate SmartNRI on a larger number of datasets and to evaluate SmartNRI in RSPOM for routine clinical use. The second phase of the study will compare behaviourally based programs and programs created using the SmartNRI principle within RSPOM. It is anticipated that SmartNRI will become a rapid and straightforward clinical method for identifying valid NRI responses, thereby potentially providing a faster and more reliable tool for setting program levels in subjects who are unable to make loudness judgments, particularly the paediatric population.

References

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