Nodal Misalignment Affects Spike Propagation in 3D Ephaptic Tracts

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Abstract

In this note the author finds that, dependent on the interaxonal distances within 3D ephaptic tracts, and condition of nodal alignment/misalignment on the constituent axons, action potential conduction profiles are different.

We build upon the model first introduced in the author's 2017 doctoral dissertation (it contains extensive code snippets for replication) [3]. The model was further refined in the 2019 paper involving Salvatore Morgera and Arthur Snider of the University of South Florida [4]. In the present note, the author extends the simulation to cover for cases when the three axons (only the $N = 3$ case has been extended so far) have differing locations for nodes of Ranvier. Axon 1 is the base case and always has nodes running from positions 20 through endlength-20 in steps of 20. Axons 2 and 3 are varied in their nodal locations. For example, in one case, axon 3's first bonafide node was at position 60, the rest being as in the base case, but none prior to 60. These changes and similar ones had a definitive impact on the obtained conduction profiles. If one further varied the W-matrix of interaxonal distances, the traces were further modified.

These results indicate the importance of nodal locations for action potential conduction in tracts with ephaptic coupling. The enclosed figures are snapshots of outputs plotted using MATLAB's for loop and subplot functions. The key variable is the structure "axon" which is an instance of the class "aXon" which models fields which hold the axon's parameters such as length, diameter, fiber resistance, Voltage profile at all spatiotemporal points, external stimulation applied at various spatiotemporal locations and so on. This struct is returned by the "packagedCNN" method which does the actual time stepping of the matrix equation. First the task is to construct this matrix equation accurately based on a Crank Nicolson discretization. Assuming one has the 2019 construction implemented already, the modifications needed to simulate the case of differing nodal locations on different axons were as follows. The superdiagonal blocks and the subdiagonal blocks didn't need to be modified. It was only the main diagonal block that needed modification. The modification was based on the fact that if at a certain position a node was missing in an axon or group of axons, the corresponding main diagonal block would need to reflect that since where the missing axons' node might have been one would now have internodal coefficients, instead of nodal coefficients. If this book-keeping is carried out carefully, one gets the graphs shown in the next figures. In the figures, the top subplot is axon 1, the middle subplot axon 2 and the bottom subplot is axon 3. The different colors represent different successive nodes. In all figures, only axon 1 is stimulated. The vertical axes represent voltage in Volts and the horizontal axes represent time in seconds.

To summarize, this work has demonstrated a tight interaction between misalignment of nodes, as depicted in Binczak-Eilbeck-Scott [2], and interaxonal distances as introduced in Chawla-Morgera-Snider [4] via the phenomenological W-matrix which was later justified in the Communications in Mathematical Biology and Neuroscience paper of the first two members of the triplet [5]. The interaction has clear impact on the conduction velocity profiles and therefore implications for neuroscience, neurophysiology and even neurosurgery. Future work will involve detailed corroboration with the results and simulations of [2]. The present work also seems to differ with the results of [1] who don't find any impact of interaxonal distances on ephaptic coupling strength, regardless of the condition of alignment.

References

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[3] Aman Chawla. *On Axon-Axon Interaction via Currents and Fields.* PhD thesis, University of South Florida, 2017.

[4] Aman Chawla, Salvatore Morgera, and Arthur Snider. On axon interaction and its role in neurological networks. *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, 2019.

[5] Aman Chawla and Salvatore Domenic Morgera. On the geometry of interacting axon tracts in relation to their functional properties. *Commun. Math. Biol. Neurosci.*, 2024:Article–ID, 2024.

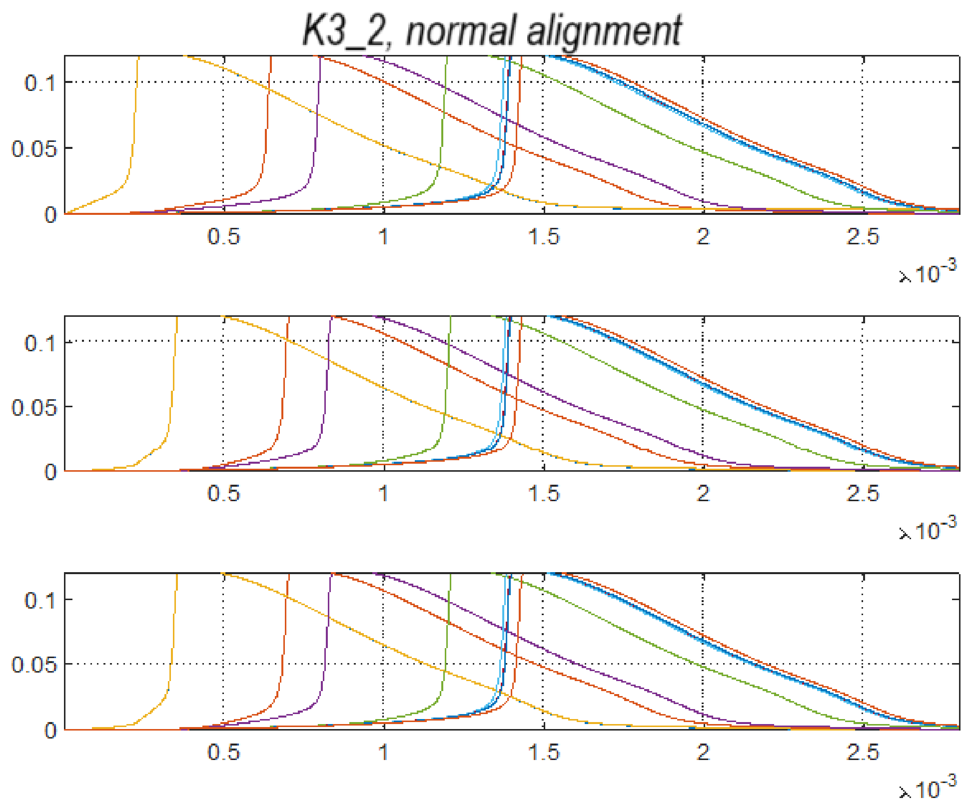

Figure 1: W-matrix used: K3_2. Normal alignment.

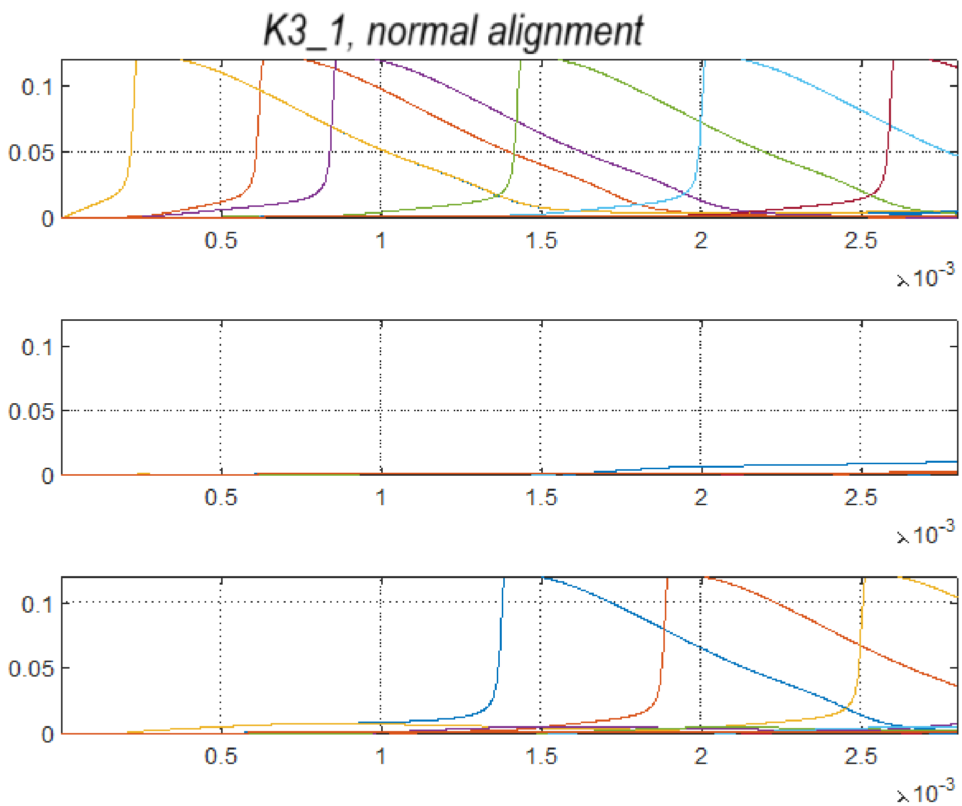

Figure 2: W-matrix used: K3_1, Normal alignment.

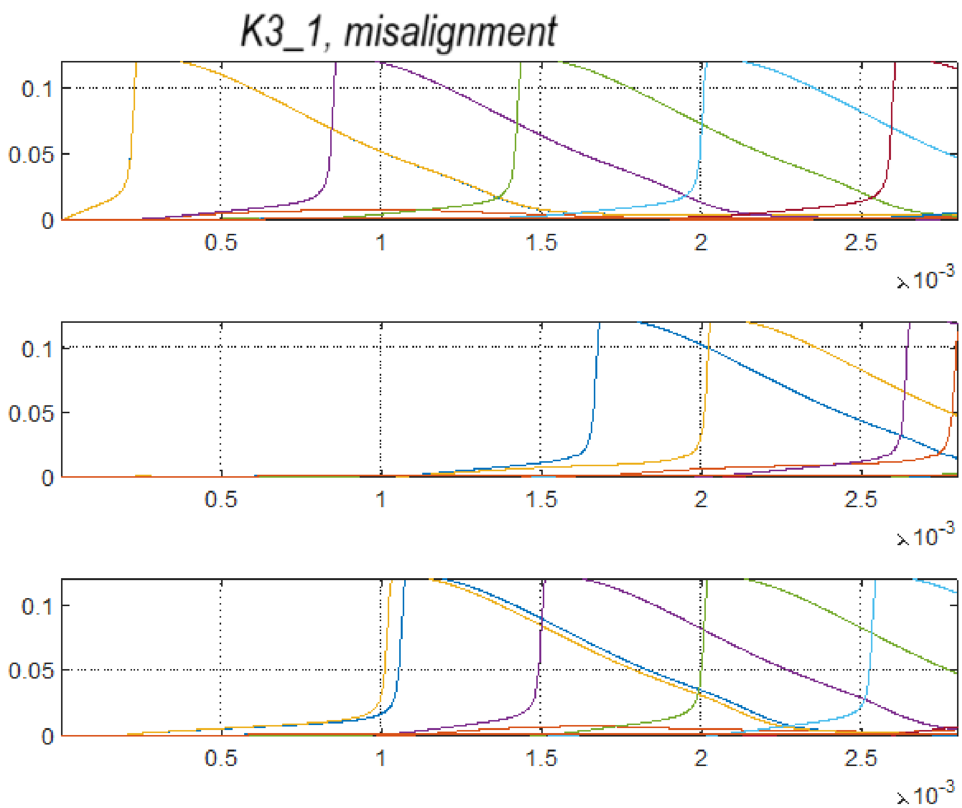

Figure 3: W-matrix used: K3_1, Nodal misalignment.

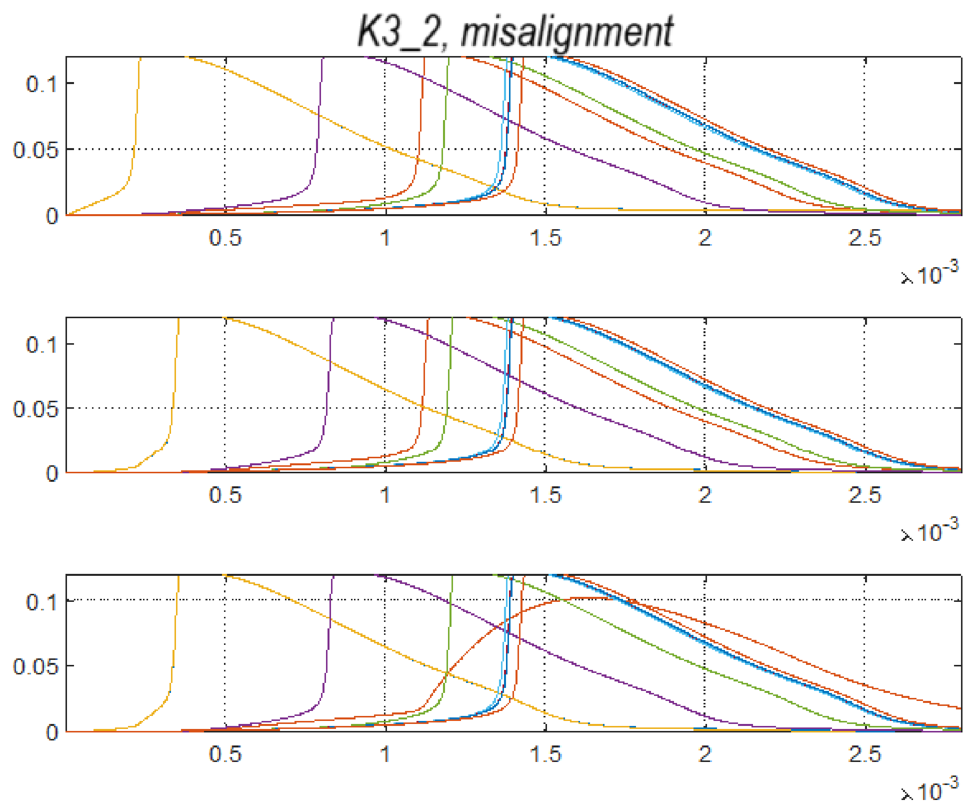

Figure 4: W-matrix used: K3_2, Nodal misalignment.