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Power-law autocorrelation of neural activity in models of mental states that are hierarchically organized

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We assume that complex tasks are executed by going through a series of inner mental states, each representing an actively maintained disposition to behavior. Each state contains task relevant information about past events and internal cognitive processes. For example, in complex tasks the same sensory stimulus might require different motor responses depending on the context. More generally, decisions are affected by a large number of factors such as motivations, emotions and intentions, which are all assumed to be encoded in the inner mental state. Every task relevant event induces a transition from one mental state to another. This implies that mental states are numerous and the event driven transitions between them are highly organized.

We constructed tasks in which the schemes of mental states and event driven transitions are hierarchically organized and scalable in complexity. We then built a model of a neural network that performs these tasks. We assumed that mental states are represented by stable attractors of neural dynamics, with external events steering the activity from one state to another. The structure of mental states and event driven transitions is encoded in the synaptic couplings between neurons, and it contains the instructions to react to the events occurring in the external world.

We show that there is a wide class of hierarchically organized schemes of mental states and event driven transitions that produce neural activity with long-range temporal correlations. In particular, the autocorrelation function of the neural activity decays as a power-law on a time interval that increases linearly with the number of mental states. The power-law behavior is entirely due to the hierarchical structure of the scheme of mental states as the events are always assumed to be delta correlated. Power-law autocorrelations are widely observed in recorded activity in behaving animals [1].

Highly variable neural activity might also be an expression of the dynamics of a neural network implementing a complex scheme of mental states and event driven transitions. Experiments show that there are rapid changes in the recorded neural activity that can be interpreted as sudden transitions from one state to another [2,3]. These transitions can occur also in the interval between two task relevant events, indicating that there might be multiple processing stages during the perception of a sensory stimulus. Such stages would correspond to different mental states and the transitions would be generated either internally, by other cognitive processes, or externally, by events that are not under control in the experimental protocol. The fluctuations in the neural activity caused by these frequent transitions have a $1/f$ power spectrum in our model. If these fluctuations are strong enough to affect the final motor response or our perceptual decisions, then our model can also explain the 1/f noise widely observed in human cognition and performance [4].

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