Application of the Two-Variable Model to Simulate a Multisensory Reaction-Time Task

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Introduction

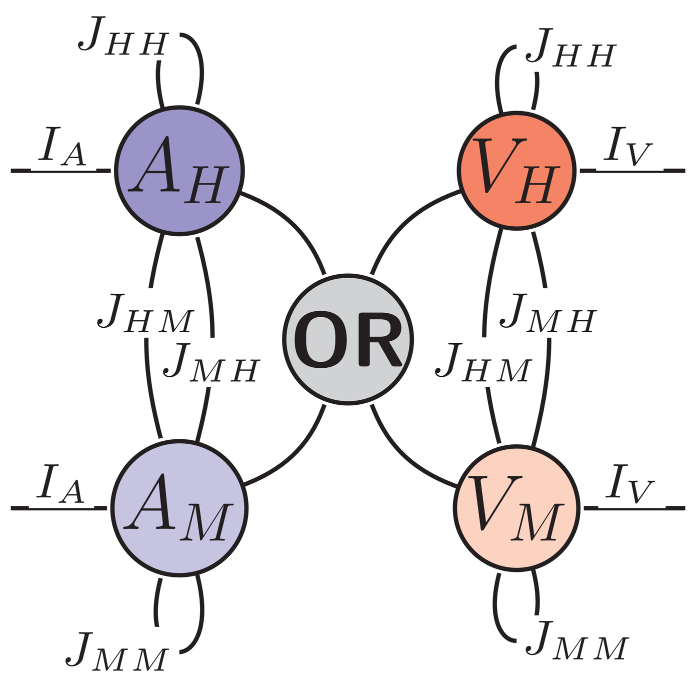
To navigate the world in an efficient manner, the brain seamlessly integrates signals received across multiple sensory modalities. Behavioral studies have suggested that multisensory processing is a range of possible mechanisms from winner-take-all sensory response to some optimal combination of sensory signals. In addition, multiple sensory cues are not always beneficial with some studies showing maladaptive multisensory processing as in people with Parkinson's Disease [1].

Here, we extend the reduced two-variable model developed by Wong & Wang, (2006) [2] to model an audio-visual speeded reaction-time task. Our model consists of a system of ordinary differential equations motivated by biological data to simulate:

1. unisensory and multisensory neurological processing and behavioral responses;
2. a participant's trial-to-trial variability;
3. different 'participants' sensory processing from auditory dominance to visual dominance.

These manipulations allow the model replicates data from multisensory behavioral studies [1, 3]

Graphical Multisensory Model



Mathematical Multisensory Model

The reduced two-variable model designed by [2] is a system of ordinary differential equations at the recurrent synapses. In this case, the system can be completely described by the following Equations (1-6),

$$\frac{dS_i}{dt} = -\frac{S_i}{\tau_S} + (1 - S_i)\gamma H_i, \tag{1}$$

where S is Audio A or Visual V, and i is Hit H or miss M labels the selective population for hits and misses, and τ_S is a time constant used to simulate different 'participant's' sensory conditions,

$$H_i = \frac{ax_i - b}{1 - exp[-d(ax_i - b)]}, \tag{2}$$

$$x_H = J_{HH}S_H - J_{HM}S_M + I_0 + I + I_{noise,H}, \tag{3}$$

$$x_M = J_{MM}S_M - J_{MH}S_H + I_0 + I + I_{noise,M}, \tag{4}$$

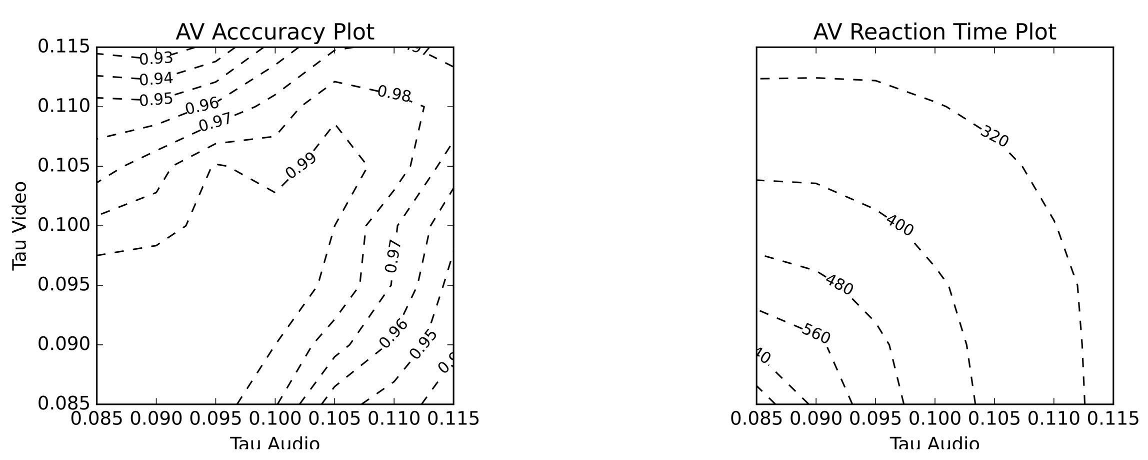
$$I_i = J_{A,ext}\mu_0\left(1 \pm \frac{c}{100}\right), \tag{5}$$

$$\tau_{AMPA}\frac{dI_{noise,i}}{dt} = -I_{noise,i} + \eta(t)\sqrt{\tau_{AMPA}\sigma^2_{noise}}, \tag{6}$$

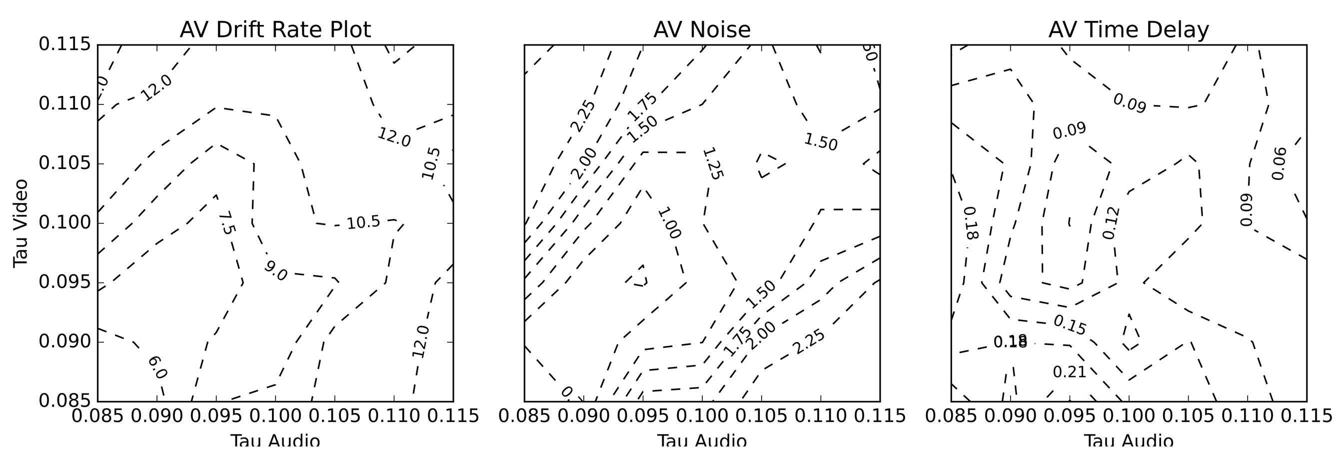
initial parameter values for the equations were taken from [2]. We model the multisensory response as a winner-take-all process, which can be coded as an OR response.

Multisensory Analysis

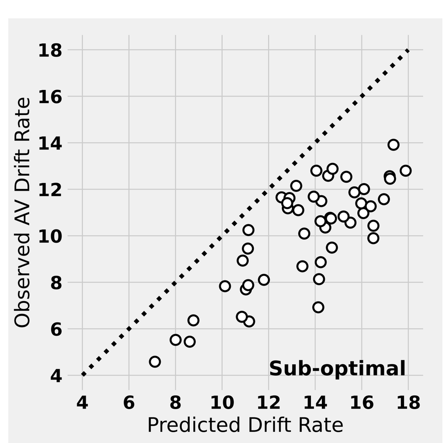
Audio-Visual Accuracy and Reaction Time for Unisensory Differences



Drift Diffusion Analysis

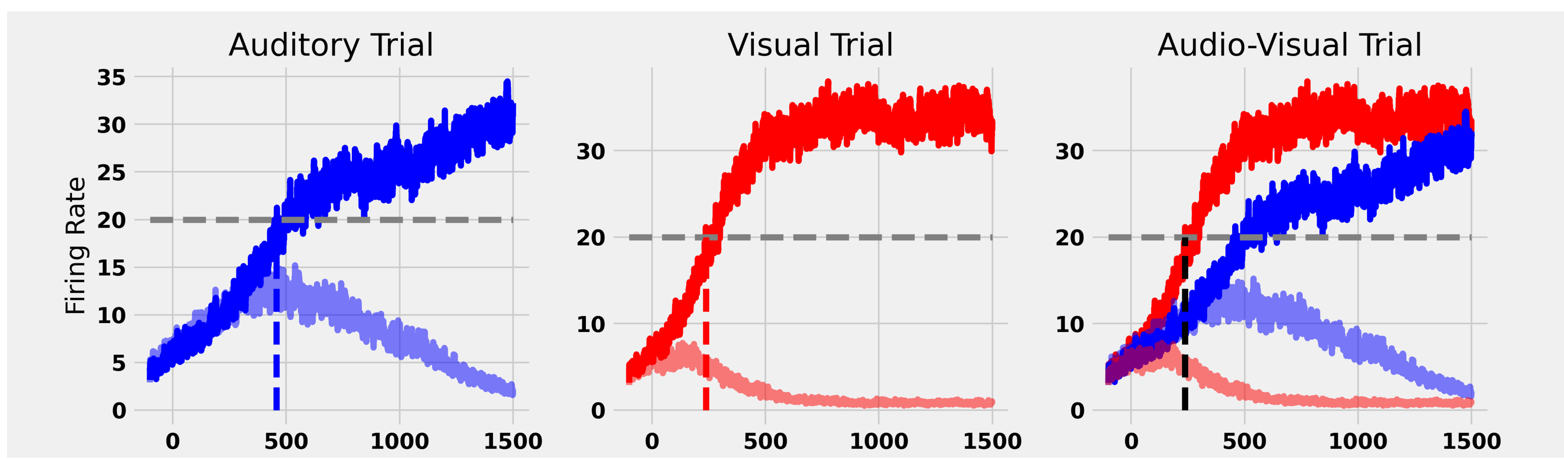


Audio-Visual Observed vs Predicted Drift Rate

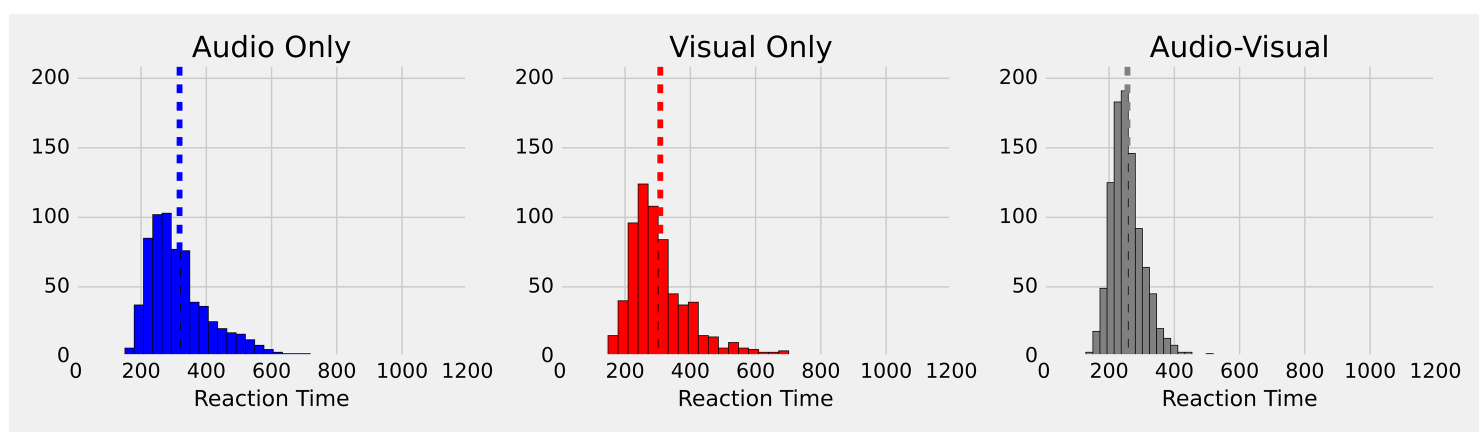


Results

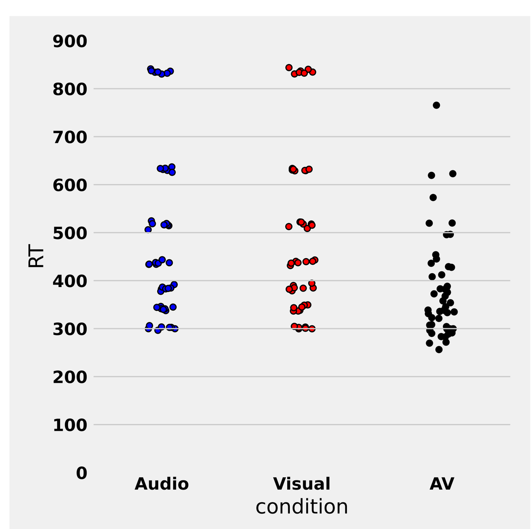
Unisensory and Multisensory Single Trial Simulation Results

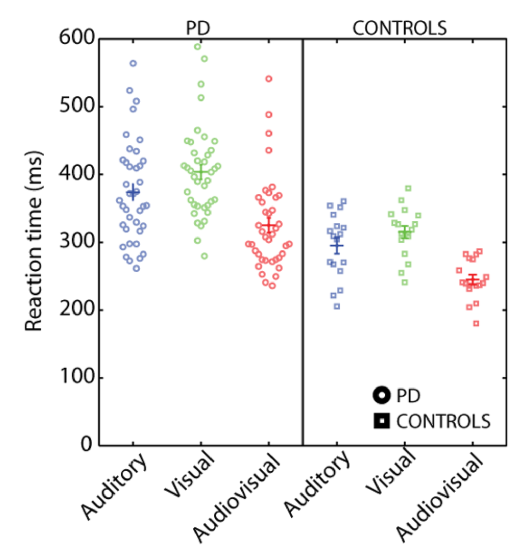


Single 'Participant' Simulation Results



Simulated and People with Parkinson's Disease Group Data





Discussion and References

- The results show that the two-variable equations are a good candidate to simulate models of multisensory integration and reproduced the findings of [1].
- A secondary benefit of these models is the ability to systematically test the sensitivity of the behavioural measures used in multisensory research, such as distinguishing between winner-take-all and optimal sensory integration dynamics [4].

Acknowledgments

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References

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[2] K.-F. Wong and X.-J. Wang, "A recurrent network mechanism of time integration in perceptual decisions.," *The Journal of neuroscience : the official journal of the Society for Neuroscience*, vol. 26, pp. 1314–1328, Jan. 2006.

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[4] G. W. Lindsay, "Testing the tools of systems neuroscience on artificial neural networks," *arXiv preprint arXiv:2202.07035*, 2022.