Wisam's Responses For Malcolm

I don't understand your results yet, and the paper is missing a clear goal.

- Our goal was to create a tempo adaptive model of event-related desynchronization (ERD) and synchronization (ERS) dynamics in the motor cortex due to periodic voluntary movement.
    - This is simpler than our original goal of capturing the dynamics of interactions between gamma-band power in the basal ganglia (BG) and beta-band power in the motor cortex (MC) for the same task.
    - Architecture 1 (Figure 5) is an over simplified prototype of the original goal. (Not tempo adaptive)
- These dynamics are evident in healthy brain function and breakdown with parkinsonism.
- Eventually we would like to extend our model to tackle the original goal (for healthy brain function)
    - This could then lead to further work exploring biologically plausible ways that these dynamics deteriorate in patients with parkinson's and the modeling thereof.

Are you claiming that one of these architectures works better than anything else that has been published?

- I am not aware of other oscillatory models that capture the ERD and ERS of the motor system in a manner that is adaptive to the frequency of its input.
    - This is in contrast to Ed Large's beat perception model which doesn't capture the dynamics of synchronization or desynchronization in the motor system. Large's model merely mode locks and peaks in amplitude at the pulse of a rhythm (similar to a cross correlation in the power spectrum).
    - In retrospect, we took on a greater challenge than finding the rhythmic pulse of an input. Our challenge required us to work outside of the structure provided by Ed Large's toolbox.
    - As one example, for Architecture 3 (Figure 7) we found the need to create an oscillator bank with a gradient over other parameters, not just frequency.

I think you are synthesizing something new, good. But for what point?

- I think this is partially answered in my response above
- We felt constrained by the structure of Ed Large's toolbox and we wanted to work with the oscillators in our own ways
- We built up progressively, from models with very few oscillators to more complex architectures
    - Along the way, we found our own motivations for gradient frequency architectures similar to Ed Large's work
    - Most of these motivations stem from our stability analysis of these oscillators (under periodic forcing). Stability is in part, a function of the oscillators relative frequency (the difference between its resonant frequency and the frequency of its input)
        - Therefore, when the desired behavior needs to be independent of the input frequency, a gradient of oscillators is often required
        - *I talk in more detail about stability analysis in my responses below*

Are the three architectures significant in some way?

These three architectures are a progressive build up in complexity and in the qualitative accuracy of the model's behavior. After Architecture 1 we put aside the gamma-band (BG) behavior and focus on tempo adaptive dynamics in the MC alone.

- Architecture 1 (Figure 5):
  This model captures beta- (MC) and gamma-band (BG) dynamics for one input frequency.
- Architecture 2 (Figure 6):

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This model focuses on beta-band (MC) ERD adaptive to arbitrary input frequencies. The adaptive ERD is possible because of the addition of a gradient over frequency for oscillators in the first layer.

- ➔ Note: The beta-band ERS is not input tempo adaptive. (Constant regardless of input frequency).

➔ Architecture 3 (Figure 7):

This model focuses on both beta-band (MC) ERD and ERS adaptive to arbitrary input frequencies. The adaptive ERS is possible because of the addition of layer 1 interconnections and a progressive gradient of "slopes" for oscillators in layer 2. The progressive change in "slope" (in the amplitude vector field (AVF)) arises from a gradient over alpha and beta1 values in layer 2 oscillators. (I discuss the AVF in more detail in my responses below).

- ➔ Note: Despite the qualitative improvement of this implementation, I can not defend its biological plausibility.

Figure 1: periodic stimulation of what? artificial or real neurons? The key thought, unstated, is the same network responds appropriately (and predicts each epoch) based only on its periodic input. Actually, now that I think about it… the response falls after the stimulation, and then rises.. what happens if there is not a stimulation? Does it fall right after missing stimulation? Your figure doesn't make the case.

- ➔ This figure shows human physiological measurements during periodic beat listening. The characteristic event-related desynchronization (ERD) and synchronization (ERS) are observed in the motor cortex. An ERD reflects the processing of the input by the motor system, which without stimulation does not show either ERD or ERS.
- ➔ After an extended time of periodic stimulation, a missing beat does not lead to an ERS. However, the ERS from the preceding beat does anticipate the missing beat.
- ➔ This is image is part of a figure published by Takako (Takako et al. 2012) which is cited in the report. (please see 'images/Fig 1 - Takako Original.jpg)
  - ◆ x-axis is time (-600 to 900 ms)
  - ◆ y-axis is the beta-band ERD (z-scored)

Bottom of page 2… in a gradient - >perhaps say over a gradient…

- ➔ Corrected

Figure 2 and the rest.. all too small to read or understand.

- ➔ I will try to update the figures in the research report to be more readable asap, but the individual figures (in figures 2 - 4) are also in the submission I sent you. I pulled the images out of the "code/" folder into the top level directory for your convenience. I think they will be most readable in this form.
- ➔ Figures 2-4 in the report are meant to show the effect on the amplitude vector field (AVF) response as I sweep different parameters while holding the rest fixed.
  - ◆ Figure 2a: beta1 sweep [-1 to -10] (all other parameters fixed)
    - ● alpha = 0, beta2 = 0, epsilon = 0
  - ◆ Figure 2b: alpha sweep [1 to 10] (all other parameters fixed)
    - ● beta1 = -10, beta2 = 0, epsilon = 0
  - ◆ Figure 2c: beta1 sweep [-1 to -10] (all other parameters fixed)
    - ● alpha = 10, beta2 = 0, epsilon = 0
  - ◆ Figure 3a: alpha sweep [-0.2 to -2] (all other parameters fixed)
    - ● beta1 = 10, beta2 = -1, epsilon = 1
  - ◆ Figure 3b: beta1 sweep [9.2 to 11] (all other parameters fixed)

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        - alpha = -2, beta2 = -1, epsilon = 1
    - Figure 3c: beta2 sweep [-0.5 to -1.4] (all other parameters fixed)
        - alpha = -2, beta1 = 10, epsilon = 1
    - Figure 4a: alpha sweep [-6 to -7.8] (all other parameters fixed)
        - beta1 = 8, beta2 = -1, epsilon = 1
    - Figure 4b: beta1 sweep [8 to 9.8] (all other parameters fixed)
        - alpha = -6, beta2 = -1, epsilon = 1
    - Figure 4c: beta2 sweep [-0.4 to -1.4] (all other parameters fixed)
        - alpha = -6, beta1 = 8, epsilon = 1
- Additionally, the figures 2 - 4 can be generated by running "autonomousOscAnalysis.m" (in the "code/analysis/" folder)

End of Section 3: MEG->ERP->Evoked->Power Fluctuations. But you don't actually make use of these terms anywhere else in the paper, do you?

- I should have done a better job connecting this data processing to the output of our models. This section describes the processing done on the MEG data in order to examine beta-band power fluctuation over time during periodic voluntary motion tasks. This is the ERD and ERS behavior we were seeking to model with our oscillators.
- The input to our model (impulse trains) are analogous to the periodic tapping movements used in the MEG experiments.

Eq. 1: z_i are the inputs?

- I corrected this in the report. The subscript is copy/paste latex residue
- The subscript should not be there in this context, good catch. There are times when we would use subscripts to index a specific oscillator in a gradient layer.
- This is a general equation for a single oscillator

what is bifurcation of autonomous behavior?

- I removed this odd wording

Page 4: what defines the behaviors you mention?

- The AVF plots (Figures 2- 4) show the amplitude (r) [x-axis] plotted against its derivative (r_dot) [y-axis]. These AVF plots show us the oscillator amplitude behavior depending on the oscillators initial conditions.
- The box on page 4 describes the parameter regimes for qualitatively different amplitude vector field behaviors.
- Generally, "super" refers to an AVF that crosses zero (rising above it), where "sub" refers to an AVF where the response stays below zero (meaning the amplitude derivative is always negative or zero).
- A critical hopf oscillator's amplitude will always decay to it's single FP at zero regardless of initial conditions.
    - i.e. Leftmost plot of figure 2
- A supercritical oscillator's amplitude will always settle to its non-zero FP. Depending on initial conditions the amplitude will either be repelled from zero toward the FP, or pulled down to the FP.
    - i.e. Center and rightmost plots of figure 2
- In General, a "double limit-cycle" (DLC) refers to an oscillator with two local maxima in its AVF. Again, "super" and "sub" referring to positive and negative values for the local maxima respectively.
- A supercritical DLC's AVF will have a positive local maxima and consequently will have 3 FPs, one for each of its zero crossings. This gives the oscillator "bistability" at zero and a non-zero amplitude.

Dependant on initial conditions the oscillator amplitude will either repel from the second non-zero unstable FP and settle to its FP at zero or repel from the second non-zero unstable FP toward the 3rd non-zero stable FP.
    - i.e. Figure 3
    - The bistability of this parameter regime is precisely the qualitative behavior we often seek to exploit.
- A subcritical DLC's AVF will have a negative local maxima and will therefore only have 1 stable FP. These oscillators will always settle to their FP at zero regardless of the initial conditions.
    - i.e. Figure 4
- Trajectories over time through the AVF for a given parameter setting are determined by the initial conditions for the oscillator relative to its fixed points. In the case of an autonomous oscillator the phase derivative is constant, therefore we are only concerned with an oscillator's initial amplitude value (r).
    - This is in contrast with oscillators under periodic forcing with which we are concerned with the initial conditions for both the amplitude and relative phase (between the oscillator and its input).
- Upon reflection I see now that the plots need arrows to indicate the direction for trajectories in the vector field. I think that would make the plots considerably more informative.
- The FP values are found by solving the polar form equation for the oscillators amplitude after setting it equal to zero (Eq 2).
- The FP stability is determined simply by the slope of the AVF at the FP. Positive and negative slopes giving us stable and unstable fixed points respectively. Some extra considerations need to be made in cases of marginal stability and for saddle points but the latter doesn't come up for the parameter regimes currently under analysis.
    - This is contrast to oscillators under periodic forcing in which FP stability analysis becomes more complicated. This involves first computing the jacobian matrix (functions of the steady-state amplitude of the oscillator) then finding regions of stability based on the signs of:
        - (1) the determinant of the jacobian matrix,
        - (2) the trace of the jacobian, and
        - (3) the determinant of the characteristic equation.
    - Additionally, these regions of stability change in character as a function of both the relative frequency (between the oscillator and its input) and the driving force (the strength of coupling between the oscillator and its input).
    - I have already implemented most of the analysis for forced oscillators (in MATLAB) as well but I didn't include anything about it in the report since it's not quite completed yet.

Figure 3-5: I can't read these, and I am not sure what they are trying to tell me. Can you elucidate?

- I will try to update the figures in the research report to be more readable asap, but the individual figures are also in the submission I sent you. I pulled the images out of the "code/" folder into the top level directory for your convenience. I think they will be most readable in this form.
- Some of this was covered in responses above
- Architecture 1 (Figure 5):
  This shows a prototype of gamma-band bursting (modeling the BG) due to stimulation, this then feeds as inhibitory input (desynchronizing) beta-band oscillation (modeling the MC).
    - This model is not tempo adaptive. The model will only respond to a fixed input tempo and will not respond to others.
    - A panel by panel description of this figure is in section 5.1 of the report.

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- Architecture 2 (Figure 6):
  This shows a prototype of beta-band (MC) ERD adaptive to arbitrary input frequencies.
  - The adaptive ERD is possible because of the addition of a gradient over frequency in the first layer.
  - The beta-band ERS is not input tempo adaptive. (constant despite input frequency)
  - A panel by panel description of this figure is in section 5.2 of the report.
- Architecture 3 (Figure 7):
  This shows a prototype of beta-band (MC) ERD and ERS both adaptive to arbitrary input frequencies.
  - The adaptive ERS is possible because of:
    - The addition of inter-layer connections in layer 1.
    - The addition of a gradient over AVF slopes in layer 2. (Explained above)
  - A panel by panel description of this figure is in section 5.3 of the report.
  - This model's biological plausibility cannot currently be defended.

End of page 4: you are talking about oscillators that can maintain a state, and thus a memory. Is this needed for your thesis?

- In retrospect, I thought about deleting this and I should have.
- I didn't connect this thought very well, but eventually future models will exploit this behavior via the oscillator's "bistability" in the supercritical DLC parameter regime.

Section 5: What is your goal? What is the desired behavior?

- I think some of this has been answered above
- Our goal was to create a tempo adaptive model of event-related desynchronization (ERD) and synchronization (ERS) dynamics in the motor cortex due to periodic voluntary movement.