Prospective Temporal Locations Tracked by Neural Power Modulations and Captured by Recurrent Neural Networks

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Abstract

Complex human behaviors involve perceiving continuous stimuli and planning actions at sequential time points, such as in perceiving/producing speech and music. The brain needs not only to predict a future event or estimate event duration, but to anticipate a sequence of prospective moments. How does the brain achieve this sequential temporal prediction? To answer this question, we adopted a tone-in-noise paradigm, in which we tagged sequentially three temporal locations in white noise by asking 27 human listeners to detect a tone presented at one of the temporal locations. We selectively probed neural processes in trials with only noise using novel modulation spectrum analyses. A multi-scale processing scheme was revealed - the neural power in the delta band encodes noise duration on a supra-second timescale; the power modulations in the alpha-beta band mark the temporal locations on a sub-second timescale and correlate with tone detection performance. To understand the functional role of the neural modulation tracking of temporal locations, we trained multiple recurrent neural networks (RNNs) on variations of the behavioral paradigm. The RNN hidden activities resembled the neural signatures; further analyses and perturbations on RNNs suggest that the power modulation in the alpha-beta band emerged as a result of selectively suppressing irrelevant noise periods and increasing sensitivity to the tagged temporal locations – a process of dynamic gain control. Our neural, behavioral, and modelling findings convergingly show that, to predict the future, the brain operates nonlinearly on multiple timescales and employs gain control in time.