An oscillation-based model of the awake and anaesthetized brain

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The long, rich history of brain models shows a predisposition towards neurons, however recent work suggests that non-neuronal brain cells—astrocytes—may play an important role in brain dynamics [1]. This unique and highly numerous cell modulates neuron-to-neuron connectivity and provides nutrition and energy to neurons via connections to blood vessels [1]. Here we present the first large-scale brain model to include astrocytes and use it to model general anæsthesia.

Conceptually, our model is founded upon the recognition that oscillations underly biological processes at all scales. Therefore, in contrast to models elsewhere we do not seek to replicate details at neuronal scales. Instead our model consists of multiple oscillatory ensembles, each of which represents a distinct neuronal or astrocytic population. This work extends the phase-oscillator model first introduced by Sheeba *et al.* [2] which itself extends the Kuramoto model of an ensemble of weakly interacting oscillators [3].

Through the inclusion of astrocytes our model successfully replicates the predominant characteristics seen in electroencephalograms (EEGs) from awake and anæsthetized subjects. In our model astrocyte-neuron interaction produces a slow variation of neuronal dynamics similar to those widely observed elsewhere through neuronal and astrocytic cellular recordings [4]. In addition faster rhythms (i.e. delta, theta, alpha and beta) are also exhibited by cortical ensembles and are dependent upon the interaction strengths between cortical and thalamic ensembles.

Literature suggests that astrocytes form a unique "bridge" between neurons and blood vessels in the brain [1], hence we take a first step towards a unified brain-body model; two aspects which are traditionally modelled separately. Furthermore, our model illustrates the rich nonlinear dynamics which can arise from comparatively basic oscillatory "building blocks", thus our work constitutes progress towards improved brain and body models, with potential applications in depth of anæsthesia monitoring. Our approach could also be adapted to model numerous other oscillatory biological systems.

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