Simulating the point of no return in human volitional action in a brain-constrained model of sensory and motor areas

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ABSTRACT

Following a decision to act, motor execution exhibits a typical "point of no return", a time after which movement can no longer be prevented [1]. Why are we unable to veto action beyond a certain point? We used a 6-area brain-constrained neural-network model mimicking neurophysiological and anatomical features of relevant cortical areas to investigate the brain mechanisms underlying this phenomenon. The same model was previously used to explain emergence of self-paced action decisions as spontaneous ignitions of learnt "perception-action" (or Cell Assembly, CA) circuits caused by noise reverberation in them [2]. We ask here if such distributed circuits exhibit a natural threshold, an activity level beyond which ignition always occurs.

We recorded network activity over ~6mil steps in absence of any "sensory" input and observed regular, spontaneous within-CA-circuit activity peaks, driven by noise. Each CA's activity typically peaked near the circuit's own maximum (100%) level, indicating a full ignition (or a "volitional action decision"). Using KMeans clustering (bootstrapping with resampling, N=3000), we then analysed within-CA activity, looking for a possible distinct group of peaks centred at values below ignition levels. A "between-clusters gap" would indicate the presence of an inherent threshold which, if reached, would always be followed by full CA ignition, thus reproducing (and explaining) the point-of-no-return effect seen in volitional action experiments.

We found that, for ten of the twelve learnt CA circuits, activity peaks could be grouped into at least two different clusters (Fig. 1), a higher, "full-ignition" one, and lower, "sub-ignition" one/s, indicating the presence, in each assembly, of a natural threshold (model correlate of the point of no return, PNR) lying near the upper boundary of the highest of the "sub" clusters. (Two of the circuits were excluded as they failed to exhibit full ignitions: their upper clusters were lower than those of the remaining CAs). We also found between-circuit differences in natural-threshold (PNR) values, ranging from 10% to 70% of a circuit's maximal activity, suggesting the presence of memory-trace-specific PNRs, and, hence, dynamic features.

The existence of a non-empty set of levels between the "sub-" and "full-ignition" clusters of activity peaks in which CA-circuit activity is unstable (as observed for 83% of the CAs) suggests that each circuit does have an inherent activity threshold which, once reached, is always followed by full ignition. Our model thus offers a tentative mechanistic explanation for the existence of a point of no return in volitional action: the ability to stop movement only up to a certain time after having committed to it may be due to the inherently unstable, positive-feedback dynamics of the sensorimotor memory

traces our cortex learns via repeated action execution, which spontaneously ignite when baseline neural activity reverberates in them.

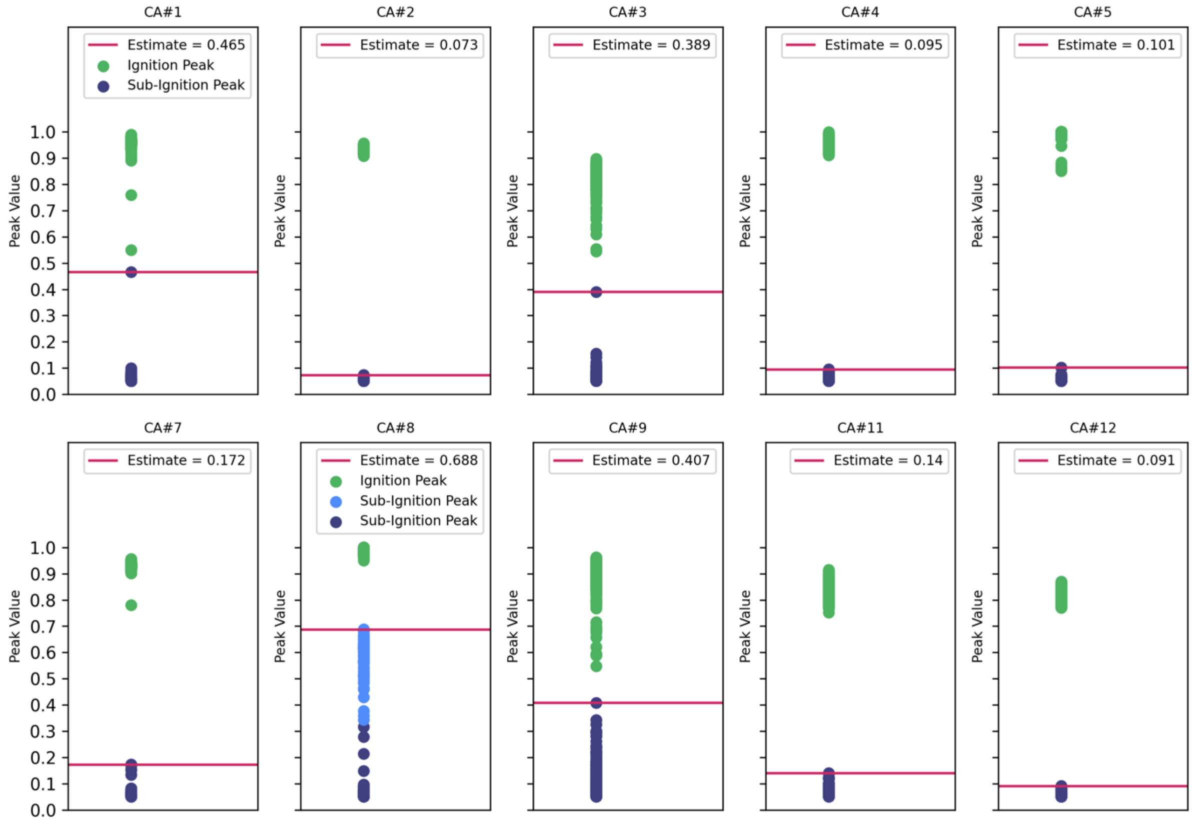

Figure 1. CA activity peaks coloured by cluster. Activity peaks are local maxima in CA activity, with peak value being the level of (proportional) CA activity reached. Note most CAs formed two clusters (chosen as maximisation of silhouette score), whilst CA 8 forms three clusters.

Keywords: [Field of study] system dynamics, [Field of study] neural circuits, [System] motor, [System] neural computation

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