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► **To cite this version:**

Ashesh Shah, Jerome Coste, Jean-Jacques Lemaire, Etan Taub, Raphael Guzman, et al.. Optimization of deep brain stimulation surgery for Parkinson's disease with quantitative rigidity evaluation. Joint annual meeting of the Swiss Societies of Neurosurgery and Neuroradiology, Sep 2015, Lucerne, Switzerland. Thieme, Joint annual meeting of the Swiss Societies of Neurosurgery and Neuroradiology, 76 (Suppl 01), pp.P054, 2015, Journal of Neurological Surgery Part A: Central European Neurosurgery. 10.1055/s-005-30110 . hal-01865490

HAL Id: hal-01865490

<https://hal.uca.fr/hal-01865490>

Submitted on 31 Aug 2018

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Optimization of deep brain stimulation surgery for Parkinson's disease with quantitative rigidity evaluation

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Background

Deep brain stimulation (DBS) is now a widely accepted surgical treatment for Parkinson's disease (PD). Electrodes are implanted in the patient's brain after intraoperative test stimulation. Changes in parkinsonian rigidity during test stimulation are detected by an evaluator, usually a neurologist, by identifying changes in the resistance of the patient's arm to a passive movement. We hypothesised that at the moment of reduction in rigidity, the speed with which the evaluator moves the patient's arms increases and that this change and its amplitude can be detected with an acceleration sensor. The aim of the present study was to test this hypothesis by collecting data during DBS surgery. Furthermore, to know more about the optimal stimulation target, these quantitative data were categorized based on the anatomical location of the electrode during test stimulation.

Methods

- Clinical study (University Hospital in Clermont-Ferrand): 9 rigidity patients undergoing DBS surgery
- Preoperative manual outlining of sub-thalamic nucleus (STN) and its anatomic neighbors was done using iPlan (Brainlab, Feldkirchen, Germany, Fig 1A and B) and the target point was selected.
- Intraoperative microelectrode recording (MER) and test stimulations (Fig 1C and Fig 1D) were performed.
- Maximum reduction in rigidity during passive movements and the corresponding amplitude (best clinical amplitude, BCA) were noted for all positions.
- 188 test stimulations in total.
- One anatomical structure was attributed to every test stimulation position [1].
- Acceleration data were recorded and evaluated for all test stimulations (Fig 2).
- Data filtering and statistical feature extraction preceded normalization of features to baseline recordings.
- Effective stimulation amplitudes inducing a reduction in rigidity were identified (best quantitative amplitude, BQA, Fig 3).
- BQA and BCA were compared using Wilcoxon 2 sided signed rank test.
- Data were grouped based on the anatomical structure in which the electrode was present during test stimulation for a particular position.
- Average BCA, Average BQA and number of side effect occurrences were compared for the STN, zona incerta (ZI) and Fields of Forel (FF).

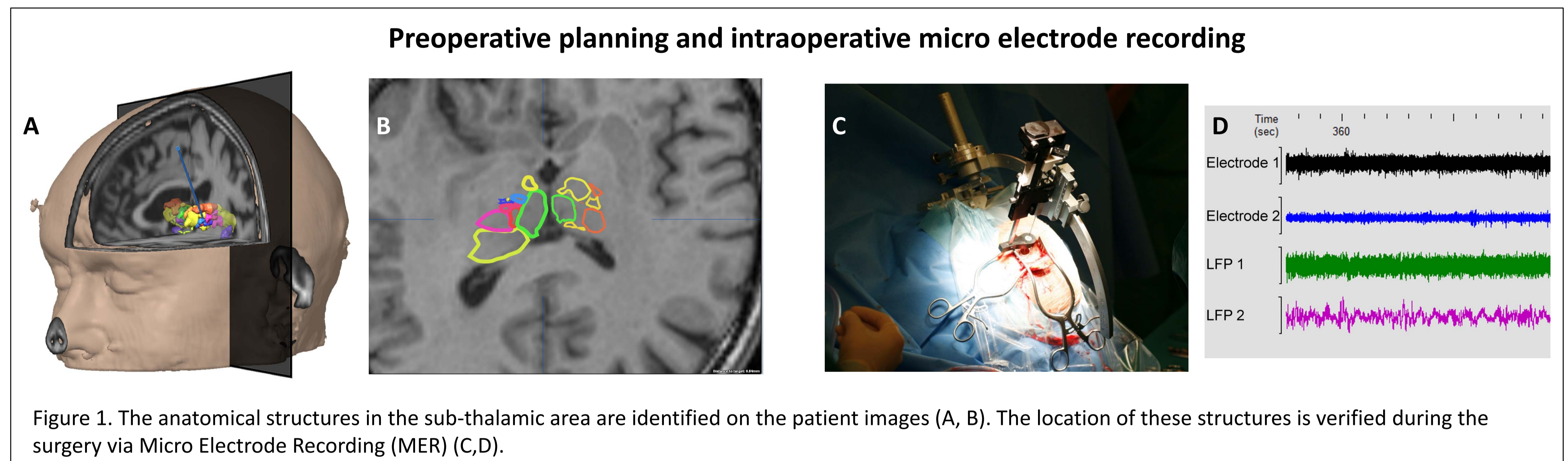


Figure 1. The anatomical structures in the sub-thalamic area are identified on the patient images (A, B). The location of these structures is verified during the surgery via Micro Electrode Recording (MER) (C,D).

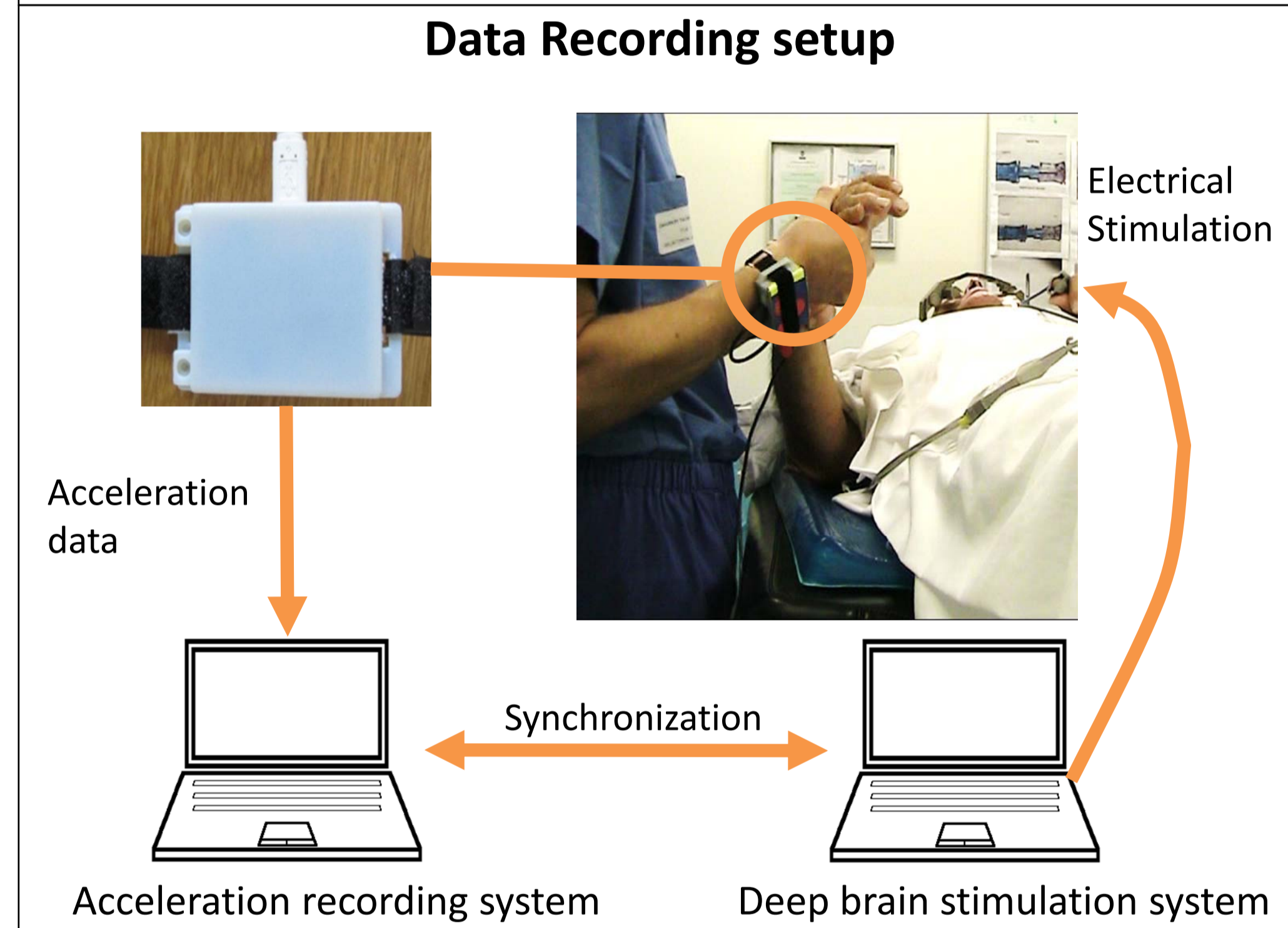


Figure 2. A 3-axis accelerometer housed in a 3D printed plastic case is mounted on the evaluators wrist and connected to a laptop with in-house developed recording software. This software is also connected to electrophysiology system which records test stimulation amplitudes.

Signal Processing and Threshold identification

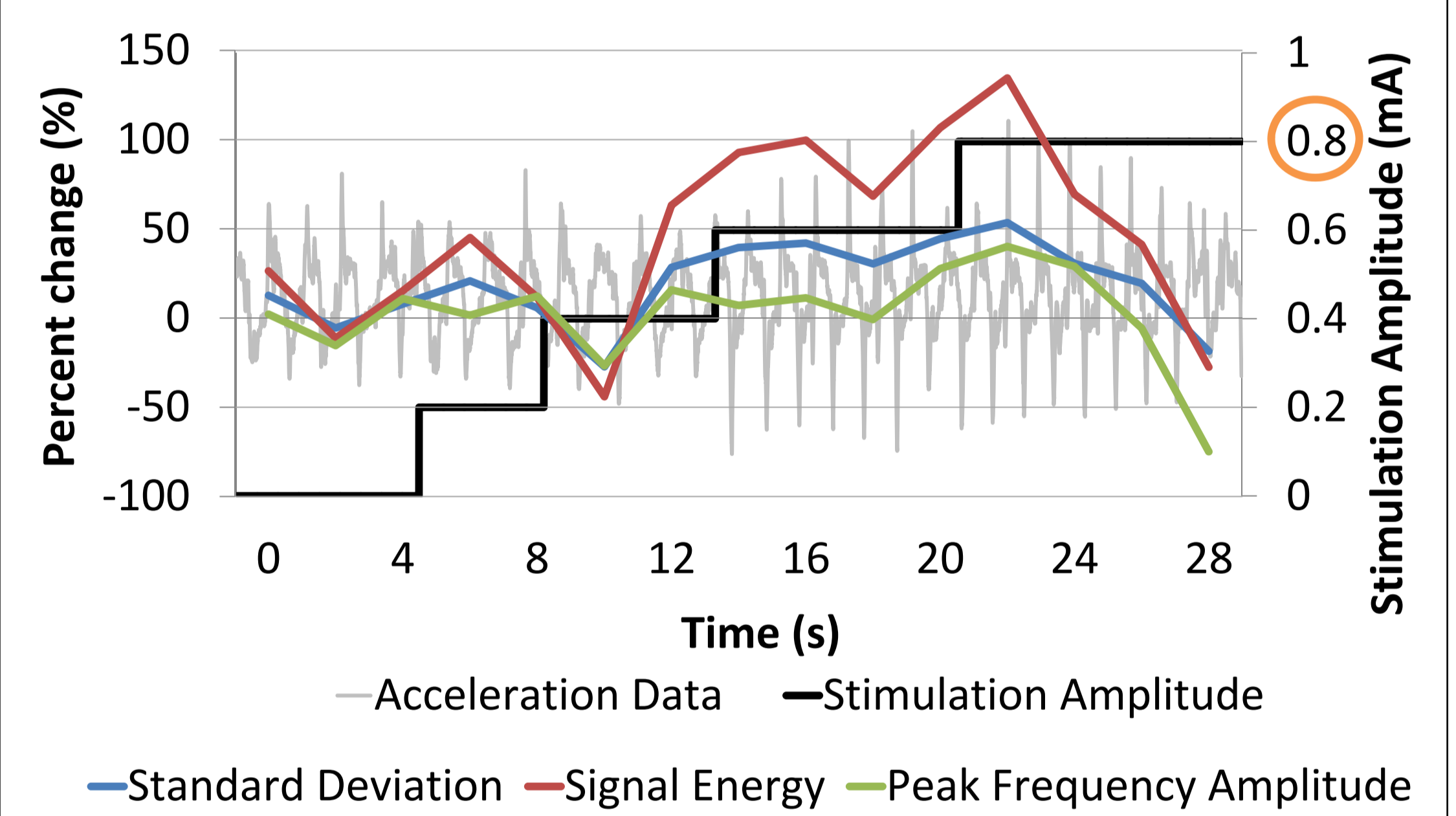


Figure 3. The recorded acceleration data is filtered and statistical features are extracted. These features are normalized to the baseline features and used to identify effective stimulation amplitudes.

Results

- Out of the 188 test stimulations, 138 evaluations were used for comparison between BCA and BQA. For 14 evaluations none of the thresholds were found, for 30 evaluations no BCA were found and for 6 evaluations no BQA were found.
- Results of Wilcoxon 2 sided rank test showed that BQAs were significantly lower than BCAs ($p < 0.001$, Fig 4).
- The 138 evaluations were distributed in 5 structures: 2 in Substantia Nigra, 3 in Thalamus, 27 in FF, 26 in ZI and 80 in STN.
- STN had the lower average values for BCA and BQA, but highest occurrences of side-effects. The comparison with FF and ZI can be seen in Figure 5.

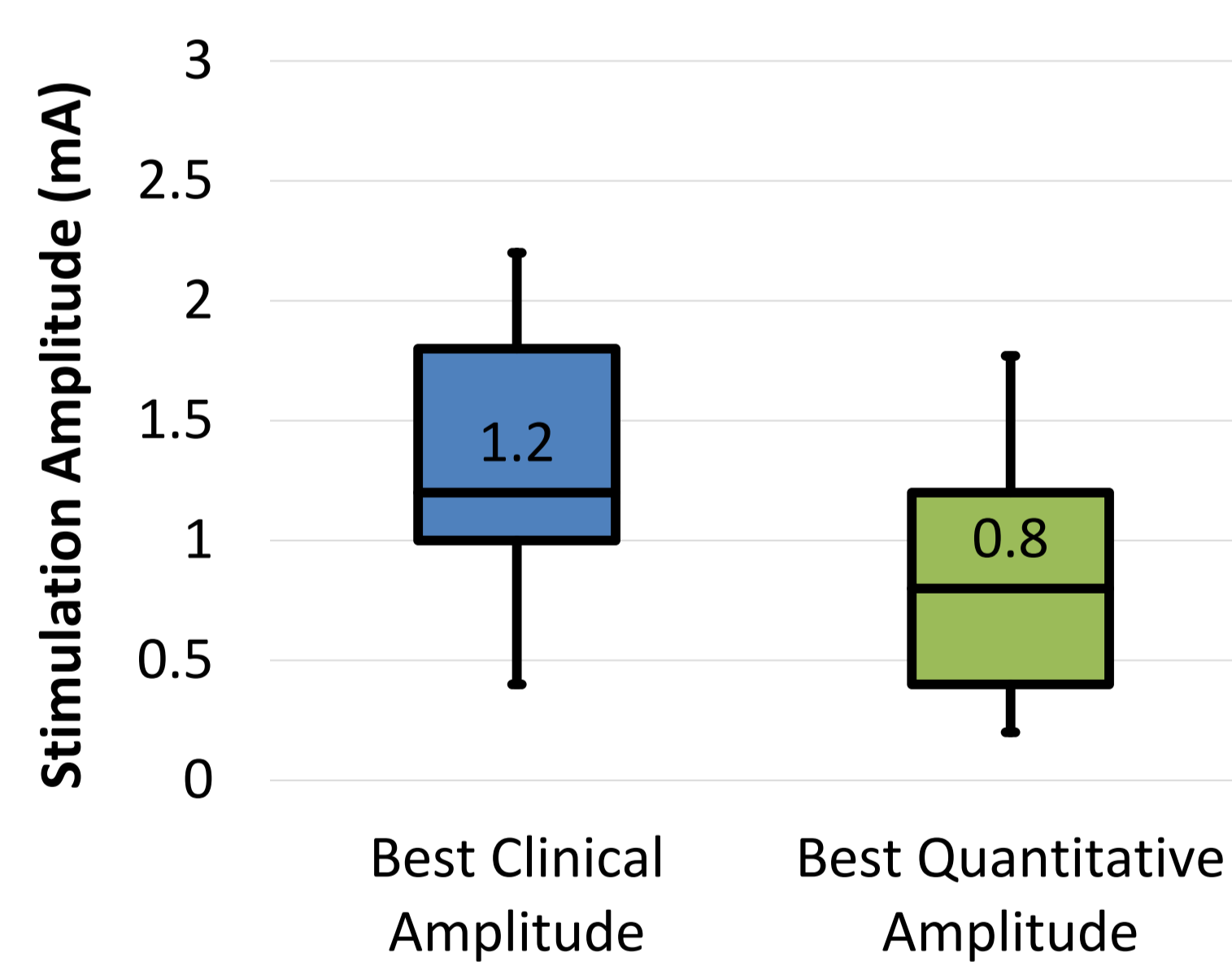


Figure 4: Box plot showing comparison between BCA and BQA

Discussion

- The additional acceleration measurements during the surgery did not increase operation time or the patient's discomfort.
- Higher sensitivity when using the accelerometer recording system; effective stimulation amplitudes were found for 33 additional test stimulations.
- Conventionally targeted STN requires the lowest stimulation amplitude to reduce rigidity, but has significantly higher chances of side effect occurrence. The Fields of Forel have slightly higher stimulation amplitudes but have much lower change of causing side effects.
- Sufficient baseline data is necessary for proper identification of BQAs.
- There is an inherent subjective component in the acceleration analysis because the evaluation is done by the neurologist.

Conclusion

- Changes in rigidity of PD patients can be quantified during passive movements by measuring data from the evaluator.
- Acceleration measurements confirm the subjective evaluation, but they seem to be more sensitive (Fig 4).
- STN may not be the most efficacious target structure. The patient may benefit from an electrode placed closer to the Fields of Forel.

Acknowledgements

This research has been supported by the Swiss National Science Foundation (SNSF) and the Germaine de Stael program of the Swiss Academy of Engineering Sciences (SATW).

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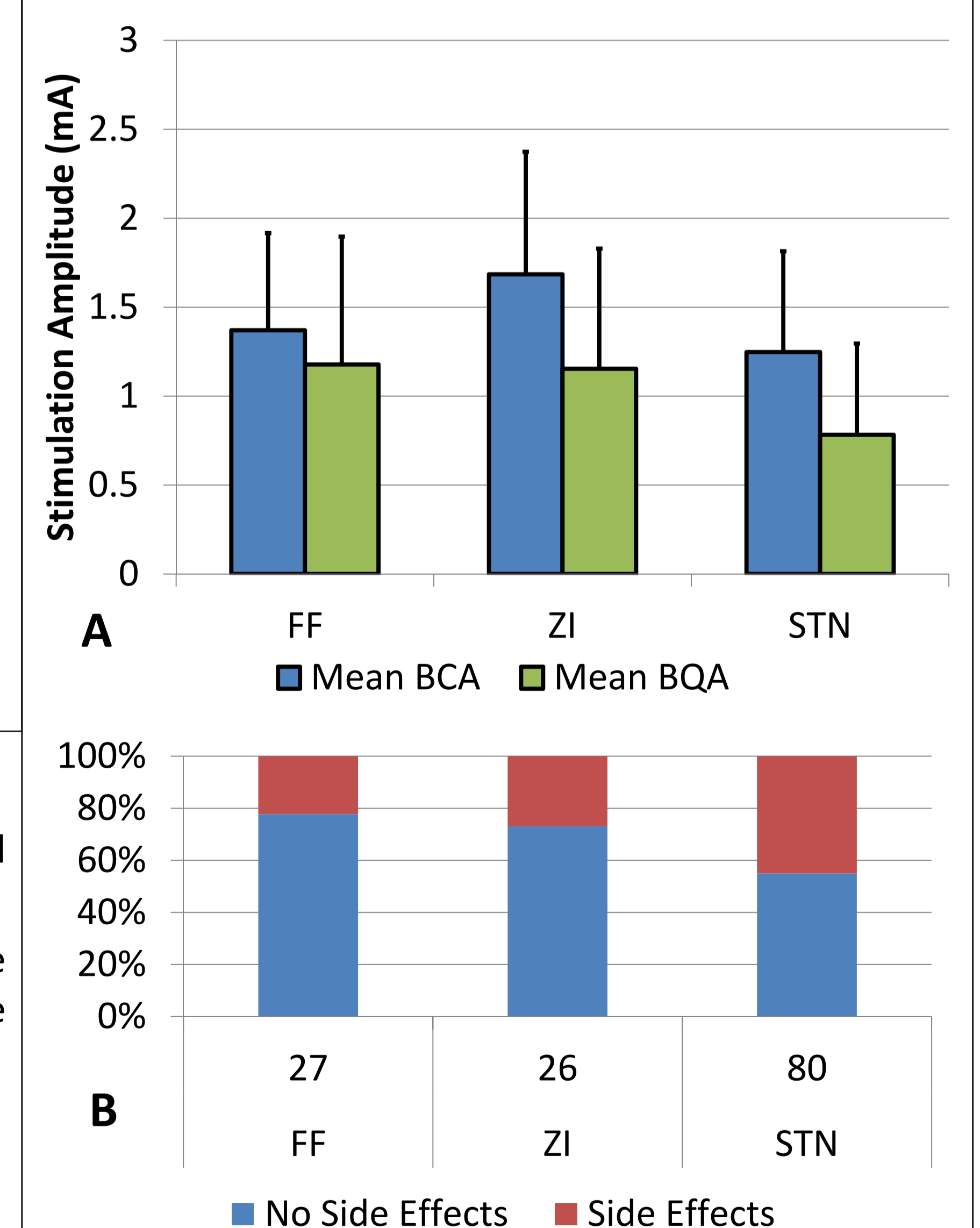


Figure 5: A) Column chart showing average Best Clinical Amplitude (BCA) and Best Quantitative Amplitude (BQA) distributed over different anatomical structures. B) 100% stacked column chart comparing side effect occurrences between different anatomical structures. The numbers on the X-axis indicate the total count of stimulations for each structure.

