CALIFORNIA STATE SCIENCE FAIR
2012 PROJECT SUMMARY

Name(s)

Sara K. Simpson

Project Number

S1899

Project Title

Neuronal Nonlinear Dynamics: From an Optical Illusion to Parkinson's Disease

Abstract

Objectives/Goals

This project applied a novel physical framework of perception, based on modeling neurons as nonlinear oscillators. The objective was to understand the underlying physical basis for the Continuous Wagon Wheel Illusion (C-WWI), the perceived switch in direction of repetitive motion under continuous illumination. Using the nonlinear dynamics of direction-selective neurons, I created equations for a neural-network model to be numerically solved on a computer to determine if they accurately reproduced published experimental data. Neurons were modeled as mutually-coupled, nonlinear phase oscillators, subject to excitatory stimuli and cortical inhibition, emphasizing common neural characteristics across different parts of the brain.

Methods/Materials

Computer simulations were conducted to determine if this model reproduced data on perception of the C-WWI and neural activity in observers during perception. The time-dependent phases of neurons in direction-selective clusters were numerically determined as a function of variables such as excitation strength of the stimulus, strength of the inhibition, and excitation and inhibition from other neurons. The resulting phases were then analyzed and graphed to determine the type and degree of synchronization between neurons.

Results

The computer simulations presented a wide range of nonlinear dynamics for the coupled neurons as a function of the input parameter values. Partial and full synchronization only between same-direction neuron clusters, or across neuron clusters, was observed for different parameter values. Significantly, switching between different clusters, representing perceptual switches, occurred with a probability consistent with published studies of the C-WWI.

Conclusions/Discussion

The model accurately simulated oscillatory temporal patterns of direction-selective neurons. The computed results also indicated that the model captured behavior of real direction-selective neurons. This was proved in two different ways: 1) the clear examples of perceptual switches and 2) the percentage of the time these perceptual switches occurred accurately reflected the frequency of their occurrence in data collected in previous studies. Further, neural synchronization without external stimulation, associated with Parkinsonian tremors, resulted from further variation in parameters, indicating broad applications in understanding brain function.

Summary Statement

Computer simulations showed that the mathematical equations I created employing nonlinear dynamics accurately described neural activity in situations ranging from perception of an optical illusion to muscle tremors of Parkinson#s Disease.

Help Received

Parents helped with board.