Exam # ________

Physiological Foundations Spring 2006: Midterm Examination
March 27, 2006

Name ____

SSN ____

I certify that all of the work in this exam is entirely my own. I have not referred to any notes or to any other individual while taking this exam.

Signature ____

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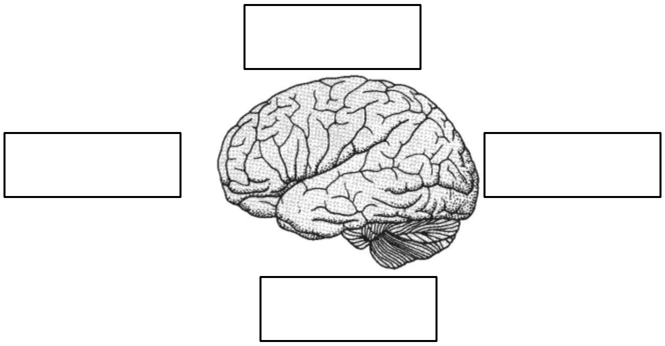
TOTAL	___ **/ 124**

Question 1

(4 points) In the boxes below, label the caudal, rostral, dorsal, and ventral parts of the brain.



Question 2

We have done an fMRI experiment and wish to determine the hemodynamic response function (HRF) for a given voxel in the brain. We will represent the HRF with vector **b**, which as 3 components: b_1, b_2, and b_3. We wish to estimate **b**. We have measured the activity in this voxel at 10 time points, and represent our measurement with vector **y**, which has 10 components: $y^{(1)}, y^{(2)}, \cdots, y^{(10)}$. We also have a record of when we presented a stimulus to the subject. The stimuli were presented at time points 1, 2, 4, 7, and 9. We begin with the model: $\mathbf{y} = X\mathbf{b}$, where X is a 10x3 matrix.

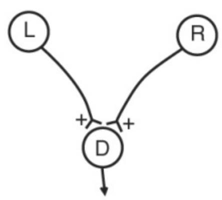
(8 points) Write out the components of the matrix X.

(4 points) Write an equation to show how you can estimate **b.**

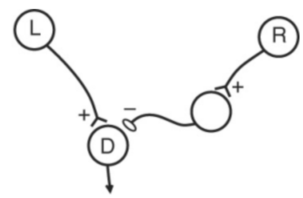
Question 3

(4 points) The olfactory system is sensitive to the difference in the strength of the activation of the olfactory receptors on the two sides of the nose. In many animals, the airflow through the two nostrils is kept separate, so that there are two olfactory epithelia, one activated from each nostril. Which of the following neural circuits would allow the animal to discriminate a difference in the strength of the odor in the two nostrils (e.g. odorant in the left nostril but no odor in the right). *L* and *R* are neurons in the left and right olfactory bulb. *D* is the output neuron, i.e. you should tell whether the activity of *D* would discriminate *L*>*R* from *R*>*L*. Assume that all synapses have equal strength. + and – mark excitatory and inhibitory synapses, respectively.

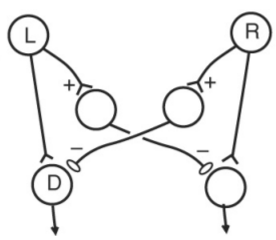
a. _______



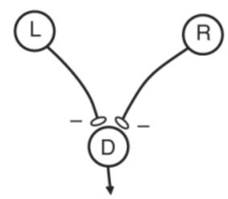
b. _______



c. _______



d. _______



Question 4

A membrane has three channels: an L-type calcium channel, a BK-type potassium channel, and a leak channel. A description of the channels is given below.

Ca channel – voltage-dependent activation only (i.e. no inactivation) with HH parameters $m_{Ca8}(V)$ and $\tau_{Ca}(V)$. Conductance G_{Ca} and reversal potential E_{Ca}. For simplicity, it's OK to use a linear model (i.e. not a GHK current model) for this channel's current-voltage relationship.

BK channel – voltage-dependent and calcium-dependent activation, with HH parameters $m_{K8}(V,C)$ and $\tau_K(V,C)$. Conductance G_K and reversal potential E_K. (*C* is the calcium concentration near the channels).

Leak channel – No HH model. Conductance G_L and reversal potential E_L.

(12 points) Write the differential equations necessary to model this system, in terms of the parameters given above. HINT #1: there are four equations. HINT #2: for one of the equations, you will have to specify some additional parameters.

Question 5

(3 points) List the steps required for transmitter release.

(3 points) Explain how activation of NMDA receptors differs from activation of AMPA receptors. List two ways in which the currents admitted by NMDA and AMPA receptors differ.

(3 points) Drug X is a neurotransmitter that causes hyperpolarization in a neuron held at a resting potential of -55mV. You are trying to figure out if it does this by regulating potassium channels or chloride channels. To determine this, you lower the extracellular concentration of potassium from 4mM to 2mM and then re-apply X at the same resting membrane potential as before. How should the response to X change if it acts by regulating potassium channels? Why?

(2 points) When a synapse is activated repeatedly at a high rate, its synaptic strength changes. Give two <u>presynaptic</u> mechanisms by which this can happen, one that strengthens the synapse and a second that weakens it.

(1 point) Describe one <u>post-synaptic</u> factor that can weaken a synapse following high-rate activation.

Question 6

Multiple Choice Questions **(1 point each)**

Which of the following is TRUE about G protein-coupled receptor systems? (circle one only)

a) The G protein-coupled, inward-rectifying K^+ (GIRK) channel is activated directly by G protein without employing second messengers.
b) G protein-coupled receptors indirectly gate ion channels by activating a GTP-binding protein, or G protein, that often engages a second-messenger cascade.
c) One kind of G-protein binds to phospholipases, which yields second messengers DAG (diacylglycerol) and IP_3 (inositol 1,4,5-triphosphate) upon activation.
d) All of the above
e) None of the above

Which of the following is TRUE about calcium-dependent potassium or K(Ca) channels? (circle one only)

a) K(Ca) channel is activated by extracellular Ca^{2+} concentration
b) The opening probability of the channel is increased by hyperpolarization
c) There are two families of K(Ca) channels: BK channels are gated by both calcium concentration and membrane potential, while SK channels are gated only by calcium
d) a) and c)
e) All of the above.

Which of the following is FALSE about the cAMP pathway? (circle one only)

a. Norepinephrine activates the cAMP pathway via ? -adrenergic receptors.
b. Increasing cAMP concentration reduces the conductance of SK type K(Ca) channels in hippocampus neurons, which results in increased spiking in response to stimuli.
c. In olfactory signal transduction, odorants stimulates adenylyl cyclase to produce cAMP and the resultant increase in cAMP opens cAMP-gated channels, leading to influx of Ca^{2+} and Na^+.
d. All of the above
e. None of the above

Which of the following is FALSE about receptor tyrosine kinases (TRK)? (circle one only)

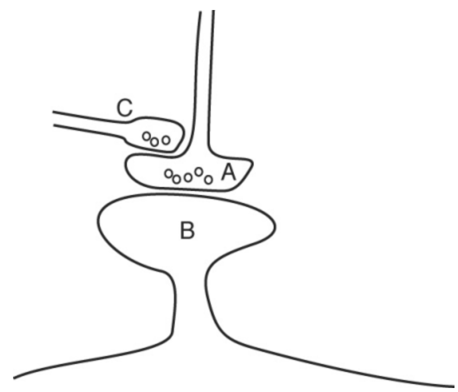
a) Receptor tyrosine kinases bind various peptides, including brain derived growth factor (BDNF).
b) Their cytoplasmic domain contains a built-in protein kinase that phosphorylates proteins on tyrosine residues.
c) Activation of TRK-B receptors blocks increases in excitability of neurons
d) All of the above
e) None of the above

Which of the following is TRUE about the dopaminergic system? (circle one only)

a) One dopaminergic tract that arises in the basal ganglia is important for the control of movement and is affected in Parkinson's disease.
b) Dopaminergic tracts are important for emotion and motivation.
c) The responses of midbrain dopamine neurons are related to the expectation of reward in behavioral tasks.
d) a) and b)
e) All of the above

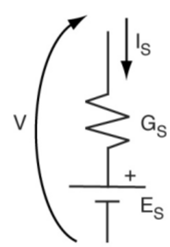
Presynaptic inhibition occurs when a presynaptic terminal (*A*) has a synaptic terminal on it (*C*). Which of the following effects of activating terminal *C* would inhibit (decrease excitatory transmission) from *A* to *B*? (circle one only)

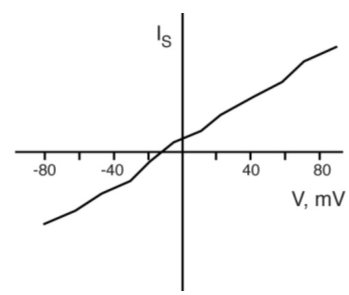
a) *C* releases glutamate that activates a metabotropic receptor on *A* that decreases the conductance of voltage-gated potassium channels.
b) *C* releases GABA that activates an ionotropic GABA receptor on *A*.
c) *C* releases a neurotransmitter that activates a metabotropic receptor on *A* that closes Ca^{++} channels and opens K^{+} channels.
d) b) and c)
e) None of the above



Question 7

In order to determine the reversal potential E_S of a synapse, the cell is voltage-clamped to a range of voltages *V*. The synapse is activated at each voltage and the current that is necessary to maintain the voltage clamp is assumed to be the current I_S that flows through the synapse when it is activated at voltage *V*. A plot of the peak synaptic current versus voltage-clamp *V* looks like the plot at right.

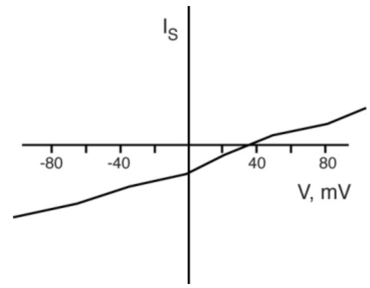




Part a) (4 points) Draw a sketch of the voltage-clamp currents that flowed when these data were obtained at various voltages (-80, -40mV, 0mV, 40mV).

Part b) (4 points) What is E_S for this synapse? Write an equation that explains why.

Part c) (4 points) If the synapse is located on a dendrite and the voltage clamp is done in the soma, the current-voltage relationship is changed as at right. Is the reversal potential of the synapse really different, as this plot suggests? If not explain why not. The answer should include some equations. Assume the dendritic tree behaves passively for this problem and that the resting potential of the neuron is –60 mV.



Question 8

For the following statements, indicate whether they are true (T) or false (F), If false, explain why in the space below each statement. **(2 points each)**

a) __ If an action potential were initiated by direct electrical stimulation of the axon midway between the cell body and the nerve terminal, it would only travel toward the cell body.

b) _ The neck of dendritic spines restricts electrical currents between the head of the spine and the rest of the dendrite, and this compartmentatlization is important for selectively altering the strength of synaptic connections.

c) __ Adding a simultaneously activated inhibitory synapse distal to an excitatory synapse will cause only small changes to the EPSP produced in the soma.

Fill in the blanks **(1 point each)**

a) Neurons are often covered in spines, small extensions of dendrites on which _ _(excitatory/inhibitory) synapses are usually made.

b) In a neuron with a myelinated axon, the action potential is triggered at the axon hillock, and regenerated at the __, where the membrane is rich in voltage-gated Na^+ channels.

c) In a myelinated axon, the conduction velocity is proportional to the __ of the axon, whereas in an non-myelinated axon, velocity is proportional to the ____.

Question 9

(6 points) Consider a simple perceptron given by $y = w_1 x_1 + w_2 x_2$ where (x_1, x_2) is the input pattern. An input is classified into one of two categories according to the sign of the output. Suppose after learning the weights become $w_1 = 1$ and $w_2 = 2$. Draw a sketch and describe the decision boundary in the input space (x_1, x_2) that separate the two categories.

Question 10

(5 points) In a linear feedforward network with n input nodes and m output nodes, each input pattern generates an output given by $\begin{pmatrix} y_1 \\ \vdots \\ y_m \end{pmatrix} = \mathbf{W} \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix}$ where $\mathbf{W}$ is the connection weight matrix. Suppose we have k input patterns given by the matrix $\mathbf{X} = \begin{pmatrix} x_1^{(1)} & \cdots & x_1^{(k)} \\ \vdots & \vdots & \vdots \\ x_n^{(1)} & \cdots & x_n^{(k)} \end{pmatrix}$ where each column is one input pattern. We want these patterns to be mapped to the desired output patterns given by $\mathbf{Y} = \begin{pmatrix} y_1^{(1)} & \cdots & y_1^{(k)} \\ \vdots & \vdots & \vdots \\ y_m^{(1)} & \cdots & y_m^{(k)} \end{pmatrix}$, or $\mathbf{Y} = \mathbf{WX}$. Among the following choices, which is the most general formula for setting the optimal weight matrix? Please circle only one answer.

(A) $\mathbf{W} = \mathbf{Y}\mathbf{X}^{-1}$

(B) $\mathbf{W} = \mathbf{Y}\mathbf{X}^{\mathrm{T}}\left(\mathbf{X}\mathbf{X}^{\mathrm{T}}\right)^{-1}$

(C) $\mathbf{W} = \mathbf{X}^{\mathrm{T}}\mathbf{X} + \mathbf{Y}^{\mathrm{T}}\mathbf{Y}$

(D) $\mathbf{W} = \frac{1}{2}\left(\mathbf{X} - \mathbf{Y}\right)^2$

Question 11

Hopfield network can store multiple memory patterns as dynamically stable states.

Part a) (4 points) What is the condition that a newly added memory pattern does not interfere with the old memory patterns?

Part b) (4 points) When many of the synaptic connection weights are destroyed, the network may still retrieve the stored memory patterns perfectly. Briefly explain why this is the case.

Question 12

Part a) (4 points) Write an equation describing Hebb's rule for synaptic learning.

Part b) (4 points) What properties of NMDA receptors make them relevant to Hebb's rule?

Question 13

(6 points) Consider a simple network model with a population of excitatory neurons and a population of inhibitory neurons that are mutually connected. Name two different types of dynamically behaviors of such a system.

Question 14

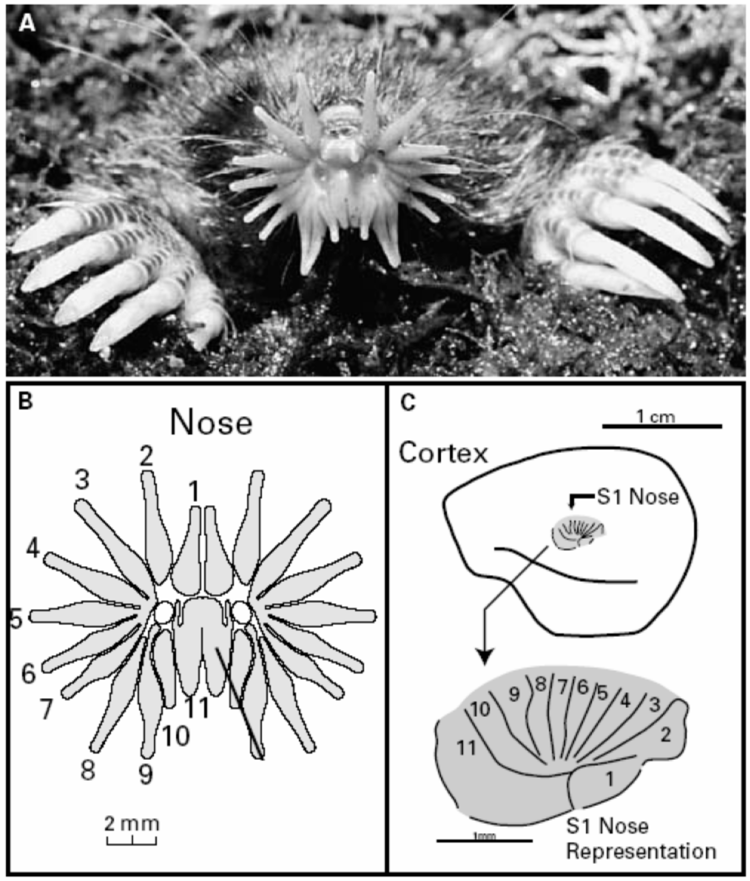
(6 points) A continuum model of neuronal network with shift-invariant synaptic weight pattern can generate either a stationary activity profile or a traveling wave of activity. What general condition of the weight pattern is required to generate traveling waves?

Question 15

(6 points) Consider a population of neurons each of which has a preferred direction for an encoded vector variable. What is a population vector? Name one condition under which a population vector can recover the true direction of the encoded variable.

Question 16

(6 points) The following figure is taken from a research paper on the primary somatosensory cortex (S1) of the star-nosed mole, an exotic animal. Tactile inputs to the left side of the nose go to the right side of the cortex. Each lobe of the nose is labeled with a number, going from 1 to 11. Based on what you know about the topographic maps in the brain and how they might be formed, which of the nose lobes you would expect to be the most sensitive and why?


A
B
Nose
1
2
3
4
5
6
7
8
9
10
11
2 mm
C
1 cm
Cortex
S1 Nose
10
9
8
7
6
5
4
3
2
11
1
1mm
S1 Nose
Representation