EVALUATING THE ROBUSTNESS OF FIBER PATHWAY ACTIVATION WITH DEEP BRAIN STIMULATION DIRECTIONAL AND MULTI-ELECTRODE DESIGNS

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INTRODUCTION

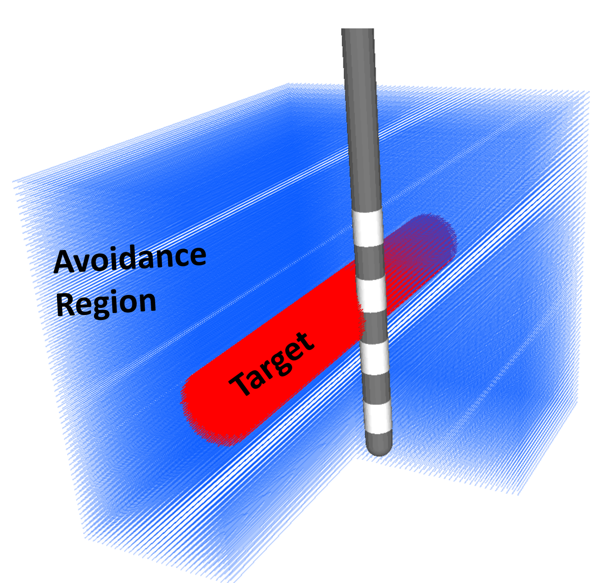
Clinical outcomes for patients with deep brain stimulation (DBS) are highly variable. Two critical factors underlying this variability are where and how stimulation is applied. Variability in lead placement has also been observed for the same target across a patient cohort. Computational modeling of DBS has demonstrated that minor variations in lead location and the shape of the electric field can lead to drastic variations in the effects of stimulation. **Our hypothesis is that the use of new directional-steering electrodes or multiple electrodes can compensate for variability in lead placement and provide more robust control over fiber activation compared to current cylindrical electrodes.** This means an electrode design or configuration is robust if it is able to provide acceptable stimulation from its contacts to maximally activate the target fiber pathway in scenarios where its location with respect to the target may vary.

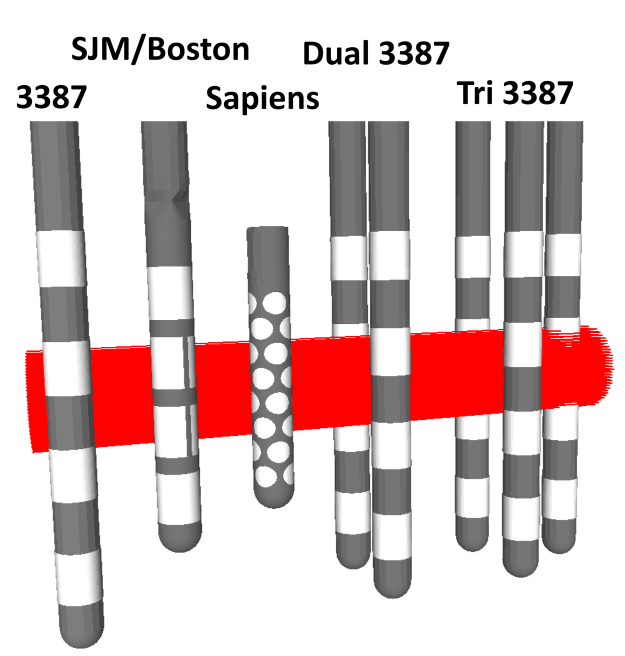
OBJECTIVES

1. Evaluate the ability of new directional electrode designs and multielectrode configurations to robustly activate target fiber pathways.
2. Determine how DBS targeting can be improved to handle lead location uncertainty.

METHODS

DBS Computational Model: A finite element model (FEM) bioelectric field model was created to calculate the external voltage on a 3mm diameter cylindrical target fiber bundle and a 16mm cube of surrounding fibers representing the region of avoidance (any area not located in the target cylinder). The activating function was then computed along each fiber. Lead location was modified in 0.25mm increments, up to 5mm, away from the target and a new FEM was generated and corresponding computations were performed at each location[1].





Finite Element Bioelectric Field

$$\nabla \cdot \sigma \nabla V_e = -I$$

Activating Function

$$A.F. = \frac{V_{e(x-1)} - 2V_{e(x)} + V_{e(x+1)}}{\Delta x^2}$$

Active Contact Optimization

$$f_{v,\Omega(x,c)} = \sum_{i=1}^{n} \frac{c_i}{|\Omega|} \max\left(AF_{i,Target}(x)\right) - s\frac{c_i}{|\Omega|} \max\left(AF_{i,Avoid}(x)\right)^2$$

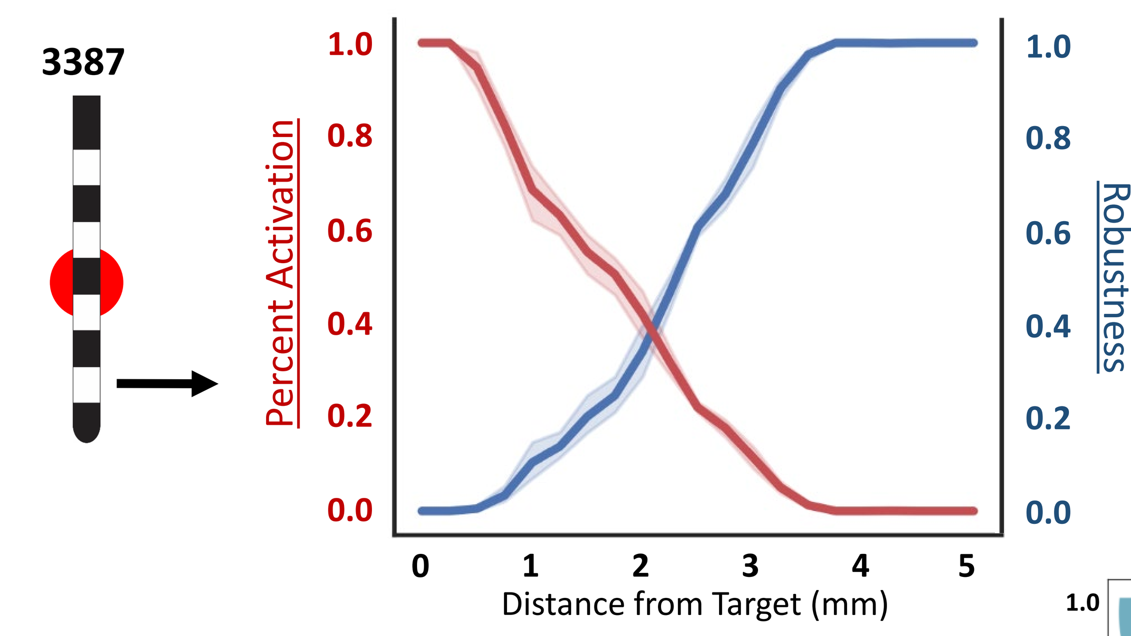
Stimulation Optimization: The active contacts and amplitudes for each lead location and configuration were computed with a convex optimization algorithm[2], with the objective function set to maximize activation of the target region and minimize spread of activation into the avoidance region.

Robustness Metric: We define robustness, similar to control theory, as the ability to achieve maximal performance despite uncertainty in parameter variations. Robustness performance, ***R***, is the ability to activate the target fiber bundle and our parameter variation is lead location around the target, calculated as a quadratic loss function. A configuration with a lower R metric is more robust.

$$R(C) = \frac{1}{L}\sum_{l=1}^{L}\left(1 - A_{l,C}\right)^2 \qquad A_l = \%\ Activation\ at\ each\ location \quad C = Lead\ Configuration$$

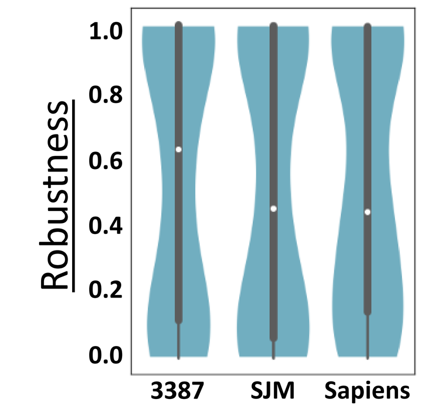
RESULTS

Single Lead Target Activation

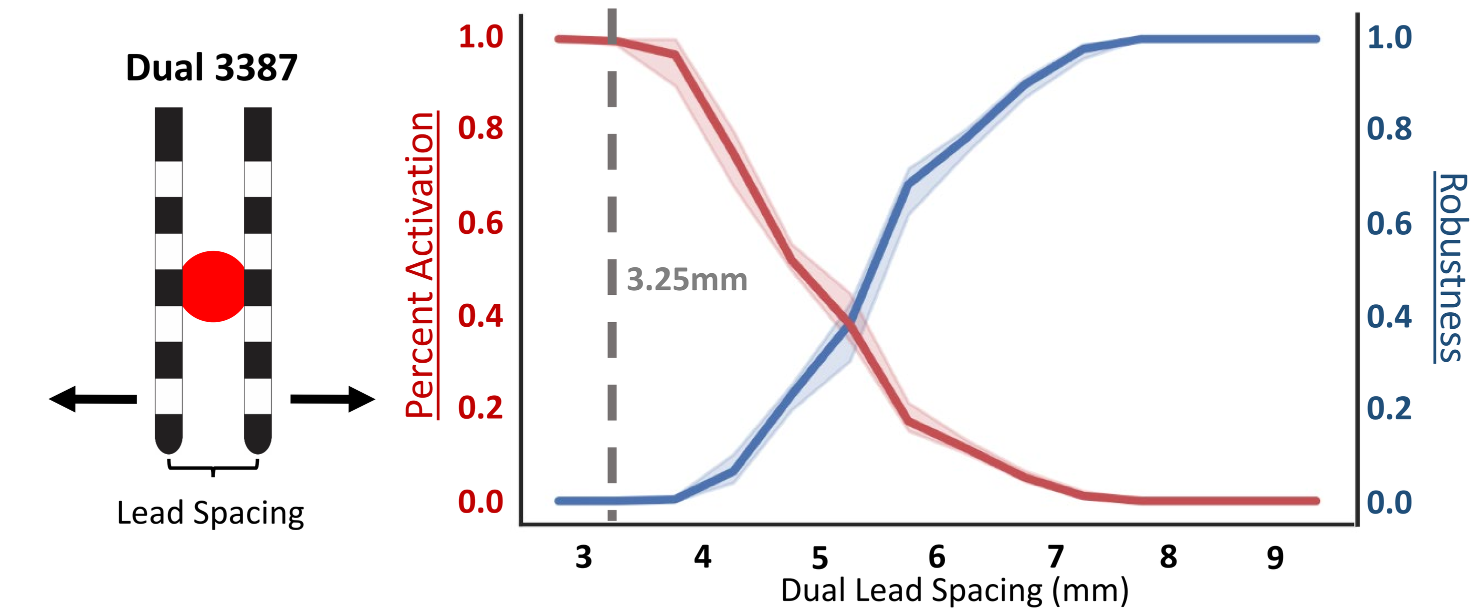


(TOP) Target fiber activation and robustness metric as a single 3387 lead is moved off target.

(LEFT) Violin plot to compare robustness for each of the three single lead configurations

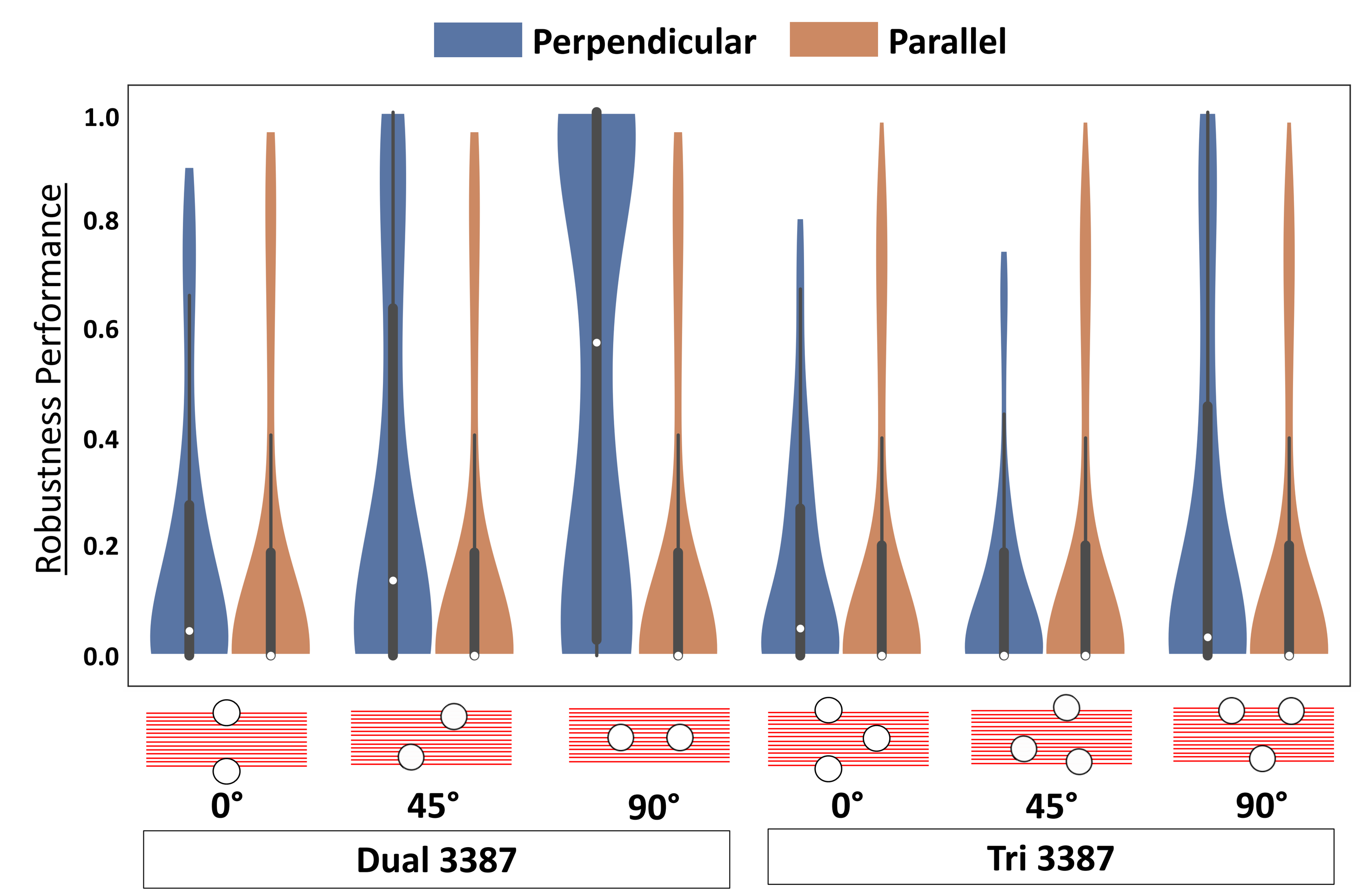


Multi-Electrode Spacing



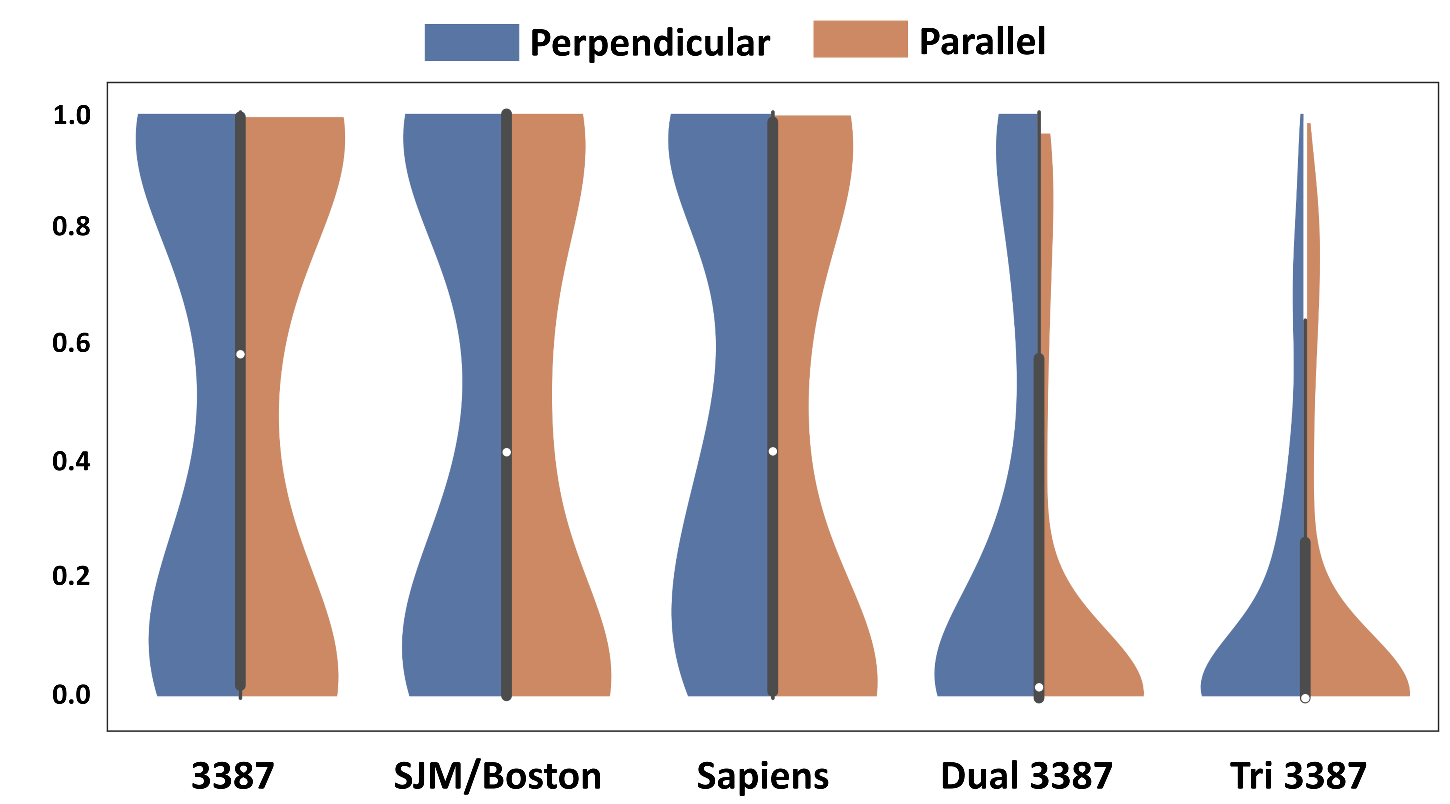
A perpendicular dual 3387 test to determine the lead spacing distance at which performance begins to drop, meaning the two leads are no longer able to contribute to the activation at the center of the target. This was determined to be 3.25mm and used as the spacing for further experiments.

Multi-Electrode Rotational Dependence



A comparison of two and three lead configurations using 3.25mm spacing. Performance decreases dramatically for the dual 3387 configuration depending on its orientation to the target.

Overall Robustness Comparison



An overall comparison of all five electrode configurations for both perpendicular and parallel targets. We observe that the two directional lead designs provide better performance over variable lead positioning and the multi-lead configurations provide drastically better performance than any of the single lead configurations.

CONCLUSIONS

Variability in lead location decreases the ability for current DBS electrodes to activate the target fiber pathway. New directional electrode designs can overcome some amount of location variability by steering current towards the target, but the ability to shape the electric field across multiple leads provides control of target activation that is more robust to off target lead locations.

REFERENCES

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