Response Variability in a Rhythmic Tapping Task During Sub- and Suprathreshold TMS Over Motor Cortex

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Background

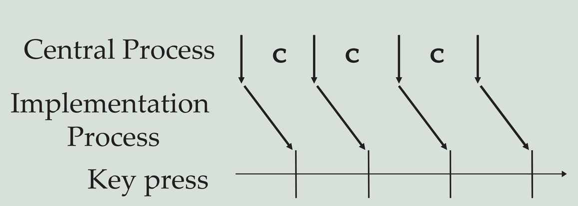
Wing-Kristofferson Model
of rhythmic tapping

- posits that rhythmic tapping variability can be attributed to two independent sources--noise in the central timing process and noise the implementation of the response

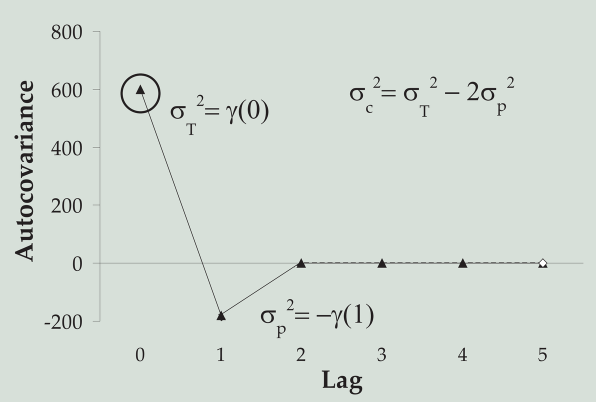
two independent components

Central Processes σ_c^2

Implementation Processes σ_p^2



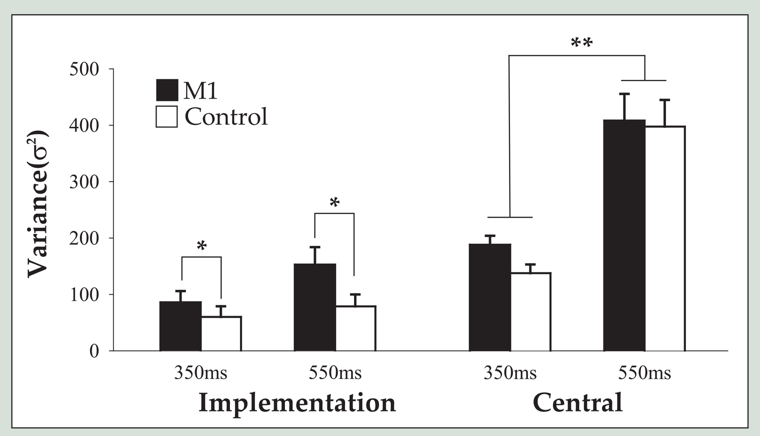
Examine the pattern of the inter-tap-intervals



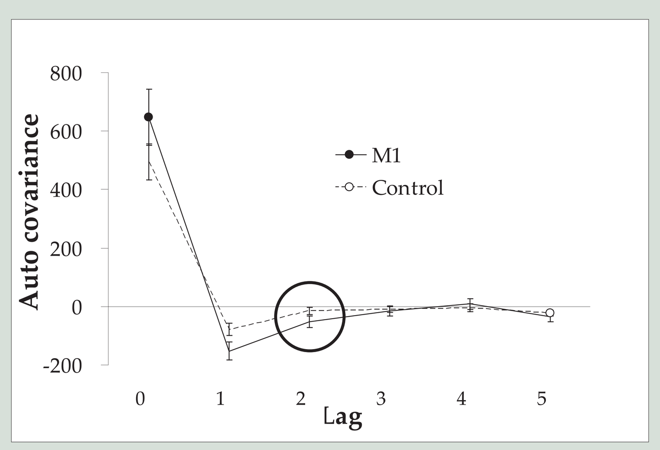
Previously:

Online TMS over Motor Cortex at a threshold half-way between EMG and visible:

* Increased tapping variability specific to the implementation componenent



* Best fit to a Wing-Kristofferson model in which the implimentation noise is positively correlated



New Questions:

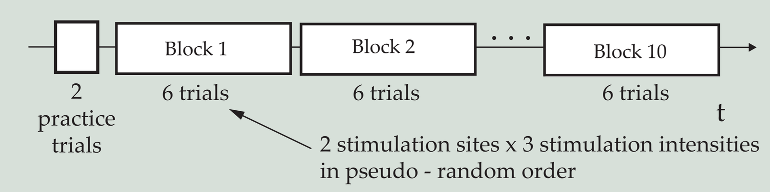
- Does Motor Cortex stimulation introduce motor noise when TMS does not produce cortico-spinal volleys?

- Was the positively-correlated motor noise that was previously observed due to TMS or other factors? If TMS-induced, does the amount of this correlation increase with stimulation intensity?

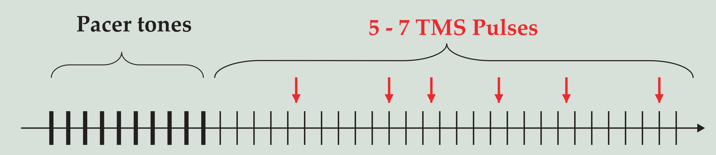
- Does Motor Cortex TMS lead to a general increase in finger variability or is there a critical window in which it disrupts the finger tap?

Methods

The Experiment:



The Trial:



10 paced taps, 30 unpaced taps
450 ms metronome

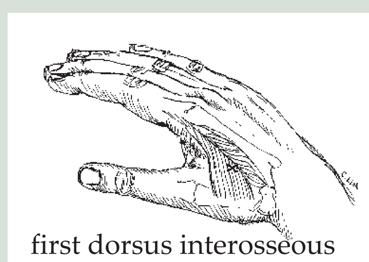
Stimulation Regions:

M1: Left Primary Motor Cortex
Control: Medial Occipital-Parietal Junction

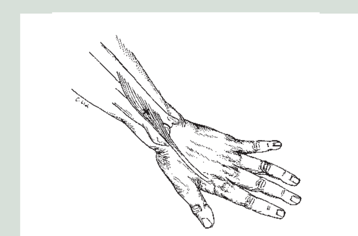
Stimulation Intensities:

85%, 105%, and 115% of active EMG threshold
(Low, Med, and High)

EMG Activity measured from:



first dorsus interosseous (FDI)



extensor indicis proprius (EIP)

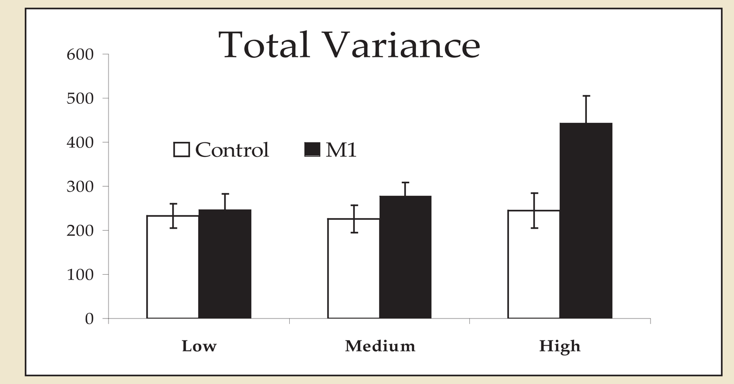
Participants:

4 female, 4 male; mean age = 25 years
all right handed

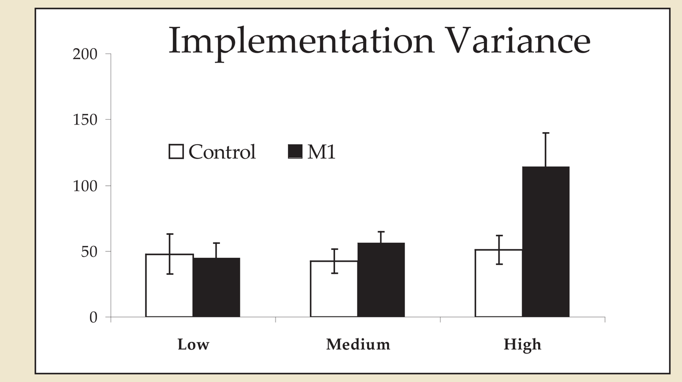
Criteria:

- Discarded trials in which any ITI was less than 225ms or greater than 675 ms (+/- 50% target interval)
- 6 valid trials required for each of the six conditions (2 regions x 3 intensities)

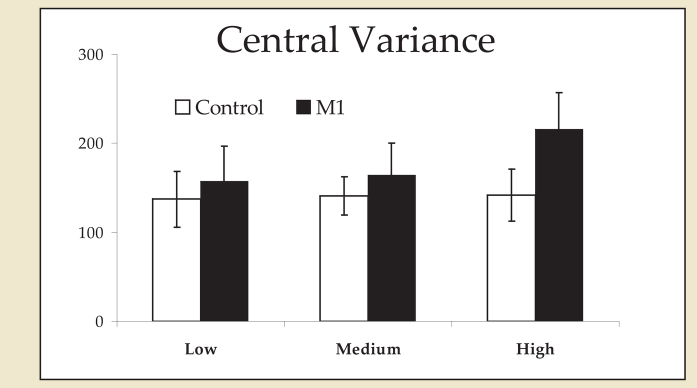
Results



* Total variance of the inter-tap-intervals significantly increased across stimulation levels

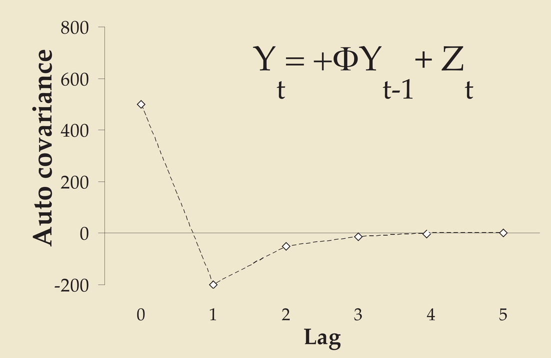


* Implementation variance estimates also significantly increased with stimulation intensity



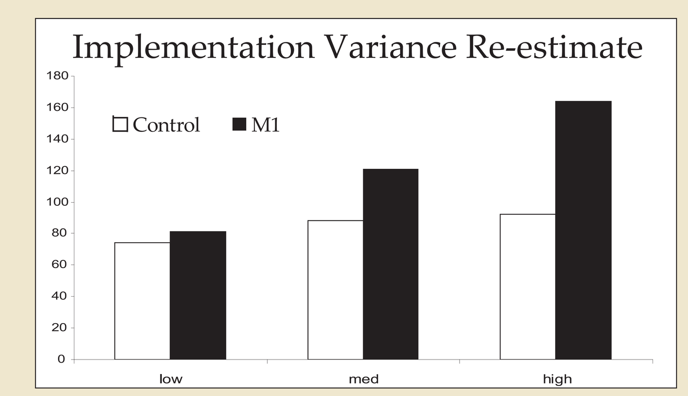
* Central variance had a significant main effect of ROI

Wing (1977) proposed models which account for deviations from the normal ACVF structure.

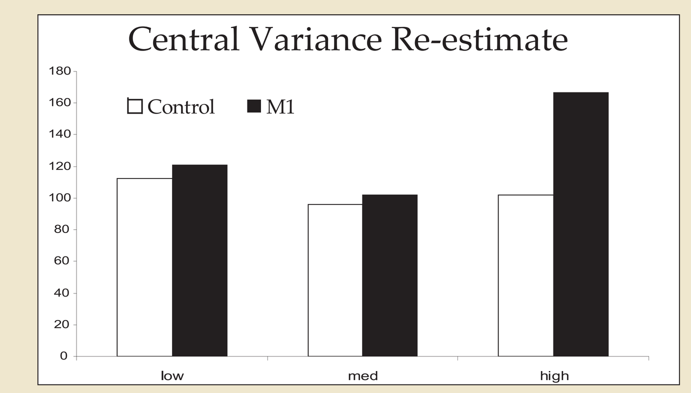


Autocovariance structure where the implementation noise is positively-correlated

Re-estimates of the implementation and central variance of our average autocovariance function within the positively correlated motor noise model:



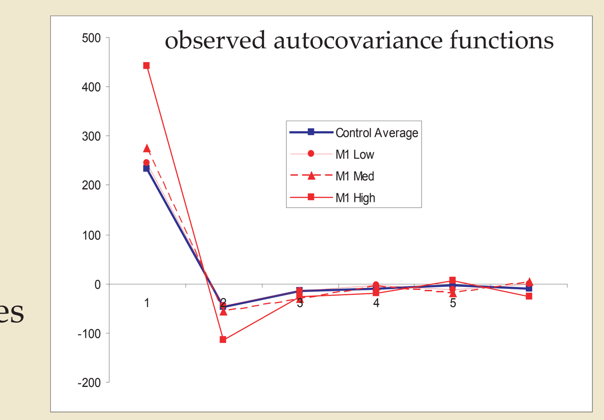
* Implementation variance more clearly reflects an increase in variability with stimulation intensity



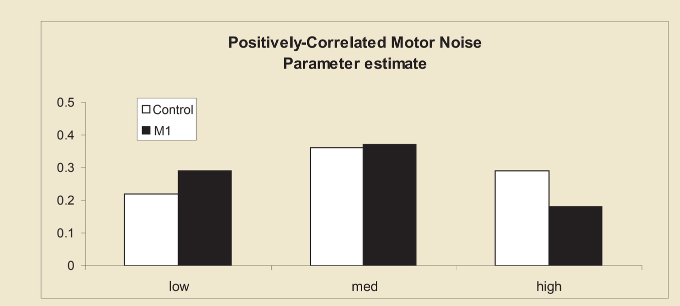
* Central variance reflect an increase in central variability with Motor Cortex TMS *only* for the high stimulation

* The observed ACVF functions for all the conditions are best fit by a model in which the implementation noise is positively correlated.

(Least-squares error estimates across lags 1 through 5 are 30% - 95% better than the standard wing model)

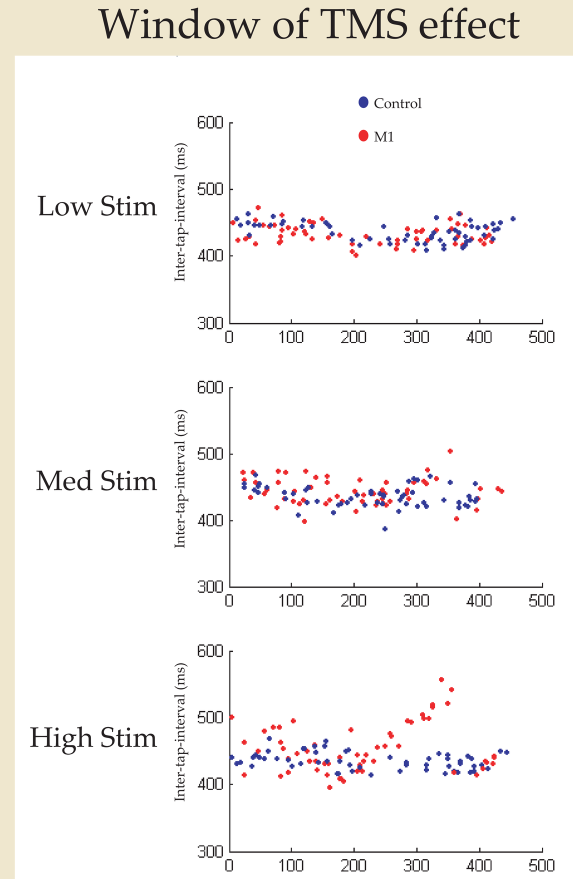


* The degree of positive correlation within the time series does not increase with intensity of stimulation or the site of stimulation. This suggests that the correlation may be due to non-TMS factors, e.g. hand posture.

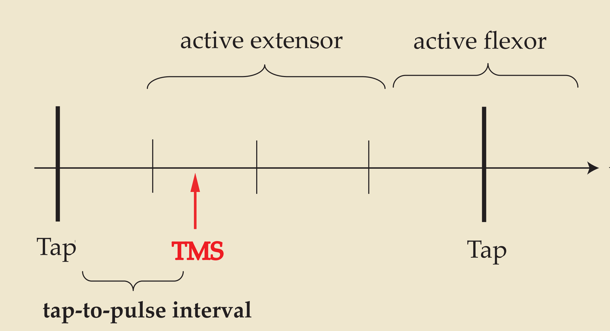


TMS effect within an Inter-Tap-Interval

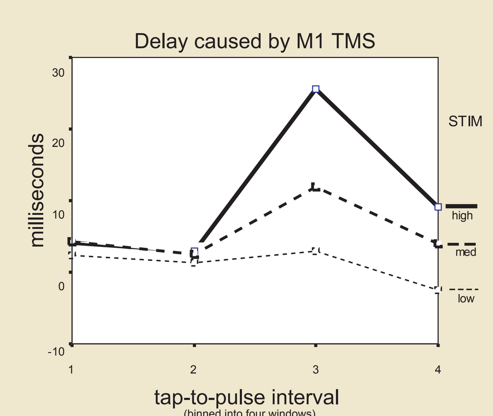
Window of TMS effect



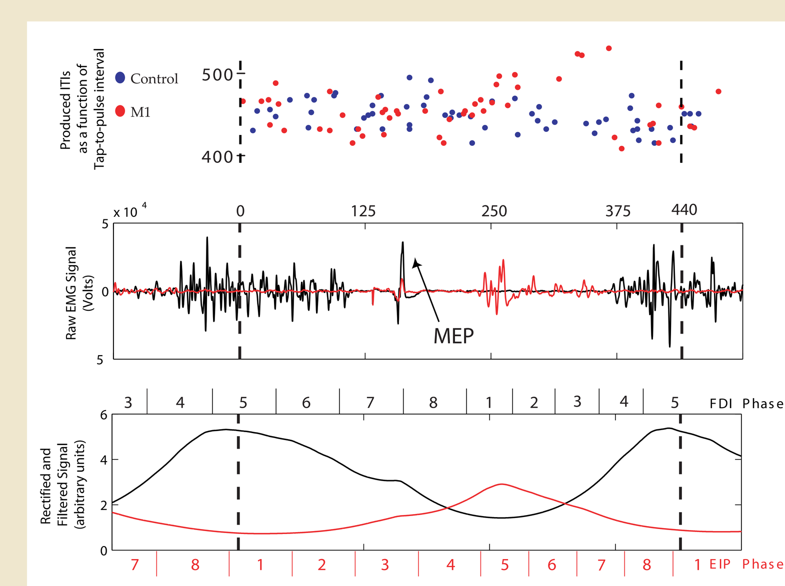
Tap-to-pulse interval



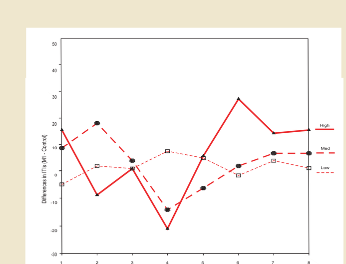
* The tap-to-pulse interval was binned into four windows and the mean ITI produced in each window were compared:

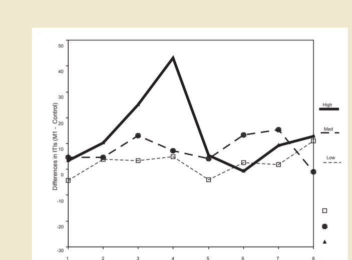


* TMS causes a lengthening of the inter-tap-interval. This effect is only observed with suprathreshold stimulation intensities and is restricted to the phase prior to the tap.



EMG traces of the inter-tap-interval suggest that the TMS induced-delay starts at the peak muscle activity of the extensor and ends at the peak muscle activity of the flexor.





Conclusions

- Stimulating over the motor cortex does not increase implementation noise at sub-threshold TMS intensities.

- Particularly at high stimulation levels, when stimulation produces a visible perturbation, TMS over the motor cortex also appears to increase the variance of central timing processes. Ongoing modeling work is addressing this.

- Positively-correlated implementation noise is not induced by motor cortex TMS and is more likely a result of tapping posture.

- TMS pulses only affect the inter-tap-interval when they occur in between peak extension and flexion of the finger tap movement.

Wing, A. M. & Kristofferson, A. B. (1973b). Response delays and the timing of discrete motor responses. *Percept. Psychophys.* **14**, 5-12.

Wing, A. M. (1977). Effects of type of movement on the temporal precision of response sequences. *J. Math. Statist. Psychol.* **30**, 60-72.